Chipsealing in New Zealand

Chipsealing in New Zealand is a distillation of information from at least 80 years experience in New Zealand, compiled by chipsealing experts from throughout New Zealand. Many years of experience based on research and backed up by references have contributed to this book.

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Chipsealing in New Zealand

Transit New Zealand, Road Controlling Authorities & Roading New Zealand

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An Important Note to the Reader

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Cover: Chipsealing the Milford Road, on the approach to Homer Tunnel below Mt Talbot (2117 m), South Island, New Zealand. This road within Fiordland National Park is a show piece for tourism and care of the environment.

Photo courtesy of Les McKenzie, Opus

Foreword

In New Zealand we have long been at the forefront of chipsealing technology in the international arena. In 1935 New Zealand's F.M. Hanson was the first to present a scientific approach to the design and construction of chipseals. The principles presented by Hanson in his paper to the Conference of the New Zealand Society of Civil Engineers promoted a rational approach to chipsealing that remained unchallenged for the next fifty years.

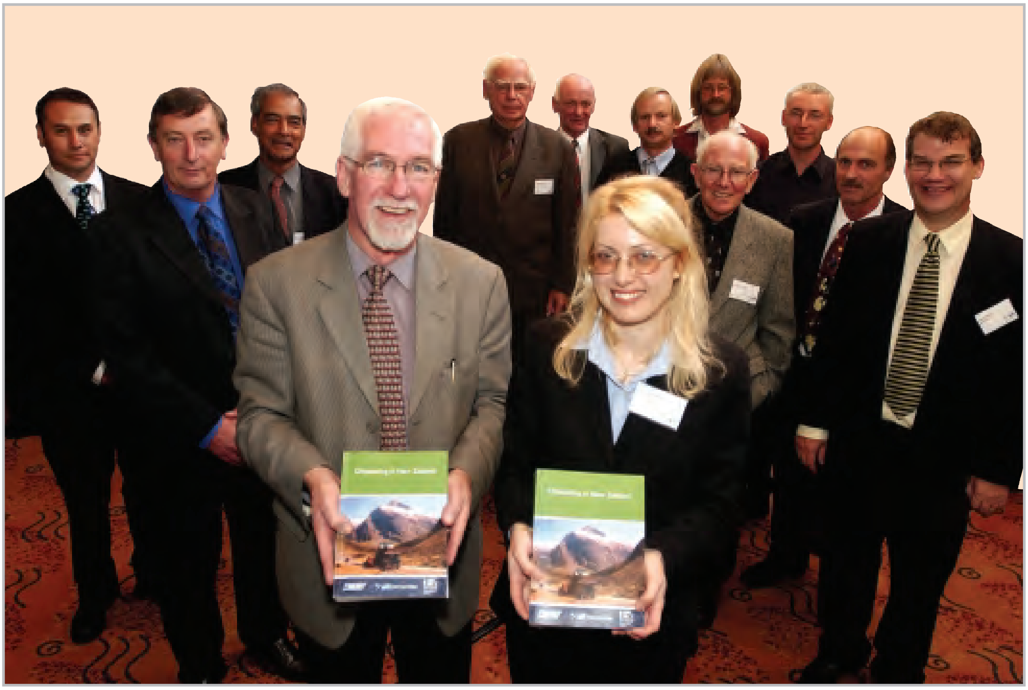
Today, Transit New Zealand, Roading New Zealand and Road Controlling Authority engineers have recognised the need to take a new snapshot of the current state of the art regarding chipseals. This project has been a basis for capturing our collective intellectual property regarding chipseals and gives us a base on which to build future improvements.

The book will be a resource, not just for those currently in training, but as a valuable guideline for roading practitioners around the country, and internationally.

New Zealand's 60,000 kilometres of chipsealed roads are a valuable but fragile asset and therefore documenting best practice is a significant project. Those involved in developing this book believed it was important that the New Zealand chipsealing industry feels that it has ownership in this book and has had an active participation in its development. As shown by the impressive list of names in the acknowledgments section, it is pleasing to see that representatives from the stakeholders, Transit, Road Controlling Authorities, contractors and consultants, have been represented at every level in the development of this book, including authorship of its various sections and as peer reviewers.

I am pleased and proud of the immense effort that has gone into the production of this book and recommend it to all involved in the chipsealing industry.

Rick van Barneveld
Chief Executive
Transit New Zealand



The book "Chipsealing in New Zealand" was launched by the Honorable Harry Duynhoven, Minister for Transport Safety, at the Road Controlling Authorities Forum held in Wellington, New Zealand, on 22 April 2005.

Pictured are (left to right): Greg Arnold (Transit NZ), Graham Taylor (Transit NZ), Deven Singh (Wellington City Council), John Dawson (Retired), John Patrick (Opus), Philip Muir (Works Infrastructure), Alan Stevens (Roading NZ) (rear), Norman Major (Retired) (in front), Peter Mumm (Hutt City Council), Gordon Hart (Transit NZ Napier), Chris Olsen (Roading NZ). In front with proof copies of the book: Hon. Harry Duynhoven (Minister for Transport Safety) and Joanna Towler (Transit NZ).

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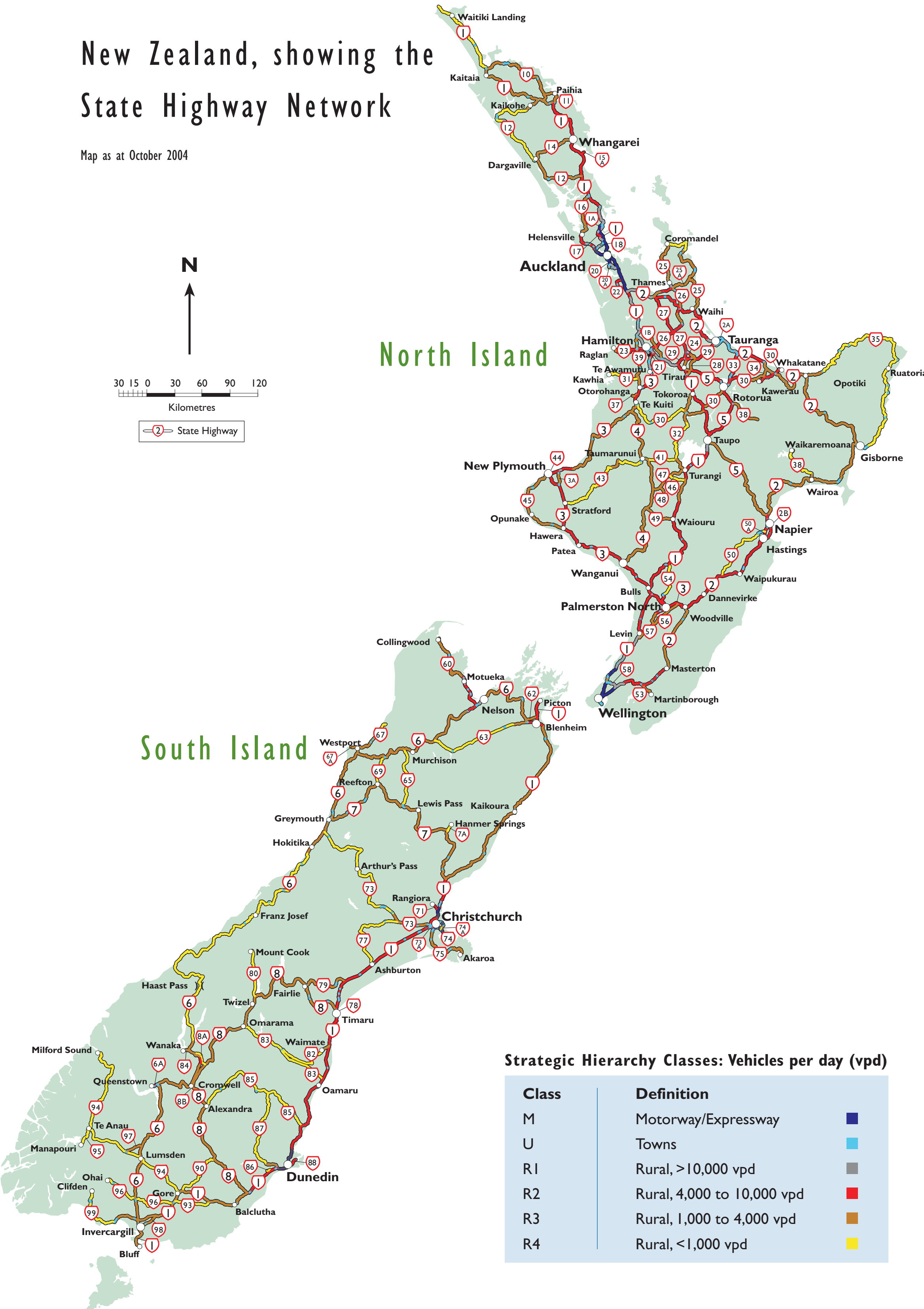
New Zealand, showing the State Highway Network

Map as at October 2004



Strategic Hierarchy Classes: Vehicles per day (vpd)

Class	Definition	
M	Motorway/Expressway	(dark blue)
U	Towns	(light blue)
R1	Rural, >10,000 vpd	(grey)
R2	Rural, 4,000 to 10,000 vpd	(red)
R3	Rural, 1,000 to 4,000 vpd	(brown)
R4	Rural, <1,000 vpd	(yellow)

Preface

This book has been compiled by chipsealing experts from four of the stakeholders who operate, maintain and build the roads in New Zealand. They are Transit New Zealand, Local Authorities, Contractors and Consultants. Many years of experience based on research and backed up by references have contributed to the concentrated work to create this book. It is a distillation of information from at least 80 years experience in New Zealand, Australia, the United Kingdom and the United States.

The experiences drawn on to write this book range from the 1920s to 2005, from the time when chipsealing was almost an 'art form' and largely guess work to its present 'technological form'. Over this time experience and research have uncovered reasons why chipseals behave the way they do under different conditions. Chipsealing techniques differ from the north to the south of New Zealand as the country is long, crossing subtropical to near-subantarctic conditions over its 2000 km length. New Zealand is narrow too, and many of its roads pass quickly from coastal plains to mountainous passes. These extremes of climate and landscape impose many constraints on road surface performance and present challenges to be overcome.

Thus there is no 'correct' or only way for a chipsealing operation to be carried out. For this reason experience and research are presented in this book so the reader can make their own informed decisions when using chipsealing technology.

Authors of the chapters are all experts in their own fields of chipsealing. They have worked on their own and collectively, discussing methods and techniques that have evolved over the years, which ones give the best results, the longest lives, and most economical returns.

This book is intended for those studying road engineering at polytechnic and university level, for those already in the chipsealing industry who want to broaden their knowledge, or those from another line of engineering to understand chipsealing for a particular project.

References are provided throughout for more in-depth reading. Its twelve chapters include topics such as safety in the industry, the main chipseal surfacings used in New Zealand, their performance, programming, and design. The materials, the plant and machinery used for chipsealing are described, as well as how to prepare for and carry out the sealing operation. The final chapter explains how to identify failure modes early before they become a major problem, and how to keep a road alive.

We hope you enjoy this book and find it informative. Comments and suggestions for future editions are welcome and should be emailed to *chipsealing.textbook@transit.govt.nz*

Acknowledgments

A joint team representing Roading New Zealand, Transit New Zealand, Road Controlling Authorities, and Consultants' groups has prepared this book to capture the New Zealand experience with chipsealing.

An industry organisational structure was developed to manage the process, and is based on the Roading Information Management System (RIMS) model for developing documents. All levels have representatives from Transit, local authorities, contractors (through Roading New Zealand), and consultants (through IPENZ and ACENZ). The levels of management in the industry organisational structure are:

- Steering Group
- Technical Group
- Project Manager
- Subject Matter Experts (Authors)
- Peer Reviewers

The members listed in alphabetical order are:

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Thanks to Jim Towler for developing and providing indexing tools.

Abbreviations & Acronyms

AADT	Annual Average Daily Traffic volume
AC	Asphaltic Concrete
ACENZ	NZ Association of Civil Engineers
ADT	Average Daily traffic
AGO	Automotive Gas Oil
AGD	Average Greatest Dimension
ALD	Average Least Dimension
AM, AQ, AS	Anionic emulsions
AP	All Passing (aggregate)
APP	Atactic Polypropylene
ARRB	Australian Road Research Board, NSW
AS	Australian Standard
ASTM	American Society for Testing & Materials
AWPT	Area-wide Pavement Treatment
B, dB	bel, decibel
BC, BCR	Benefit/Cost ratio
BCA	Bitumen Contractors' Association
BPN	British Pendulum Number
BPT	British Pendulum Tester
CM, CQ, CS	Cationic emulsions
CMA	Calcium magnesium acetate
COP	Code of Practice
COPTTM	COP for Temporary Traffic Management
cSt	Centistoke
dBA	adjusted decibel
dTIMS	Deighton's Total Infrastructure Management System
e	Surface correction factor
elv	equivalent light vehicles
EMA	Ethylene Methyl Acrylate
ESC	Equilibrium SCRIM Coefficient
EVA	Ethylene Vinyl Acetate
FWD	Falling Weight Deflectometer
GC	Graded Crushed aggregate
H_{fe}, H_{fh}	Heating factor for emulsions, hot bitumen
HCV	Heavy Commercial Vehicles
HDM-III	Highway Design & Maintenance Standards model Version III
HDM-4	Highway Development & Management model Version 4
HDPE	High Density Polyethylene
HMA	Hot Mix Asphalt
HSD	High Speed Data
HSE	Health & Safety in Employment Act 1992
HSNO	Hazardous Substances & New Organisms Act 1996
Hz	Hertz
IPENZ	NZ Institute of Professional Engineers
ISO	International Standards Organisation
ISSA	International Slurry Sealing Association
K&C	Kerb and Channel
km	Kilometres
km/h	Kilometres per hour
ℓ	Litres
LA	Local authority
LCV	Light commercial Vehicles
L_{eq}, L_{max}, L_{10}	Sound levels
LDPE	Low Density Polyethylene
LGA	Local Government Authorities
LL	Liquid Limit
LTMA	Land Transport Management Act 2003
LTSA	Land Transport Safety Authority
MC	Moisture Content
MDD	Mean dry density
MHB	Main Highways Board
min	minute
MOW	Ministry of Works
MPD	Mean profile depth
MSSC	Mean summer SCRIM coefficient
MTD	Mean Texture Depth
MWD	Ministry of Works and Development
NAASRA	National Association of Australian State Roads Authorities
NDM	Nuclear Densometer
NES AQ	National Environmental Standard for Air Quality

NRB	National Roads Board
NZ	New Zealand
NZIE	NZ Institute of Engineers
NZIHT	NZ Institute of Highway Technology
NZ PBCA	NZ Pavement & Bitumen Contractors' Association
NZQA	NZ Qualifications Authority
NZRF	NZ Roadmarkers Federation
NZS	NZ Standard
OGA	Open Graded Asphalt
OGEM	Open Graded Emulsion Mix
OGPA	Open Graded Porous Asphalt
OMC	Optimum Moisture Content
Opus	Opus International Consultants Ltd
Pa	Pascal
PAH	Polyaromatic hydrocarbons
PAP	Premium All Passing
PBCA	Pavement & Bitumen Contractors' Association
PBD	Polybutadiene
PCC	Portland Cement Concrete
PE	Polyethylene
pen.	Penetration grade
PI	Plasticity Index
PL	Plastic Limit
PMB	Polymer Modified Binder
PME	Polymer Modified Emulsion
PMS	Pavement Management System
PPE	Personal Protective Equipment
pph	parts per hundred
psd	particle size distribution
PSV	Polished Stone Value
PTR	Pneumatic-tyred roller
PVC	Polyvinyl chloride
PWD	Public Works Department
QA	Quality Assurance
R	Residual binder
RAMM	Road Assessment & Maintenance Management
RAP	Reclaimed Asphalt Pavement
RCA	Road Controlling Authorities
RIMS	Roading Information Management System
RMA	Resource Management Act 1991
RNZ	Roading New Zealand
RoAR	Road Analyser & Recorder machine
RPM	Raised Pavement Marker
RRPM	Reflectorised Raised Pavement Marker
rpm	revolutions per minute
RRU	Road Research Unit
RTFO	Rolling Thin Film Oven test
RWIS	Road Weather Information System
SAM	Stress Absorbing Membrane
SAMI	Stress Absorbing Membrane Interlayer
SBR	Styrene-Butadiene Rubber
SBS	Styrene-Butadiene-Styrene
SC	Sized or Sealing Chip
SCRIM	Sideway-force Coefficient Routine Investigation Machine
SFC	Sideway Friction Coefficient
SIS	Styrene-Isoprene-Styrene
SLP	Stationary Laser Profilometer
SMA	Stone Mastic Asphalt
SNZ	Standards New Zealand
SRA	State Roading Authority (Australia)
t	tonne
T_d	Texture depth (mm)
Tf	Traffic factor
TMP	Traffic Management Plan
TNZ	Transit New Zealand
UK	United Kingdom
US, USA	United States of America
UV	Ultraviolet light
V_{air}	Volume of Air
V_b	Volume of Bitumen
V_e	Volume of Chip Embedment
V_s	Volume of Stone (chip)
V_v	Volume of Voids
v/l/d	vehicles per lane per day
vpd	vehicles per day
VTI	Swedish Road & Traffic Research Institute
WBOP	Western Bay of Plenty
WC	Water Content
WW1	World War 1 (1914-18)
WW2	World War 2 (1939-45)
4WD	Four Wheel Drive vehicle

CHAPTER ONE

History of Chipsealing in New Zealand

Chapter 1 History of Chipsealing in New Zealand

Previous page: Laying a first coat chipseal on a New Zealand state highway in the 1970s. From left is a 9-ton 3-wheeled roller, a bitumen distributor and on the right a fan-tailed chip spreader on a short wheel-based tip truck.

Photo from NRB (1974)

Chapter 1 History of Chipsealing in New Zealand

1.1 Before Chipsealing

The technique of sealing roads with tar or bitumen binder[1] and stone chip has been used to provide protective waterproof, relatively flexible, road surfaces for wheeled traffic for only the last 175 years. Roman roads that have survived for at least 2300 years were also constructed with protected surfaces, but they were rigid usually made with slabs of stone, over a built-up base (as are today's roads), or bridge-like causeways across soft soils. Remnants of these straight roads include the Appian Way which was begun in 312BC. There is evidence that bitumen was used by Nebuchadnezzar of Babylon to grout stone roads and to waterproof the masonry of his palace (Morgan & Mulder 1995) about 600BC. However, the present use of a bituminous binder in a road pavement started with tar macadam in Nottinghamshire as recently as 1830. (Tarmac later became a general term for a tar- or bitumen-bound material used for a pavement, especially the surface layer of pavements for aircraft runways.)

1.2 Chipsealing comes to New Zealand

Two advances made in the latter part of the 19th century encouraged sealing roads with protective surfaces in New Zealand. One was of the increased production of coal gas for lighting and heating, and its by-product coal tar. The other was the automobile which required smoother and safer surfaces than the rutted gravel surfaces which had previously provided the needs of lighter horse-drawn traffic (Figure 1-1).


Figure 1-1 Chipsealed roads made a great improvement to travel in New Zealand, as "up to the axles in mud" was commonplace in the early days of transport. Right image shows a horse-drawn wagon bogged down on its way to Frederic Truby King's farm at Tahakopa, South Otago (c. 1910s).

Photos courtesy of Alexander Turnbull Library, ATL PAColl-5932-14 (left); ATL F-46755-1/2, PAColl-6097-001 (right)

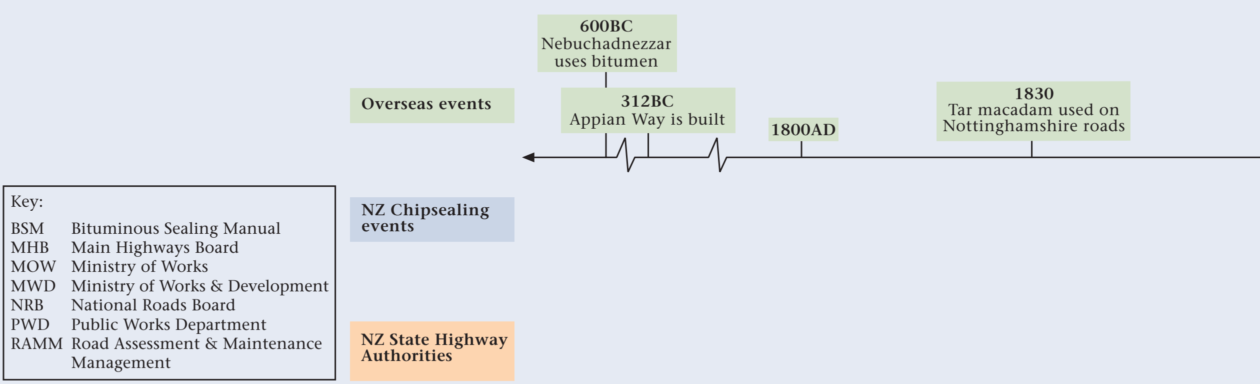
[1] Terms relating to roads and chipsealing are explained in Chapter 3, and in the Glossary.

A contributing reason to the wide use of chipsealing in New Zealand in the early 20th century was its lower production costs. Chipseals could be constructed using simple plant and some local materials. It was a process which could be applied over a conventional water-bound macadam pavement (which then became the basecourse of stones of the pavement), yet provided enough flexibility to resist cracking under normal service by traffic. It was and remains simpler and cheaper, requiring much less energy than making the bitumen-bound macadams used in the northern hemisphere for which the stone chip (or aggregate) and the binder have to be heated together and for which specialist mixing plant is required. As a result, the technique of chipsealing roads has been developed to a high degree and consequently New Zealand's roading engineers are acknowledged to be among the world leaders in this field.

From about 1880 in New Zealand, tar from the local gasworks was sprayed over roads or footpaths and covered with locally sourced chips to make a dust-proof and waterproof surfacing. The technique was to hand-spray about a quarter of a gallon per square yard (about $1.35\ell/m^2$) of binder over the compacted basecourse. This produced a film of binder about 0.05 inches (1.35 mm) thick. It was covered with bigger than sand-sized gravel or crushed chips, and the seal was compacted with a roller. Gradual refinement in techniques evolved.

1.3 Principles and Philosophy of Chipsealing

During the early 1930s, development of the automobile and increase in traffic volumes created a demand for improvement in the quality of road surfaces. About this time, testing and experimenting with aggregates and bitumen were carried out in an effort to be more quantitative, and less dependent on the skill of the on-site manager, overseer or foreperson, and on their eye for best practice.



A more scientific approach to the design of the chipseal road surface was needed. When F.M. Hanson presented his paper *Bituminous surface treatment of rural highways* to the Conference of the NZ Society of Civil Engineers, in 1935, he made the first steps to quantify the chipseal concept.

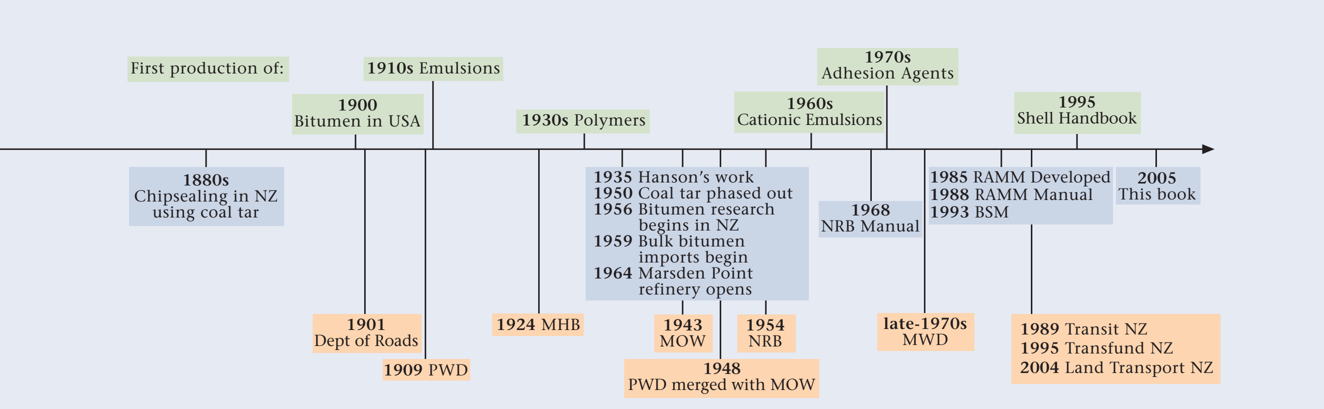
Based on his methodical approach for this paper, chipsealing as we know it today was established. The precept was that the rate of application of the binder should be designed to rise 2/3rd up the height of the stone chips, to leave a non-skid, non-glare stone surface to take the wear and stress imposed by traffic.

Hanson's principles relating to the theory of surface sealing (Figure 1-2) were summarised in the National Roads Board (NRB) 1968 *Manual of sealing and paving practice*, and are quoted here:

1. *When sufficient chips are placed on a seal binder to ultimately bed into a single layer in shoulder to shoulder contact, the percentage of voids in the initially laid loose state is approximately 50%. This is reduced to about 30% by construction rolling, and to 20% by traffic compaction.*
2. *The amount of binder required bears a definite relationship to the volume of voids in the cover stone aggregate; the quantity should be such that between 65 and 70% of the voids in the finally compacted layer of sealing chips are filled with binder.*
3. *The average depth of the layer of stone chips forming the cover coat, after construction and traffic compaction is approximately equal to the average least dimension (ALD) of the chips used.*

Although the principles that Hanson promoted are still current, refinement to the values of voids has been made as more information has been gathered.

The whole basis of Hanson's theoretical approach relied on the concept that the percentage of voids in the loose state as initially laid was 50%. This concept was verified by the



following experiment carried out for Hanson (by Mr Tom McLoughlin who was a public works overseer and later became a prominent sealing contractor). A 44-gallon (200-ℓ) drum was filled with the smallest single size chips available, then water was poured into the drum until it was full. The volume of water poured into the drum filled the voids between the chips, and equalled 50% of the volume of the drum. This established that the percentage voids in the loose chips was 50%. The experiment was repeated using each of the other chip sizes and the results always came out at 50%.

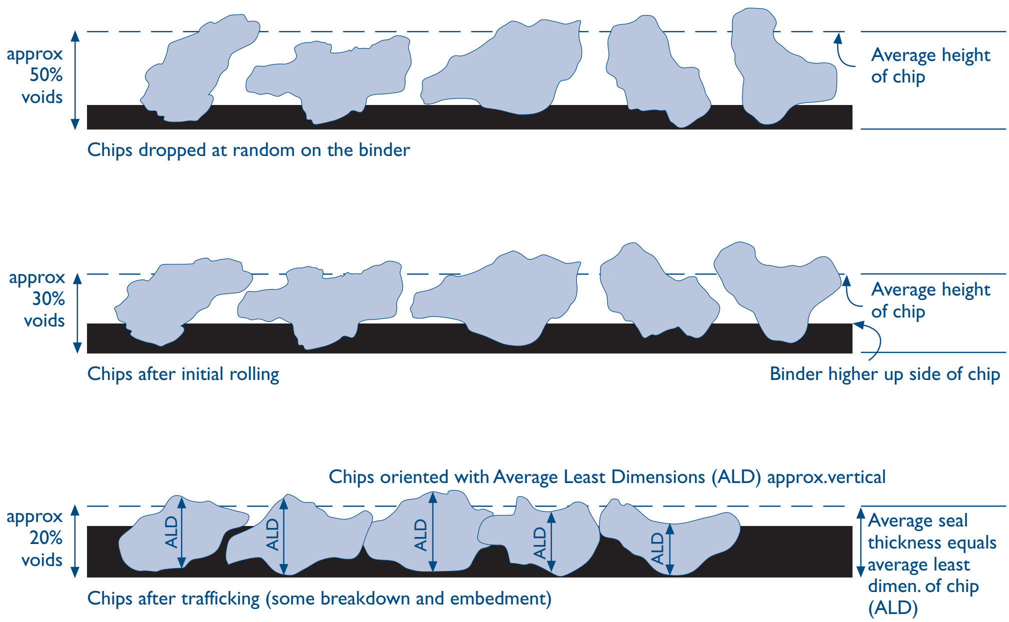


Figure 1-2 States of embedment of sealing chips in binder (from NRB Manual 1968).

These measurements demonstrated that the physical properties of packing and the 50% voids between chips were independent of the size of chip. To achieve this end result, chips need to be near-cubical (a shape which became possible to attain when the impact crusher came into use), with low (<1.1%) fines, and with little silt or clay on the chip surfaces (i.e. high cleanness value).

Later Hanson (1948) reasoned that a scientific and rational approach to road construction was essential to overcome the failure of roads built on clay and silt foundations, and the general deterioration caused by increasing axle loads and tyre pressures. Otherwise overdesign with the accompanying waste of money, or underdesign with costly failures, would continue to be applied.

This Chapter outlines some of the changes made to binders and stone chips in order to better achieve these basic principles on the road. But since the 1970s other factors have changed. The stresses on high traffic volume roads have increased caused by heavier vehicles (up to 43 tonnes gross laden weight, or 42.3 tons), the introduction of power steering and braking, single drive axles, higher engine power and higher speeds. These began pushing the technology to its limit. The demands have led to the development and use of more shear-resistant chipseal systems (e.g. modified binders, multicoat seals). The research that continues today on developing relevant algorithms for modern bituminous-surfacing seal design is described in subsequent chapters of this book. Where the demands are too high for chipseals, other surfacing techniques such as hot mix asphalt have to be employed, and only brief reference is made to these techniques in this book.

Sealed roads were originally confined to towns but the total length of chipsealed road steadily increased each year until by 2004 the length of state highways under chipseal recorded in Transit NZ's annual statistics report was 10,837 km, with the last 20 km to Cape Reinga still to be sealed. This is only 12% of the total length (including state highways) of the road network in New Zealand, which now totals 92,760 km. The Road Controlling Authorities (RCAs) who administer the other 81,923 km or 88% are the 74 Local Authorities (i.e. City Councils and District Councils).

1.4 Changes in Binder Materials

Coal tar

Coal tar is a by-product from local gasworks and was the earliest and only binder used in New Zealand until about 1910, when bitumens for roading use first became available. With about 65 gasworks around the country it was generally available. Most New Zealand tar was undistilled and was hazardous to work with. Workers, such as the spray operator on the hand spraybar, could suffer skin burns from the high sulphur content and other chemicals in the tar, and it was known to be carcinogenic. Distilled tar that came mainly from England was more benign and also had a longer life in the pavement. However substantial processing was required to produce a tar having good road-making properties, and many works did only minimal processing. Their tars were suitable for use as primers which were exposed for only a short time before being covered by the next seal coat, and the requirements were less stringent and far easier to meet.

This source was dwindling by the mid-1950s by which time only four or five gasworks were producing roading tar, although imported English coal tar was used in Central Otago as late as 1959 for first coat sealing on state highways.

Bitumen

Bitumen is the heavy residue obtained from refining crude oil. Roading grade bitumen had been first produced in the United States around 1900, and it came into use in New Zealand as a more durable and less temperature-sensitive material than coal tar about 1914, just before World War 1. The first bitumen to be applied to a pavement in New Zealand was undertaken by Sir Russell Matthews in 1914 in New Plymouth. The bitumen had been imported in wooden stave barrels from the Standard Oil Company from Pennsylvania, USA. Until the early 1930s, crude oil products (penetration grades used for chipsealing, emulsions and hot mixes, and more fluid road oils) were imported mainly from the United States. The barrel staves made a good fuel for the decanters or heaters (tar kettles) which supplied bitumen to the sprayers (Figure 1-3) and were horse-drawn (Figure 1-4). A rope extended along the side of the heater to the horse-hitching harness so that the horse could be released if the bitumen caught fire. This escape mechanism was used in the case of explosion or fire so if the horse bolted it did not drag the unit up the street leaving a trail of catastrophes for both workers and bystanders.

Figure 1-3 This bitumen heating kettle (left) being used in Taranaki was the way to heat bitumen in the 1920s. The fire, stoked with staves from empty bitumen barrels, was in the firebox under the kettle. The firebox gases passed around all sides of the kettle. Photo courtesy of John Matthews, Technix Group Ltd

As if the task was not hazardous enough, the bitumen was pumped by a hand-operated gear pump, and that was a very unpleasant occupation for the person standing alongside the uninsulated surfaces of the tar kettle.

Supplies of lighter penetration grade bitumens, road oils and some cutbacks came from California and Mexico, and were transported in 44 gallon (200 ℓ) steel drums (which later found an interesting end use, see box). They were the main sources until after World War 2, about 1945, after which sources widened to include the Middle East oilfields.

Figure 1-4 Draughthorse-drawn bitumen hand sprayer ready for sealing the main street of Opunake, Taranaki, in the 1920s. Photo courtesy of Feaver Collection, Puke Ariki Museum Archives, New Plymouth

Later containers were steel drums and, rather than waste them, at least one contractor had a sideline business recycling them. He used equipment that peeled the ends off the drums (similar to a can opener), opened up the cylindrical part of the drum which was then passed through a flat roller, and finally through a corrugated roller. The product, bitumen-coated corrugated sheets, proved very popular for sheds and other buildings, particularly in the country.

As road building activity increased, annual bitumen use doubled between 1950 and 1960 to about 60,000 tons (about 60,960 tonnes). It levelled out at about 100,000 tons (about 101,600 tonnes) per year until 1980. To cope with this increase, and in anticipation of refining oil in New Zealand, the first imports of bitumen in bulk tankers were in 1959 from Venezuela. In 1964, the New Zealand Refining Company's plant at Marsden Point, near Whangarei, opened and took over supply almost totally, with distribution to a total of nine ports around New Zealand. To maintain consistency in meeting the fairly demanding requirements set by Specification (see box) NRB M/1 (now TNZ M/1:1995) and to be within the refinery's capability, crude oil generally came from a single Middle East oilfield which could be accessed by the main New Zealand oil companies. Its higher price was a relatively small disadvantage compared to the high transport costs of importing the bitumen.

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Specifications and Notes contain best practice for the construction and maintenance of roads, including specifications for materials, paving, surfacings, road formation, equipment, traffic control, and quality assurance. In this book, most of the specifications are dated to indicate the versions that are referred to. Specifications referred to in contract and other works documents may not be dated to indicate that the latest version available is the one that applies. Specifications and Notes have been produced by the various government departments which have been responsible for the nation's roads over the last 105 years.

Extensive research into bitumen properties began at Dominion Laboratory (forerunner of Chemistry Division, Department of Scientific & Industrial Research) in 1956, and continues today mainly at Opus Central Laboratories, but also at the laboratories of some of New Zealand's roading contractor companies. Much of the information given in Chapters 4, 8 and 9 is based on this New Zealand research.

Bulk bitumen created some logistical transport problems that had a major effect on the bitumen contracting industry and road making generally. Initially the bitumen was transported by ship to bulk storage facilities at the ports of Auckland, Wellington and Lyttelton. Transport by road in the early 1960s was limited by law to 90 miles (145 km) from the port facility. If bitumen had to be carried beyond that 90-mile limit, it had to be transported by rail tankwagons that were purpose-built. The rail wagons were fitted with flame tubes that could be fired by demountable burners for heating the bitumen. However, purpose-built spray tankers were exempt from this 90-mile restriction, and soon some contractors had fitted pumps and sprayer equipment to their bulk-bitumen delivery tankers in order to circumvent these regulations.

Oil industry policy was to supply bitumen heated only to a pumpable viscosity (a temperature which is too cold for spraying). In practice this meant that each independent contractor had to have dedicated heating plant to raise the bitumen to spraying temperature. This discouraged small contractors from becoming involved, causing instability in the bitumen contracting industry over many years, and affecting the rate of road building.

Another problem arising from importing crude oil for processing at the refinery was the need to balance the barrel, i.e. for every barrel of crude oil refined there had to be a market for each by-product (e.g. for kerosene, petrol, diesel, bitumen). This meant that each oil company was required to balance the marketing of its products with the yield from the crude oil imported.

Bitumen Emulsions

Bitumen emulsions were first used in New Zealand about 1910, and their use today is detailed in Sections 8.3 and 11.4. Until the mid-1960s only one type of emulsion was available for roading. It is called 'anionic' because the droplets of emulsion have negative charges, and it was manufactured with 55% to 60% water content. This created an on-road viscosity that is very much lower than that of conventional spraying-grade straight-run or cutback bitumen. Thus application rates had to be kept quite low to avoid the binder running into the side water channels before the chip was applied. Also the low application rates meant that only small chip sizes could be used in single coat seals. Foaming often occurred while blending the bitumen and water to make these emulsions.

By the mid-1960s new technology and chemicals had become available that allowed production of the alternative 'cationic' type of bitumen emulsion (in which the dispersed droplets of bitumen carry positive surface charges) at about the same cost as anionic emulsion. Another point in their favour is that they have higher on-road viscosities immediately after spraying. These advantages of the cationic type over anionic make it the main type now used in New Zealand.

Rubber and Polymers

Natural rubber and synthetic polymer compounds were first trialled in the 1930s. They were found to make the binder less susceptible to softening at high temperatures, less brittle at low temperatures, and more ductile. These modified binders that are now being used on more heavily trafficked routes to achieve a longer seal life are covered in Sections 8.4 and 11.5 of this book.

Initially introduced in the mid-1960s, based on research by the Malaysian Natural Rubber Bureau and others, rubber latex (i.e. natural rubber as an emulsion) or semi-vulcanised crumb rubber were two more commonly used additives.

Totally synthetic polymers came into use in the early 1980s. Their formulation for easier blending allows higher proportions to be added that give better performance properties than are achieved with natural rubbers.

Precoating

Precoating sealing chips improves some adhesive properties of the binder and is covered in Section 8.2.3. Initial precoating trials using imported petrochemical tar were carried out about 1964, and trials with locally produced primer from coal tar followed shortly afterward. In addition to promoting adhesion in wet conditions, tar primer precoating was also very effective in countering effects of dust on chips as it penetrates through to the chip surface.

Precoating was originally carried out by spraying the primer onto the stockpile, and then mixing the stockpile. This inefficient method of mixing has since been replaced by the mobile precoating plant. Use of precoating decreased markedly in the mid-1970s when chemicals (called adhesion agents) that improved adhesion of chips to the binder came on the market.

Adhesion Agents

Adhesion agents improve the development of adhesion between the binder and the damp chips by causing the binder to preferentially 'wet' the chip, as explained in Chapter 8.2. Chip loss that occurs following rain on a new seal was a common problem in the 1960s, and so the use of adhesion agents gained popularity.

Laboratory investigation of adhesion agents was followed by site trials north of Auckland in 1956-57. The procedure came into general use in the 1970s, eventually replacing the use of precoating. Their continued use has proven to be good insurance against chip loss which more than outweighs their cost.

Priming

Priming is the application of a low viscosity coal tar or bitumen, and was widely used from the 1930s to 1950s to improve the top surface of a complete 'ready to seal' basecourse. The less refined coal tars were used extensively as a priming treatment as they penetrated the gravel basecourse, producing optimal conditions for the application of the first seal coat.

Until the mid-1950s, aggregates used in basecourse construction were generally not uniform in grading, and usually damp, dusty, or dirty with clay and silt. In such less than ideal conditions, and before adhesion agents were available, primers applied as prime coats were very successful as a means of binding and waterproofing the surface of an unbound basecourse. After the prime coat had cured, the basecourse could then accept a full chipseal consisting of a seal coat of high viscosity binder that could retain chip of the chosen size.

Once tar was no longer produced, cutback bitumen containing around 50% kerosene was used as a primer and, although it proved to be satisfactory, it did not have the same penetrating capabilities of tar. It was also hazardous to use as it has high risks associated with its very low flash point (about 49°C) and high flammability. Now the use of cutback bitumen as a primer is discouraged mainly because of these hazards (which are described in Chapters 2 and 3). Also improvements in the quality of basecourse materials and construction techniques have resulted in cleaner and tighter surfaces on which to seal, which means that prime coats are not needed.

1.5 Changes in Aggregate Materials

In the early days of chipsealing, it was quickly discovered that if graded sandy aggregates were used for cover stone or chip, the binder tended to work its way to the surface. Observation showed that cover chip of a restricted size range produced a good job, and also that angular stones tended to lock into place better than rounded gravel.

When the Main Highways Board (MHB) began issuing specifications in the late 1920s, consensus was that unweathered chip, free of sand, silt and clay, of a defined range of sizes should be used. (The typical size was given as nearly all passing a $^3/_4$ inch (20 mm) round-hole screen and nearly all retained on a $^3/_8$ inch (10 mm) round-hole screen.)

Hanson's 1935 recommendations placed considerable emphasis on the use of a single layer of uniform sized chips, even though he was recommending use of much larger chips than we now use 70 years later. Well crushed material was required and river-sourced material before crushing had to be larger than a $1^1/_2$ inch-diameter circular ring. Cleanness and durability were required of the chips (at source), with maximum wear numerically limited by testing using the tumbling test (Duval Attrition test) or the ball mill test (Los Angeles Abrasion test).

Chip selection was by size (measured by average least dimension (ALD)), shape and uniformity. The surge of sealing work after World War 2 led to more formal categorisation of sealing chip sizes, using Grades A, B and C which had ALDs of 0.50 (12.7 mm), 0.40 (10 mm), and 0.30 inches (7.5 mm) respectively. Specification limits added from time to time through to 1964, to deal with perceived quality shortfalls, led to a worrying proportion of good quality batches of chips being rated as non-complying. Further, as demand for sealing chips grew, use of clean alluvial-sourced aggregates (from which most soft materials have been removed by river action) had to be supplemented with quarry-sourced materials. As these retain less durable fractions (e.g. clays), this meant that quantifying durability and weathering of these chips became necessary tests as well. Problems of stone polishing caused by increased traffic required Polished Stone Value (PSV) limits to be added to the specification.

In 1965, a complete review resulted in a changed specification format, very similar to the present TNZ M/6:2004. It defined Grades 1 (coarsest), 2, 3, 4 (finest), the limits on % sand and clay fractions, and presence of broken faces for chips. As well, two finer grades (Grades 5 and 6) used for voidfilling and similar purposes were added. The development and use of these grades is explained further in Section 8.5.

The 1970's oil shortage affected the amount of bitumen available for sealing in New Zealand. It made the use of smaller chip more attractive as a surfacing, especially as smaller chip is considered to use bitumen more efficiently, although greater skill is required by the operator to use it successfully. Smaller chip also cuts down on road noise and vehicle fuel consumption (by creating less rolling resistance).

1.6 Changes in Equipment

Advances in engineering technology over the last 50 years have seen some notable improvements and developments to overcome the hazards of the early equipment (see also Chapter 10).

Sprayers

Early chipseal methodology compared to modern methods was quite primitive and based more on experience than research. Before the introduction of spraybars, bitumen was hand sprayed (Figure 1-5), and typical equipment used for hand spraying included:

- Spray lance for spraying direct from the drum;
- Suck-blow sprayer;
- Tankwagons (distributors) fitted with motor-driven pumps and hand-spraying equipment.

Hand spraying became a highly developed skill and good operators needed to have the rhythmic grace and style of a ballroom dancer. In addition they had to be able to vary this rhythm to compensate for any variation in surface texture, and the tanker driver moved the tanker along the road synchronised with the movements of the sprayer operator. Without this synchrony of the driver and the sprayer operator, the quality of the job could be seriously lowered.

Figure 1-5 Most early chipsealing was carried out to keep down dust in the summer and mud in winter. In the 1920s this spray operator in Opunake County was using a hand sprayer with a swinging boom that kept the hose clear of the hot bitumen tank. Photo courtesy of John Matthews, Technix Group Ltd

The pumps on the tankwagons could not be reversed, so once a job was started it had to be kept going until it was finished. So, at 'smoko' time, the lance would be poked back into the tank to keep it warm and prevent blockages. Initially, when fully circulating systems were introduced, the return line went into the top of the tank and the binder flowed down through the vapour space into the tank. When using emulsions this caused aeration with many foam-overs or boil overs, and very messy results. This arrangement has been discontinued and the return line now enters at the bottom of the tank.

Early mechanical spray bars had very unreliable control of transverse or longitudinal distribution, and of the application rates of the bitumen. Blockages were common as well. The first gangbar-operated sprayers (which had the spray nozzles in an interconnected line, like a gang) were not well received by the roading authorities, and hand spraying remained the preferred method of applying bitumen for some time.

Figure 1-6 An old-style bitumen distributor (sprayer). Note the tall handle behind the distributor tank which was used to open and shut the spraybar. Photo courtesy of Laurence Harrow, Opus

Spray nozzle valves were interconnected with a gangbar-lever system to enable all the nozzles to be operated together. All these spray bars were operated manually, and the sight of someone swinging on the lever to turn taps on and off was common (Figure 1-6). The V-jet nozzle has been the most favoured for use on spraybars and, although the quality has significantly improved, they have never been able to produce a uniform spray pattern. To compensate for this, triple overlapping of the nozzle sprays (so that three fans of spray covered each section of the road) was adopted at a very early stage. This arrangement is discussed further in Chapter 10.

Dipping the tank

The task of dipping the tank had to be done to measure the volume of bitumen used before and after a sealing job. It was also done regularly during a sequence of spray runs to determine the actual spray rate of bitumen that was being applied. It involved clambering up to the top of the distributor tank and could be a hazardous job, especially in the poor light of a plant shed at the end of a long hard day's work. There are tales of shortcuts like using a cigarette lighter to peer at the dipstick while holding it over an opened hatch (with the real possibility of an explosion, and not recommended in any Codes of Practice)!

Thermostats

Early thermostats used on tankers had wide temperature differentials and the difference between the cut-off and cut-in temperatures could be as high as 20°C. These had some repercussions as in the following instance. To ensure the temperature would be right for a early morning start, one over-conscientious operator set the temperature 20°C higher than the normal. When he arrived on the Monday morning, flames were licking around the top hatch of the tank.

Heating equipment

Heating equipment has undergone considerable changes since the tarpot days, but nonetheless can be lethal devices.

Flame tube heating – this is heating by direct firing into a burner tube located near the bottom of the tank. The quest for faster heating rates resulted in flame tubes being equipped with burners that had a capacity greater than the rate at which the bitumen could transfer the heat throughout the tank. Flame-tube wall temperatures could reach dangerous levels, and the internal walls of the flame tube would be glowing red hot for some considerable time after the heater was turned off. Spot heating of the tube walls was another problem to watch for.

The main causes of tanker explosions and fires have been a consequence of these tubes becoming exposed to the flammable vapours inside the tank, explained further in Chapter 2.

Research work on flame-tube heating was initiated by the NZ PBCA[2] in the mid-1990s, and maximum heating rates and temperatures (i.e. 350°C) for flame tube heaters were established.

[2] NZ PBCA (NZ Pavement & Bitumen Contractors' Association) is now Roading New Zealand as from 26/06/2004.

Heat transfer oil systems – these systems heat by circulating hot oil via a heating chamber, and then through a tube 'nest' immersed in the bitumen tank. Bulk storage installations continue to use this system but extra care is required if they are to be used in the blending tanks used for cutback bitumen.

Electric elements – these were the preferred and safest option (and still are) for heating bitumen and various types have been used. A low-voltage transformer supplies current through elements comprising mild steel rods, such as reinforcing steel, mounted on insulated supports located near the bottom of the tank. These are safe and reliable provided that the heat rate of the rods is kept low.

Controlling sprayer road speed

In the early days of mechanical sprayers (Figure 1-7), another skill the driver needed was to alter spray rates by altering road speed. The gearing systems of some trucks could not cope with the slow speeds needed for high application rates, and many clutches were burnt out.

Road surfaces with varying textures called for additional skills of observation to achieve acceptable application rates. The overseer walked alongside the tanker observing the road texture ahead of the sprayer and signalled the driver to slow or speed up as required.

Figure 1-7 A 1940s bitumen distributor and hand sprayer, vacuum-filled and pressure discharged, on display at the property of John Matthews, Technix Group Ltd, New Plymouth.

Photo courtesy of John Matthews, Technix Group Ltd

Early calibration of sprayers and uniformity of transverse distribution were checked by placing paint tins underneath each nozzle and measuring the amount collected over a selected time. A more sophisticated method was to run the sprayer over a set of 50 mm-wide absorbent pads to measure the variability in transverse distribution.

Fan-tail chip spreaders

These chip spreaders have fan-tailed shaped rear gates and were generally used on short-wheel-based trucks to allow the tray to be raised high enough in all situations (see Frontispiece). As these trucks were operated in reverse, they were an occupational hazard for the fan-tail operators who had to perform a number of dangerous tasks, e.g. walking alongside the rear of the truck, sometimes on the driver's blind side, and running in to put in dividing plates. Operators were likely to be injured if the driver of the reversing truck could not see them.

Fan-tail spreaders were difficult to operate successfully and the driver had to be very skilful. Also they did not give uniform application, especially on corners. Windows or gaps in the sealing chip had to be spotted and covered by hand-spreading from the back of a truck. In addition to the spotting team, drag brooms were used as a means of redistributing the uneven chip layers. With the advent of roller spreaders in the mid-1960s, chip coverage improved significantly. These days there is less need for drag brooming or spotting and they are seldom used. Kinds of spreaders and rollers are covered in Chapter 10.

The Flaherty Chip Master spreader was imported from the United States in 1960 and, as this machine was driven forwards rather than reversed, both driver and operator were able to see each other. It was safer, but as it was a single purpose machine it never gained general acceptance.

While purpose-built chip-spreading machines are used today, roller spreaders mounted on trucks are the predominant type.

Rollers

At first, 7 or 9 ton (7.11 or 9.14 tonnes) 3-wheel steel rollers were used (without ballast for easy transport and to reduce crushing of the aggregate on the road). Over the years, rollers improved and new models were introduced, such as the 13-ton (13.2 tonnes) rubber-tyred roller which required fewer passes. Now fewer passes are needed and the chip is not crushed but kept at the design size required for the job.

1.7 Changes in Procedures

Asset Maintenance

A problem with chipseal is that it is not permanent. Though relatively flexible, cracks left untreated will let water in and increase the incidence of potholes and deformation. Because wear and weathering require spot repairs and eventual resealing, a deliberate maintenance regime and provision for resealing are needed in the longer term care of a chipseal.

To keep track of the state of the roads and their needs for maintenance and resealing, the database Road Assessment and Maintenance Management System or RAMM was established in 1985. RAMM is an inventory of road assets and of their condition. Its function is to use the inventory and condition to predict short-term treatment needs. The *RAMM Road Condition Rating Manual* (known as the *RAMM Rating Manual* but now out of print) was issued in 1988 by the then National Roads Board, and has been administered by Transit New Zealand since 1989, and uses software supplied by CJN Technologies (2004).

In 1994 the Minister of Transport, in consultation with the Minister of Finance, required all local authorities to have in place a maintenance management system based on RAMM no later than 30 June of that year. As a result, all Road Controlling Authorities (RCAs, i.e. authorities responsible for roading within their jurisdictions) are now using RAMM.

From the mid-1990s, intelligent systems have been implemented in New Zealand that use the RAMM inventory and condition information to predict long-term maintenance needs when developing maintenance Forward Works Programmes (explained in Chapter 5). dTIMS[3] is the software now used for pavement deterioration modelling in New Zealand, and its models are largely based on the World Bank HDM-III and HDM-4 models[4]. All these systems are essential components of a Pavement Management System (PMS).

Bitumen Burns Card and Safety

Because bitumen burns require special treatment differing from that for burns caused by other sources of heat, the yellow Bitumen Burns Card was developed by the roading industry. It is to alert medical staff in rescue teams and hospitals to these special requirements and to communicate directly with specialist Burns Units. It is illustrated in Chapter 2, in which the importance of safety in the chipsealing industry is emphasised.

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3 dTIMS – Deighton's Total Infrastructure Management System.

4 HDM-III – Highway Design and Maintenance Standards model, version III
HDM-4 – Highway Development and Management model, version 4

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Predecessors of Transit New Zealand

Since 1989, Transit New Zealand is the RCA responsible for the national State Highway system. Its predecessors are various, and the brief family tree that follows almost needs a genealogist to interpret (see also timeline on pages 4 & 5).

The Department of Roads was established in 1901, and then amalgamated with the Public Works Department (PWD) in 1909, which had been in existence from 1870.

From 1924 the Main Highways Board (MHB) became responsible for state and main highways, serviced by the PWD. In 1954 the MHB was replaced by the National Roads Board (NRB). NRB had responsibility for state highways design, construction and maintenance, and for the distribution of most central government roading disbursements to RCAs. NRB was serviced by the Ministry of Works (MOW) which had come into existence when the Ministry of Works Act was passed in 1943. The PWD was merged with the MOW in 1948 and then ceased to exist. Following some re-organisation in the late 1970s, the MOW was succeeded by the Ministry of Works and Development (MWD).

The NRB and its Road Research Unit (RRU) continued until 1989 when the Transit New Zealand Act was passed and Transit New Zealand came into existence. Amendments to the Act were passed in 1991 and 1992, before a major amendment in 1995 created Transfund (the funder of roads) and split it from Transit (the provider of roads).

The latest change made to the family was in 2004, when Transfund and the Land Transport Safety Authority were amalgamated to form the new Land Transport New Zealand.

For a full history up to 1970, read *By Design. A brief history of the Public Works Department.* Ministry of Works, 1870-1970 (Noonan 1975).

Training

Early training was in the field, on the job and by the boss, overseer or supervisor. Generally it was minimal and learned by rote. Thus workers could become good operators but did not necessarily understand what they were doing. When problems arose the general rule was to get the boss onto them quickly. In addition technology was poor, and crews worked in high temperatures and with flammable materials, so it was a dirty hard dangerous job. High staff turnover was always a problem, meaning that training was usually not adequate to cope with these hazards. For highly trained overseers and staff however, a major source was the Ministry of Works.

Today, training programmes leading to National Qualifications within the NZ Qualifications Authority (NZQA) framework, such as NZ Certificate of Engineering, and courses at the NZ Institute of Highway Technology (NZIHT) in New Plymouth, mean more skilled staff can be trained and prepared to be career-oriented employees for the industry.

Other highly qualified people, chemists and engineers can also find niches in chipseal research. Research on the physical and chemical properties of chipseal components and the chipsealing system ensures that producing a final chipseal surface is no longer an art, but instead a controlled and consistent procedure that will deliver the desired results. This book is about the various ways that those results can be obtained.

Hanson's advocacy for scientific and rational research into roading is now a reality, and this book aims to continue building on his vision.

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CHAPTER TWO

Safety in the Chipsealing Industry

Chapter 2 Safety in the Chipsealing Industry

Previous page: Chip-spreading trucks are operated in reverse, so for safety the driver and the chip-spreading operator should be visible to each other at all times.

Photo courtesy of Julien van Dyk, The Isaac Construction Co. Ltd

Chapter 2 Safety in the Chipsealing Industry

2.1 General

2

Working in the chipsealing industry can be hazardous and all people involved need to familiarise themselves with the safety requirements demanded by the hazards encountered when handling sealing materials and carrying out sealing operations. Hazards include burns, steam scalds, explosions and fire, fire fighting, toxic fumes, asphyxiation, handling flammable and corrosive materials, transportation of dangerous goods, as well as traffic in the work area.

This Chapter contains only a brief summary of the main safety points, and more detail is provided in Appendix 1 of the Roading New Zealand[1] Code of Practice (COP) BCA 9904 (NZ PBCA 2000), and First Aid Manuals available from New Zealand Red Cross Society, and St John (1999).

The entire Code of Practice BCA 9904 details the hazards and safety requirements, but its Chapters 4, 5, 6 and Appendices 2 to 11 are especially relevant. Many of the hazards are industry-specific and, over the years, specialised safety measures have been developed through expertise and experience. Legal requirements are given in the Preamble of BCA 9904. Procedures and safety measures relating to traffic are to be in accordance with Transit New Zealand's Code of Practice for Temporary Traffic Management (COPTTM 2004).

Hazards to the environment caused by chipsealing are also of concern to the roading industry. The procedures in BCA 9904 follow a very responsible approach to managing environmental factors and to minimise the effects of chipsealing on the environment.

> Employers have a duty to ensure that their employees are either sufficiently trained and experienced to do their work safely or supervised by a trained and experienced person. In addition employees must be adequately trained in the safe use of equipment in their place of work, including use of protective clothing and personal protective equipment (or PPE). Inexperienced individuals, regardless of position, must take advice from trained and experienced operators until they have received the appropriate level of training. Employers should arrange such training including courses on safety and first aid.

1 NZ PBCA (NZ Pavement & Bitumen Contractors' Association) is now Roading New Zealand as from 26/06/2004. However, as COP BCA 9904 was published in 2000 by the then PBCA, it keeps its original publication number.

2.2 Legal Requirements

The NZ Government Acts that are relevant to chipsealing carried out by the New Zealand roading industry include:

Health and Safety in Employment Act 1992 (HSE), the principal object of which is to prevent harm to employees at work.

Hazardous Substances and New Organisms Act 1996 (HSNO), and **HSNO Regulations**, which are to ensure correct and safe use of hazardous substances in the work place and environment.

Resource Management Act 1991 (RMA), which is to protect the environment.

Dangerous Goods Act 1974, and **Dangerous Goods Regulations**, which cover the carriage and use of dangerous goods.

Surfacing engineers, consultants, practitioners and roading asset managers must ensure that their designs and specifications are compatible with safe practices in the chipsealing work place and operations.

2.3 Hazards to Health from Chipsealing Materials

Some of the materials used in chipsealing can present hazards to health if they are handled incorrectly. Detailed information on health and safety, environmental hazards, chemical and physical properties for bitumen binders and associated materials used in chipsealing are given in Appendix 10 of BCA 9904. Material Safety Data Sheets are supplied in that appendix for:

Bitumen, Bitumen cutback, Kerosene, Turpentine, and Diesel.

The temperatures at which heated bituminous binders will catch fire are useful to know and they are:

Flash Point – the lowest temperature at which a flammable liquid gives off enough vapour to flash momentarily when a small flame is applied. For bitumen it is 240°C–320°C, and for kerosene 43°C–48°C.

Ignition Point – the temperature at which a solid, liquid or gas will take fire and continue to burn. The ignition points for bitumen are 500°C, and for kerosene 255°C.

2.3.1 Fire

The normal spraying temperature of a binder is in the range of 140°C–170°C, depending on the type of bitumen and amount of diluents in it. Straight-run bitumen at these normal spraying temperatures is below its flash point (i.e. 240°C–320°C) and is relatively safe. However, binders containing kerosene or AGO (automotive gas oil or diesel) have spraying temperatures above the flash points of these diluents and are therefore hazardous.

2.3.2 Explosions

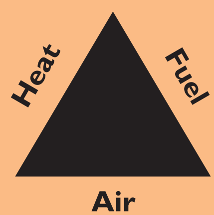
Explosions associated with chipsealing cause injury and significant damage. The industry, through its BCA 9904, has set procedures to avoid situations that will cause explosions.

Explosions caused by Vapour in Confined Spaces
Cutback binders give off vapours at temperatures lower than their flash points. These vapours build up in confined spaces such as the bitumen distributor. All sources of ignition, including obvious sources such as matches and lighters, and less obvious sources such as torches, transistor radios, steel boot caps and hobnails, must be kept at least 1.5 m away from such areas to prevent explosions. Many areas of chipseal operations must therefore be no-smoking zones for safety reasons, and ideally should be 'smoke-free'.

The nature of the materials and the high temperatures used in sprayed binders means the risk of fire and/or explosion is significant.

Explosions caused by Water in Binder
Other potentially explosive situations can occur by the introduction of water to a hot binder. Because water expands approximately 1500 times in volume when converted to steam, even a small amount of water introduced into a binder that is hotter than 100°C can result in a dangerously violent foaming eruption. BCA 9904 (Appendices 6 and 11) details the problem and precautions needed.

The Fire Triangle
The three ingredients needed for a fire or explosion to occur are fuel vapour, source of heat or ignition, and air (oxygen). This is called the Fire Triangle. If all three are present, as can occur in a bitumen distributor, the potential for a fire, or an explosion if the space is confined, becomes very real.



2.4 Hazards to Health from Chipsealing Operations

Chipsealing work can be hazardous and, according to the HSE Act, employers must take steps wherever practicable to eliminate the hazard, or if that is not practicable to isolate the hazard, or if both these actions are impracticable to minimise the hazard to employees. The following stages of chipsealing present the most hazards:

- Filling tanks with cutback binders (i.e. binder containing kerosene);
- Emptying tanks of binders;
- Blending binders;
- Venting tanks, working around tank vents and hatches;
- Using spraybars;
- Heating binders using flame tubes, electric elements, with potential for spot heating;
- Accidental mixing of water with binders.

The BCA 9904 provides details on these hazards.

2.4.1 Operational Hazards

Full PPE and clothing (Figure 2-1) must be worn at all times when working with hot bitumen, even on the hottest days, for protection against operational hazards.

As with other types of road construction plant, sealing plant is heavy, moving backward and forward at varying speeds, and therefore is potentially dangerous. Good practice is essential in accordance with BCA 9904, especially operations that need to be carried out within the confined width of the carriageway. Use high visibility garments in accordance with Transit NZ's COPTTM (2004) to ensure high visibility on site at all hours of the day and night.

Site workers often work in very hot operating conditions while wearing full cover protective clothing, and supervisors should consider how this affects their staff. Appropriate rest periods and refreshments, especially water, should be provided.

Figure 2-1 Chipsealing workers must wear appropriate clothing and gear (Personal Protective Equipment) so that they are protected when dealing with hot binder containing bitumen, cutter, and additives. This clothing is also used when working with emulsion and polymer modified binders.

Photo courtesy of Philip Muir, Works Infrastructure Ltd

2

2.4.2 Burn Hazards

In the roading industry burns can be caused by hot bitumen, flame, electricity, radiation (e.g. as sunburn), extreme cold (e.g. from liquid gases), and chemicals. Burns can also be caused when bare skin or flammable clothing come in contact with the hot surfaces of spraying equipment. Scalds (burns from moist heat) can be caused by steam or foam flashing off if water comes into contact with hot bitumen.

Treat these burns and scalds by pouring cold water over the burnt or scalded area immediately. Continue for at least 10-15 minutes or longer until pain subsides, and get the victim to medical treatment.

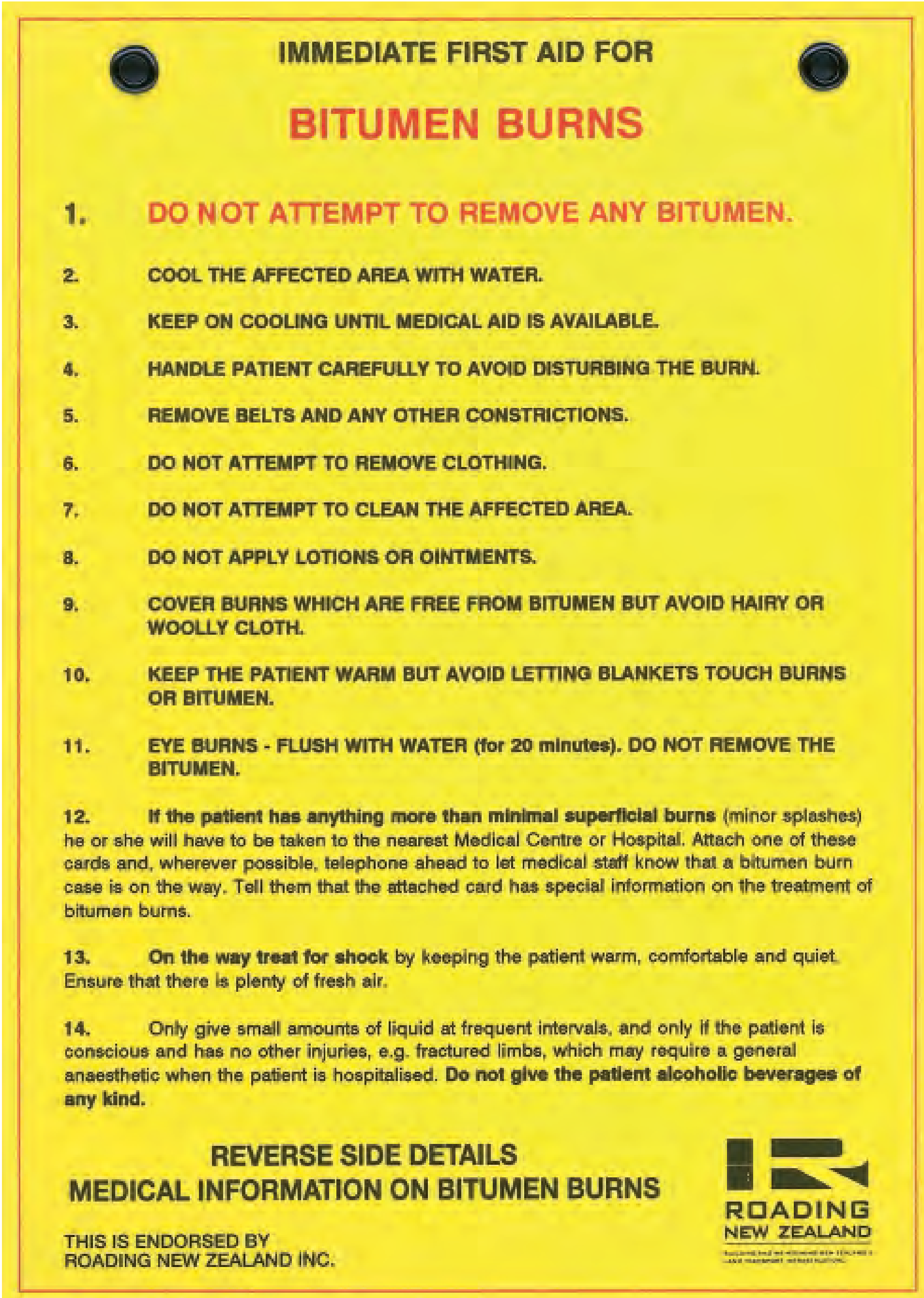
As binder is usually sprayed at temperatures between 150°C and 200°C, contact with it at these temperatures causes very severe burns that are possibly fatal or disabling. Binder sticks to the skin and the heat continues to burn the victim, but the binder must be left in place because removing it will cause far greater damage. Because it traps heat, keep cooling the binder by pouring cold water all over the area for at least 10-15 minutes. Treat as for other burns and for shock.

Because bitumen does stick to the skin, special first aid procedures are required that are not usually covered in basic first aid courses. Also because they do not occur often, the appropriate treatment procedures are often not understood by doctors and other medical staff. Therefore the industry has, in conjunction with specialist Burns Units, developed procedures for treatment. It has published, in its *Bitumen Safety Book* (NZ PBCA 2001), the yellow *Bitumen Burns Card* (Figure 2-2) on which is outlined the correct treatment of bitumen burns. All individuals working in the industry must make themselves aware of these treatment procedures for bitumen burns.

In the unfortunate instance of a burn, the card is attached to the victim with string through the eyelets on the card to make sure that doctors are aware of these procedures when they receive the burn patient for treatment.

Past experience has shown that attaching the card to the patient and relying on the doctor to read it, as well as to treat the patient, may not be enough. Therefore a person must accompany the patient to ensure that the treating doctor is aware of the card, and that he/she reads it before beginning treatment.

First aid courses specific to chipsealing requirements can be provided on request by recognised first aid organisations (e.g. NZ Red Cross, St John) and are the best way of training staff to increase their safety in the work place.



IMMEDIATE FIRST AID FOR

BITUMEN BURNS

1. DO NOT ATTEMPT TO REMOVE ANY BITUMEN.

2. COOL THE AFFECTED AREA WITH WATER.

3. KEEP ON COOLING UNTIL MEDICAL AID IS AVAILABLE.

4. HANDLE PATIENT CAREFULLY TO AVOID DISTURBING THE BURN.

5. REMOVE BELTS AND ANY OTHER CONSTRICTIONS.

6. DO NOT ATTEMPT TO REMOVE CLOTHING.

7. DO NOT ATTEMPT TO CLEAN THE AFFECTED AREA.

8. DO NOT APPLY LOTIONS OR OINTMENTS.

9. COVER BURNS WHICH ARE FREE FROM BITUMEN BUT AVOID HAIRY OR WOOLLY CLOTH.

10. KEEP THE PATIENT WARM BUT AVOID LETTING BLANKETS TOUCH BURNS OR BITUMEN.

11. EYE BURNS - FLUSH WITH WATER (for 20 minutes). DO NOT REMOVE THE BITUMEN.

12. **If the patient has anything more than minimal superficial burns** (minor splashes) he or she will have to be taken to the nearest Medical Centre or Hospital. Attach one of these cards and, wherever possible, telephone ahead to let medical staff know that a bitumen burn case is on the way. Tell them that the attached card has special information on the treatment of bitumen burns.

13. **On the way treat for shock** by keeping the patient warm, comfortable and quiet. Ensure that there is plenty of fresh air.

14. Only give small amounts of liquid at frequent intervals, and only if the patient is conscious and has no other injuries, e.g. fractured limbs, which may require a general anaesthetic when the patient is hospitalised. **Do not give the patient alcoholic beverages of any kind.**

REVERSE SIDE DETAILS
MEDICAL INFORMATION ON BITUMEN BURNS

THIS IS ENDORSED BY
ROADING NEW ZEALAND INC.

ROADING NEW ZEALAND

Figure 2-2 The yellow ***Bitumen Burns Card*** must accompany the burns victim to a doctor or hospital. Remember to dial 111 for the Ambulance and to alert A&E at the hospital of the specialised nature of the accident. A person must also accompany the victim.

Reproduced from NZ PBCA (now Roading NZ) 2000, 2001

BURNS CAUSED BY BITUMEN REQUIRE SPECIAL MEDICAL TREATMENT.

1. SKIN BURNS.

1.1 In the event of hot bitumen contacting the skin, no immediate attempt should be made to remove the bitumen.

(Except after admission to hospital and only at the direction of a burns specialist.)

1.2 The burn area should be drenched in cold running water or, preferably, placed in a basin of cold water to which ice cubes have been added.

1.3 In the case of burns to the head and neck, shoulder, chest, abdomen or back, cold wet towels, which are kept in a bucket of cold water (preferably iced), should be applied to the burned area.

1.4 The ice water treatment should be continued until pain no longer occurs when the burn area is removed from water. The time required is seldom less than 30 minutes.

1.5 Where possible the burned area should be continually wet until advanced medical aid is reached.

1.6 Remove any constricting rings, belts etc., and handle the patient gently to prevent further injury.

1.7 Cover any exposed burns, i.e. areas not covered by a protective layer of bitumen or clothing, with sterile dry dressings and lightly bandage to exclude the air. Keep the patient warm but avoid letting blankets touch burns or bitumen.

1.8 If there are burns to the face or head ensure that the airways for breathing are kept clear.

1.9 Do not apply lotions or ointments.

1.10 Do not prick blisters.

2. BURNS ENCIRCLING ANY PART OF THE BODY.

2.1 When a hot hard grade of bitumen completely encircles a limb it is theoretically possible for there to be a tourniquet effect as the bitumen cools. This will diminish blood circulation to the limb - **a potentially serious medical emergency.**

2.2 In such a case, elevating the limb will normally reduce the swelling enough to allow satisfactory circulation. If it does not and advanced medical care is more than 20 minutes away it could become essential to attempt to release the tightening effects of the cooling bitumen by carefully splitting the bitumen from the top to the bottom using a heavy pair of scissors. **Extreme caution must be taken** during this procedure to ensure that no damage is caused to the underlying skin. Toes and fingers require individual attention.

3. EYE BURNS.

3.1 The eye must be immediately flushed with cold water. This should be continued for 20 minutes by pouring water or, if available, sterile saline or eye irrigation solution, eg. 'Eyestream' gently over the open eye and away from the unaffected eye.

3.2 The cooling process will be most beneficial if it can be done at the same time as the casualty is being transported to hospital.

3.3 No attempt should be made by untrained personnel to remove the bitumen.

3.4 If the eye needs to be covered with a dressing, apply a sterile eye pad. Stay close, reassure and support the casualty while travelling to seek medical care.

4. FURTHER TREATMENT.

4.1 **No attempt should be made to remove the bitumen which, in itself, supplies a sterile dressing to the underlying burned area of skin.**

4.2 The bitumen is covered with tulle gras dressings and left for two days after which time any bitumen that can easily be removed (that is bitumen which is detached from live dermis), is removed. The remaining burned area to which bitumen adheres is re-covered with sterile tulle gras dressings and left for a further week.

4.3 The appearance of the burns when the dressings are first taken off, together with the body surface area involved and the general condition of the patient will dictate when removal to a specialised Burns Unit is indicated. Certainly any forced removal of bitumen should only be undertaken in a specially equipped Burns Unit.

5. BITUMEN REMOVAL.

5.1 If for special reasons it becomes essential to remove bitumen, use peanut oil (arachis oil).

6. SPECIALIST BURNS UNITS.

Auckland - Middlemore Hospital (09) 276 0214
Wellington - Hutt Hospital (04) 566 6999
Hamilton - Waikato (07) 839 8899.
Christchurch Hospital (03) 364 0640.

(There are no other specialist units in the South Island.)

Figure 2-2 Continued.

2.4.3 Traffic Hazards

Any roadworks on trafficked roads have the potential to be hazardous to both workers and the travelling public. Sealing operations present significant traffic problems because they affect long lengths of road at the time of sealing, and they progress at a slow speed.

Close liaison between the contractor, the Road Controlling Authority (RCA), road user groups, affected neighbours, the wider community and general public is important. This is to minimise and manage any impacts or disruption to sealing, and to traffic flows, as well as to avoid conflict with other events.

These aspects of chipsealing are discussed in more detail in Chapters 6 and 11. Always carry out temporary traffic control associated with roadworks in accordance with Transit NZ's COPTTM (2004).

As explained earlier in this Section 2.4, according to the HSE Act, hazards are to be eliminated preferably, or isolated, or at least minimised. As it is difficult to totally eliminate traffic hazards, safe temporary traffic management practice focuses on isolating and minimising hazards.

Temporary traffic management is described in COPTTM (Transit NZ 2004), or in client-specific or site-specific requirements as appropriate. If using COPTTM, traffic management plans (TMPs) must be approved by the client before work commences.

TMPs aim to alert all drivers, whether in the sealing crew or of the public, to vehicle and worker movements and to minimise placing themselves or their vehicles in danger. The usual rules apply when driving operational plant, such as wearing seat belts, checking that tyre treads are not clogged with bitumen and chip, and keeping speed down when driving on the open road.

Conversely, workers on foot should also be alert to all vehicle movements, and avoid placing themselves in dangerous situations. So they can be seen, workers must wear high visibility garments at all times.

2.4.4 Chip Spreading Hazards

Most modern roller spreaders mounted on the rear of chip-spreading trucks are equipped with operating controls on the driver's side of the vehicle (as described in Chapter 10, and shown on the Chapter 2 frontispiece). These trucks are operated in reverse, and the driver and the chip-spreading operator should be visible to each other at all times.

Truck drivers should check for tray clearance from overhead wires, protruding objects and the like before commencing work. Consult BCA 9904 for further details in its Chapters 4, 5, 6.

2.5 Hazards to the Environment from Chipsealing

Sealing activities have the potential to cause both good and bad effects on the natural environment and on neighbouring communities. As briefly referred to in Section 2.1, the industry's BCA 9904 provides ways which will help minimise the effects of chipsealing on the environment. To avoid costly remedial work and unwanted negative publicity, such effects should be considered early when planning chipsealing works (Chapter 11).

The objectives of RCAs reflect a commitment to, and a duty of responsible management of effects on, the environment and community. When operating under the RMA, the objectives should incorporate the duty to "avoid, remedy, or mitigate any adverse effect on the environment". They also have a duty under the NES for Air Pollutants (NES 2004) to reduce production of air pollutants (see Chapter 7 for details).

Some of the key environmental and community concerns to be considered that are relevant to sealing, and described in more detail in Chapters 6 and 11 of this book, are:

- Waste reduction;
- Energy efficiency, e.g. in use of fuel;
- Water use reduction and management;
- Pollution control, e.g. CO_2 emissions, leaks to stormwater, fumes;
- Spillage containment (see BCA 9904 Chapters 3.12, 5.11 for procedures);
- Noise mitigation;
- Community liaison.

2.6 References

St John. 1999. *New Zealand First Aid Manual*. The Order of St John New Zealand. Penguin Books (NZ) Ltd.

NZ PBCA (NZ Pavement & Bitumen Contractors' Association Inc.). 2000. The safe handling of bituminous materials used in roading. *Code of Practice BCA 9904.* NZ PBCA (now Roading New Zealand), PO Box 12-412, Wellington, New Zealand.

NZ PBCA (NZ Pavement & Bitumen Contractors' Association Inc.). 2001. *The Bitumen Safety Book. A guide to the safe handling of bituminous materials used in roading*. Edition No. 8. NZ PBCA (now Roading New Zealand), PO Box 12-412, Wellington, New Zealand. 68pp.

Transit New Zealand. 2004. Code of Practice for Temporary Traffic Management (COPTTM). *Transit NZ SP/M/010*. 3rd edition and amendments.

NZ Government Acts and Regulations

The Health and Safety in Employment Act 1992 (HSE).

The Hazardous Substances and New Organisms Act 1999 (HSNO).

HSNO Regulations.

The Resource Management Act 1991 (RMA).

The Dangerous Goods Act 1974.

Dangerous Goods Regulations.

Resource Management (National Environmental Standards relating to certain air pollutants, dioxins, and other toxics) Regulations. 2004 (NES).

NZ TRANSPORT AGENCY
WAKA KOTAHI

ntroduction

A common fault seen on New Zealand's lightly built roads is flushing and/or rutting in the wheel paths.

This is the result of heavy traffic loading which is often confined to set wheel paths particularly where the pavement vidths are narrow.

Combination chipseal provides a cost effective option for repair.

he issue

shing and/or rutting in the wheel paths are the result of avy traffic loading. This is often confined to set wheel ths particularly where the pavement widths are narrow.

nsification occurs in both the layers of chipseal and also underlying pavement layer causing depressions in the eel paths.

e wheel paths often become flush as the chipseal layers ld up over the life of the pavement.

me densification of the pavement in the wheel paths n also occur on new pavements.

ss of skid resistance can be a significant hazard on se sites due to loss of texture/flushing, ponding of ter or both in the wheel paths.

e application of a conventional chipseal in this situation uld inevitably lead to early flushing of the wheel paths d possible chip loss in the coarse un-trafficked areas of surface. There would be no improvement to any wheel h depressions that may exist.

ditionally these risks have been reduced or eliminated completing pre-reseal treatments[1] such as:

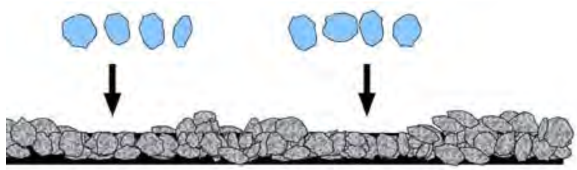
- completing pavement smoothing repairs or rut filling of the wheel track depressions
- completing the chipseal using a sprayer fitted with a variable spraybar[2].

However, a cost effective alternative may be to use a combination chipseal.

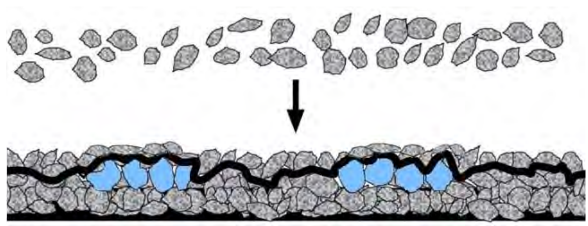
What is a combination chipseal?

A combination chipseal uses a sandwich[3] seal in the wheel paths and a voidfill[4] seal outside the wheel paths in the un-trafficked areas.

Apply large chip to wheel paths



Apply binder then small chip across width of lane



Combination chipseals are designed to chipseal surfaces where the wheel paths are clearly defined by significant bitumen rise/flushing or depressions or a combination of both.

There is generally a significant variation in texture of the surface between the coarse un-trafficked areas, (the shoulders, between the wheel paths and the centreline), and the lower textured wheel paths.

application of the large chip, tightly packed, applied only in the well defined wheel paths (flush and/or depressed) approximately 0.6 to 0.9m wide strips

rolling of this layer of chip if desired (not essential)

assessment and application of the bitumen across the full width of the carriageway

application of the second smaller chip across the full width of the carriageway

rolling of the total chipseal.

sandwich chipseal.

The small chip will then be supported high in the chipseal and not fall into the voids between the large chip. This is to ensure that a matrix of sealing chip and voids is formed. This matrix has internal voids that can soak up some of the surplus bitumen in the wheel paths.

The two chip sizes for a combination chipseal need to be chosen carefully. The small chip should fit correctly in the void of the coarse un-trafficked areas of the existing surface as a voidfill chipseal.

The bitumen application rate can then be determined based on the amount of bitumen required to complete the voidfill chipseal without flushing occurring.

The large chip will be selected based on the depth of rutting and/or the depth of bitumen where flushing is present in the wheel paths.

Experience has established that the bitumen application rate for a combination chipseal is somewhere between the design rate for a voidfill, (dependent on the chip grade, generally 4 or 5), and the design application rate for a large chipseal, (usually grade 2 or 3), if either of these chipseals was completed at the site.

This is somewhere between 20 and 30% less than the standard application rate for the large chipseal.

Experience has shown that the large chip should be spread along the entire length of the wheel paths and not stopped and started depending on the apparent amount of bitumen in the wheel path.

Scabbing of the seal does not occur where there appears insufficient bitumen to hold the large chip but flushing will often occur on those areas where flushing was not evident at the time of sealing and so the large chip was not applied.

Variation in the construction of a combination chipseal

On young pavements that have wheel track depressions without the flushing associated with a layer of chipseals, a light coat of bitumen may need to be applied in the wheel paths prior to the application of the large chip to ensure sufficient bitumen to hold the sandwich seal together.

CHAPTER THREE

Introduction to Chipsealing Technology

Previous page: Chipsealing underway on the West Coast of the South Island, New Zealand. On the left is the bitumen sprayer (distributor) applying the binder, the yellow machine in the center is a self-propelled chip spreader being fed chip by the truck on the right. Photo courtesy of Les McKenzie, Opus

Chapter 3 Introduction to Chipsealing Technology

Chapter 3 Introduction to Chipsealing Technology

This Chapter aims to introduce the practitioner to the basic principles and terminology used in chipsealing technology. These basic principles are expanded in Chapters 4, 5 and 6 in sufficient detail so that they can be applied to the design and selection of chipseals and other surfacing seals. Chapters 7 to 11 describe the practical details of preparing for and constructing the seals including Chapter 9 which describes the chipseal design process.

3.1 Terminology for Road Surfacings

Before learning the basics of sealing technology, it is important to learn some of the terms used in roading and some of them are shown in Figures 3-1 and 3-2 relating to rural and urban roads.

3.2 The Road

A road[1] is a route trafficable by motor vehicles. In law, it is the public right-of-way between the boundaries of adjoining properties and is owned or administered by a Road Controlling Authority (RCA). It is often shown as 'road' or 'legal road' on a plan. In customary use, road refers to all land between the legal road boundaries and typically includes the carriageway, footpaths and other accessways, berms and other unpaved areas constructed for public travel. Where roads have not been formed, the term also refers to so-called 'paper roads'.

The carriageway or roadway is that portion of a road or bridge devoted particularly to the use of vehicles, inclusive of shoulders and auxiliary lanes. A divided road is considered to have two carriageways.

3.3 The Pavement

The pavement is that portion of the road placed above the design subgrade level for the support of, and to form a running surface for, vehicular traffic.

Pavement Layers
The subgrade is the trimmed or prepared surface (or upper line) of the formation, i.e. the surface of the ground, soil, rock or other material. It is the width of the road-bed after earthworks have been completed, on which the pavement is constructed. It has been worked and compacted to sustain the traffic load to be imposed on the pavement.

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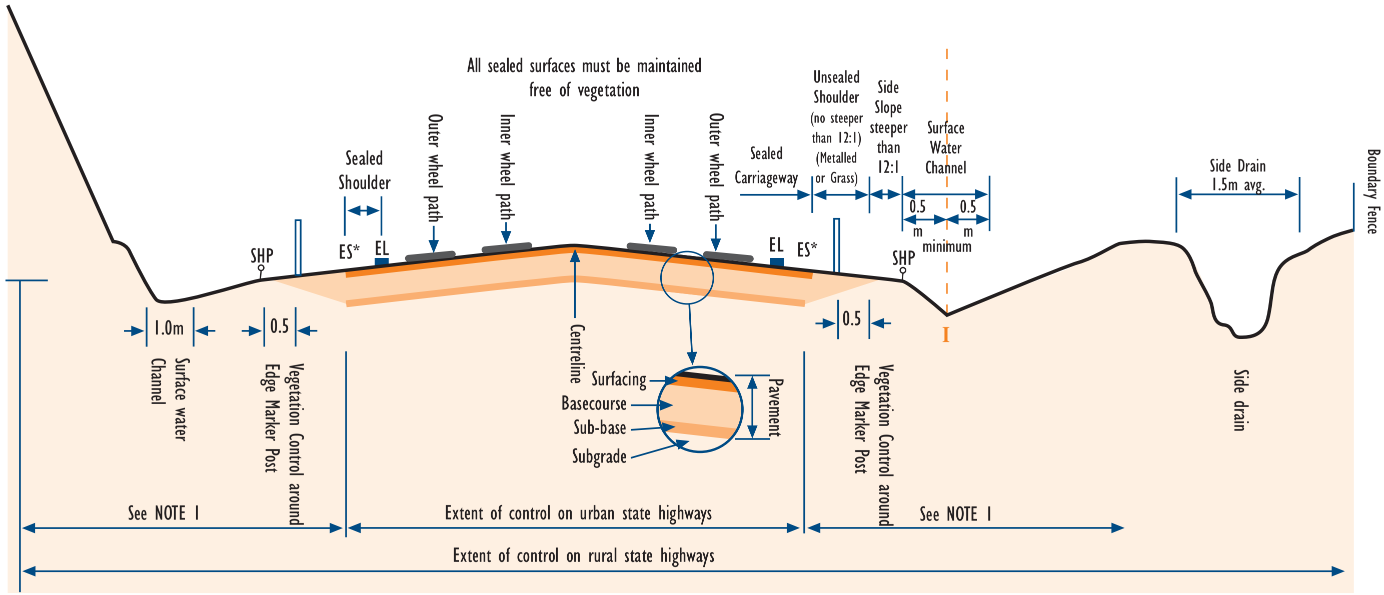
[1] Definitions of terms are listed in the Glossary.

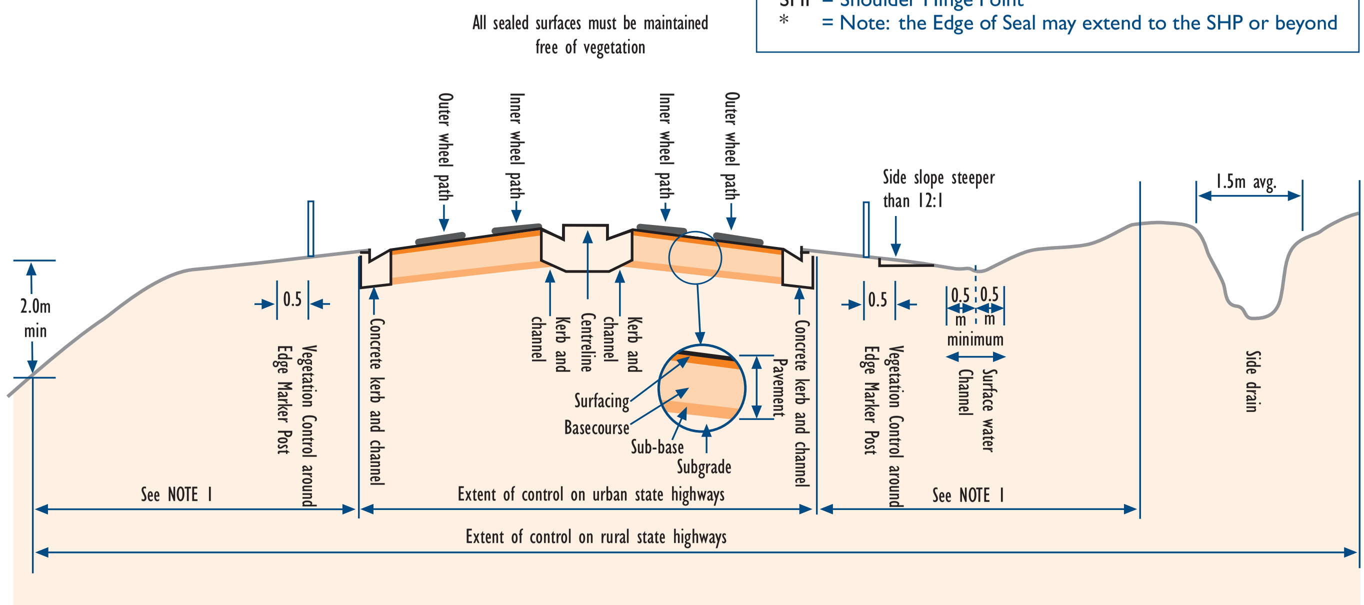


NOTE 1 Limit of vegetation control required for safe site distances. This distance must be a minimum of 3.0 m on straights and on the outside of curves, and a minimum of 5.0 m on the inside of curves

Figure 3-1 Terminology applied to a typical rural road.
Adapted from TNZ C1 Addendum No. 1:1997 and Transit New Zealand State Highway Maintenance Contract Proforma Manual SMO32, Issue 2: March 2002

KEY

I = Invert
EL = Edge Line
ES = Edge of Seal
SHP = Shoulder Hinge Point
* = Note: the Edge of Seal may extend to the SHP or beyond



NOTE 1 Limit of vegetation control required for safe site distances. This distance must be a minimum of 2.0 m on straights and on the outside of curves, and a minimum of 5.0 m on the inside of curves

Figure 3-2 Terminology applied to a typical urban road.
Adapted from TNZ C1 Addendum No. 1:1997 and Transit New Zealand State Highway Maintenance Contract Proforma Manual SMO32, Issue 2: March 2002

The sequence of layers of a pavement, working up from the subgrade, are:

- Sub-base – the material laid on the subgrade below the basecourse, either for the purpose of making up additional pavement thickness to prevent intrusion of the subgrade into the base or to provide a working platform. It is the bottom layer of a pavement, usually constructed from coarse material.
- Basecourse (base, road base) – one or more layers of material usually constituting the uppermost structural element of a pavement and on which the surfacing may be placed. It may be composed of fine crushed rock, natural gravel, broken stone, stabilised material, asphalt, or Portland cement concrete.
- Surfacing (also called top surface, wearing course, surface course) – the uppermost part of a pavement, specifically designed to resist wear, including abrasion, stress caused by turning traffic and similar damage from traffic, and to minimise the entry of water to the pavement. The purpose of the surfacing is to improve the service that a pavement gives to traffic by making it safer, more economical or more pleasant to use.

  Surfacings may be constructed of chipseal or asphaltic concrete, or other material. The materials may be bound, i.e. by a binder; or unbound granular material of particles consisting of gravel and sand that is compacted but not bound.

Types of Pavement

Flexible pavements – the thin granular flexible pavement is ideal for use in New Zealand and is typically low cost. In an unbound flexible pavement the basecourse is constructed of unbound granular material. Surfacings for flexible pavements are of the following types: running-course metal (not covered in this book); top surfaces of chipseals; several layers of chipseals; or thin asphaltic concrete. Thin surface flexible pavements are by definition less than 45 mm thick.

Rigid pavements – pavements in high stress situations may be of rigid construction, using high strength rigid concrete as a construction layer, or layers of dense asphaltic concrete. These pavements, while very strong and durable, have relatively high cost. Thick rigid pavements constructed of structural asphalt are generally 110 mm or greater in thickness.

(Asphaltic concrete layers of 50 to 110 mm thickness are avoided for road pavements for structural reasons, and are not considered in this book on chipseals. Austroads Pavement Design Guide (2004) covers the topic.)

Functions of the Pavement

One of the most important functions of a pavement is to withstand the loading imposed by traffic and the resulting stresses. The surfacing engineer's task is to design a pavement that performs well under those stresses.

- Compressive Stresses (Figure 3-3) – these are the vertical stresses generated by a vehicle that are dissipated down through the pavement layers.

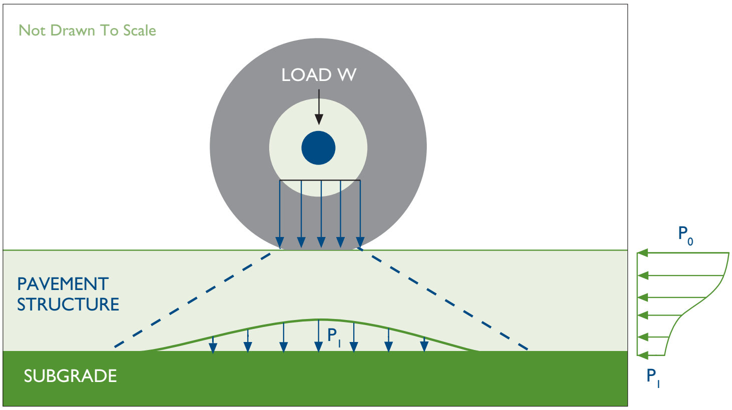


Figure 3-3 Compressive stress exerted under a wheel load.

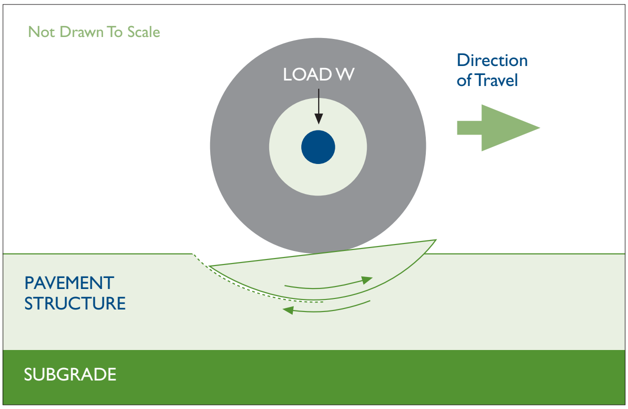


Figure 3-4 Shear stresses exerted by a braking wheel.

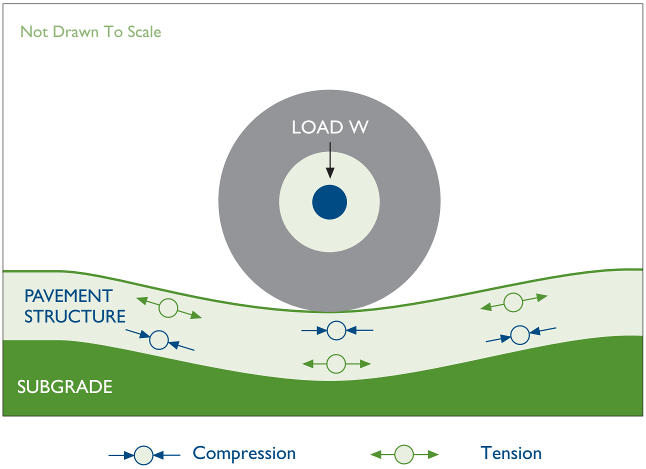


Figure 3-5 Tensile–compressive stresses exerted by a load in a bitumen-bound layer (from Transit NZ 1993).

- Shear Stresses (Figure 3-4) – these are generated by shear in the pavement during braking, acceleration, etc., by the loaded vehicle tyre.
- Tensile Stresses (Figure 3-5) – these are generated by deflection of the pavement surface by the loaded vehicle tyre. The tensile stresses can only be generated in bound materials such as cement and bitumen-bound materials, and are not present in granular basecourse.

The basic philosophy of pavement structural design is to choose, for the different layers, materials that have sufficient shear strength to carry the traffic loading, and to use those materials to limit both compressive stress on the subgrade, and tensile strain at the bottom of any bound layer.

3.4 The Chipseal

The surfacing known in New Zealand as a chipseal, or seal, is called a 'surface dressing' in the United Kingdom and many other countries, or a 'sprayed seal' in Australia. It comprises a uniformly sized stone, aggregate or 'sealing chip' embedded in a 1 to 2 mm-thick film of bituminous (or synthetic) binder, to provide a thin waterproofing layer as the top surface of a pavement (Figures 3-6 and 3-7).

Each grade of chip is made up of very nearly single-sized chips of the same shape to provide a uniform depth of macrotexture.

Macrotexture is the texture of the chipseal that can easily be seen with the eye, i.e. 0.5 mm to 10 mm and is frequently referred to as 'texture'.

Microtexture is the microscopic surface of the chip, i.e. up to 1 mm.

Single or multiple layers of binder and chip may be used.

3.4.1 The Binder

The binder is a waterproof adhesive viscous material that binds to both the existing road surface and to the sealing chips of the chipseal to make a cohesive mass.

The binder needs to be liquid enough (i.e. have low viscosity) to be sprayed onto the pavement surface. To achieve this low viscosity, it may be heated, or diluted with a volatile solvent such as kerosene when it is called a cutback bitumen, or mixed with water to make a bituminous emulsion.

It hardens as it cools, or as the solvent evaporates, or the emulsion breaks (i.e. the emulsion breaks down to its constituents of water, and bitumen which forms a continuous film on the chips). It then hardens or cures sufficiently to be able to hold the chip firmly

Figure 3-6 Constructing a first coat chipseal near Gisborne in the 1920s was not highly mechanised, compared to the line of construction machines used in the 2000s shown in Figure 3-7.
Left: Hand spraying the basecourse, from the tractor-drawn bitumen distributor. Right: Spreading the chip by shovel as the tip truck was not yet in use. Photos courtesy of John Matthews, Technix Group Ltd

Figure 3-7 Constructing a chipseal.
Clockwise from top left: Spraying binder and spreading chips in one operation. Top right: Spraying the binder. Bottom right: Spreading the chips. Bottom left: Rolling the surface. Photos courtesy of Les McKenzie, Opus

in place when it can then withstand the action of traffic. This may be within a matter of minutes or hours, depending on the binder type. The binder must stay at a relatively low viscosity for long enough after it first lands on the road for the chips to re-orient to their final positions, under rolling and gentle trafficking (Figure 1-2). By the time the binder has hardened the chips must have re-oriented and locked into their final positions.

A seal is tender for the first 24 to 48 hours depending on traffic loading, seal type, binder type, and environmental conditions. It may be susceptible to damage from heavy rain or low temperatures for some weeks after construction. Traffic control measures are used to reduce vehicle speeds during this time.

In New Zealand, a binder is almost always based on bituminous material that is produced as one of the products of refining crude oil at an oil refinery. Bitumen may be called asphaltic bitumen or asphalt in the US or other countries, and it is the primary material in 99% of surfacings used in New Zealand. It occurs either as a natural deposit or produced by non-destructive distillation of natural deposits, generally crude oil. (For more information, see Chapter 8.) Some special purpose seals use synthetic binders or polymer modified binders (PMB).

3.4.2 The Aggregate or Sealing Chip

The aggregate or sealing chip is an essential part of the top surface as it adheres to and protects the binder and basecourse from traffic wear, supports all the wheel contact forces, and provides surface friction thus creating a skid-resistant surface.

Aggregates for chipsealing are manufactured to meet specified properties, which include strength, weathering resistance, size (and uniformity of size), shape and polished stone value (PSV).

Usually chip is manufactured from crushed rock (details are in Chapter 8) and, in the past, specifications have required that 'naturally occurring aggregates' were to be used. However in recent years, chip has also been manufactured from synthetic materials such as 'calcined bauxite' (see Section 8.5.2), for specialist or exceptional circumstances. New materials are likely to be developed for use as sealing chip in the future. There is a growing trend toward conservation and the re-use of materials and recycling.

Sealing chip should be required to meet the performance properties of a certain sealing specification, rather than be specified according to the origin of the parent material. The current specification in New Zealand for sealing chip is TNZ M/6 *Specification for sealing chip* (Transit NZ 2002).

Manufacture of chip involves producing chip with angular faces and of similar size and shape within each grade. Traditionally this process is achieved by crushing and screening into sizes or grades as required by the TNZ M/6 specification (more details in Section 8.5). Different sizes or grades of chip are used. The size and type of chip is decided during a detailed treatment selection and design process for a chipseal (Chapter 6). Grade sizes of sealing chips are Grades 2 (coarsest), 3, 4, 5, and 6 (finest). For chipseals constructed of two or more layers of different sized chips, a two figure convention is used. The first chip listed is the lower layer in the chipseal, therefore Grade 3/5 means that Grade 3 is used in the first layer or coat, and finer Grade 5 chip is used in the overlying second layer or coat.

3.5 Basic Requirements of a Surfacing

The purpose of a top surface is to:

- protect the pavement and subgrade from environmental damage related to weathering;
- waterproof the pavement;
- provide a wearing surface that is resistant to abrasion by vehicles using it, and resistant to crushing under traffic loading;
- provide a dust-free surface under any conditions, and thereby contribute to traffic safety, comfort, and convenience by providing a smooth surface;
- provide non-skid properties to an existing surface;
- provide pleasant travel at an economical cost.

3.6 Sealed Pavement Types

Pavements in New Zealand fall into one of two main classes:

- Unsealed (not discussed further in this book);
- Sealed.

Sealed pavements can be divided into a further four broad classes of surfacing:

- Chipseal surfacings (Section 3.7)
- Slurry Seal surfacings (Section 3.8)
- Asphaltic Concrete surfacings (Section 3.9)
- Specialist surfacings (Section 3.10).

3.7 Chipseal Surfacings

Many chipseal types exist. Some can be used for more than one purpose while others are very specialised in their use or require a specific set of circumstances in order to be successful.

Chipseal surfacings are considered as either:

- First coats (includes Prime coats);
- Reseals (includes Second coats and Pretreatment Seals).

3.7.1 First Coats

3

A first coat is the initial seal on a prepared unsealed surface, which is usually a basecourse. They must be designed to adhere to and provide waterproofing for the unsealed prepared basecourse. They are the first treatment for a granular pavement or overlay, and serve principally to prepare the base for the main treatment.

A first coat seal (Figures 3-8 and 3-9) should be an integral part of the pavement construction design and the planned subsequent seals in years to come. Selection of a first coat treatment and of future seal coats must therefore be included during the initial pavement construction design. Generally, a first coat is only expected to last one year before being resealed, although they may last much longer on low traffic volume roads.

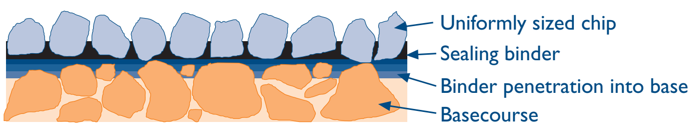


Figure 3-8 A first coat seal. Courtesy of Austroads Sprayed Sealing Guide (2004)

Figure 3-9 A first coat seal under construction on a road on the West Coast of the South Island.
Photo courtesy of Les McKenzie, Opus

First coat binders need to be fluid enough to wet through dust and adhere to the stone surfaces, yet not so fluid that they will neither hold the sealing chip nor run off into side drains. Past practice has been to include relatively large quantities (>6 parts per hundred (pph)) of cutter[2] in first coat binders to aid the wetting process.

Although very few occasions occur where the first coat seal itself does not perform its function, the success of the first coat seal is a direct reflection of the quality of pavement or basecourse construction at the time of sealing.

Construction of a surface to which a first coat will adhere must be a well-bound, relatively dry, smooth hard surface, with a surface of clean stones showing and with no unbound fine material (dust), see Chapter 7 for more details.

A first coat may be applied to an existing pavement as part of a repair patch or applied to the pavement shoulders as a seal widening.

3.7.2 Prime Coats

High cutback-content prime coats (also called prime seals) which have up to 50% cutter in the bitumen have been used and are often specified in other countries. In New Zealand however, the use of high cutback prime coats is not encouraged because of the hazardous nature of the cutback binder (known as the primer) and its effects on the environment.

If a prime coat is used, its main function is to ensure a good bond between the larger stones in the basecourse and the surfacing. To achieve this, a low viscosity, bitumen-based binder (the primer) is used, which penetrates or 'wets through' any surface dust layer then adheres firmly to the stone beneath (Figure 3-10).

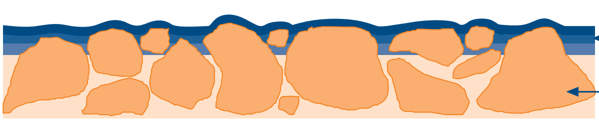


Figure 3-10 A prime coat seal. Courtesy of Austroads Sprayed Sealing Guide (2004)

To achieve this function of providing a good bond between basecourse and surfacing, the primer must have the following properties:

- It must be able to penetrate the fine surface dust layer that always coats the aggregate particles of a granular basecourse surface.

2 Cutback bitumen is a bitumen which has its viscosity temporarily reduced by the addition of a volatile diluent or 'cutter', such as kerosene, to make it more fluid for ease of application.

- It must adhere easily and quickly to the surface of the coarser particles in the basecourse surface.
- It must be compatible with the subsequent surfacing to promote rapid adhesion to it.

These demands can be met by using a penetration grade bitumen binder which is cut back to a low viscosity with a rapid to medium curing volatile cutter, and contains an adhesion agent. Kerosene is the usual cutter although other solvents such as mineral turpentine can be used.

Because cutback prime binders are hazardous, alternatives to prime coats are available. These can include emulsified primes, and the mixing of slow-breaking emulsions into the basecourse layer during the construction process of watering and compacting the basecourse.

These techniques can allow the use of harder, more viscous chipsealing binders in the next seal coat to be applied. These can provide improved waterproofing, longer seal life, and allow the use of larger sized chip.

Prime seals can also be used on timber bridge decks to promote adhesion between the chipseal and the timber.

3.7.3 Reseals

A reseal is any chipseal applied to a surface which has previously been sealed. A reseal is applied because the existing surfacing is showing, or is about to show, signs of distress. Reasons for resealing a surface is to improve one or more of the following:

- Loss of waterproofing;
- Reduced skid resistance;
- Ageing and brittleness of binder;
- Chip loss;
- Old chipseal showing hairline cracks requiring repair;
- To reinstate or increase surface texture (macrotexture).

3.7.4 Second Coats

The term second coat refers to the reseal applied to a first coat seal. In the past, the term was used to differentiate between the reseal applied after a first coat and subsequent reseals. They were almost without exception applied within 12 months of the first coat being laid on state highways but other RCAs had different policies. Such policies had usually been made because the RCAs were confident of obtaining adequate waterproofing and long life of the seal using a delayed second coat.

However today, for all intents and purposes, a second coat is a reseal and will be referred to as a reseal from here on.

In more recent years pavement and surfacing designers have been resealing first coats on a 'need to' basis rather than following a blanket policy. If the timing of a reseal is based on engineering judgement, the reseal to a first coat can extend the overall life of the pavement surfacings, because it is then sealed at the most appropriate time which maximises the value gained. Some first coats may not need to be resealed for several years, depending on factors such as the quality of pavement construction, the first coat seal type, and traffic volume. However care needs to be taken because extending the life of a first coat beyond its appropriate life may result in premature pavement failures.

3.7.5 Pretreatment Seals

Treatments which may be applied to a surface as a pretreatment to resealing are many, and some are included in the category of seals. They are discussed in detail in Section 7.1.3.

3.7.6 Single Coat Chipseal

A single coat is a single sprayed application of sealing binder followed immediately with a single application of chip which is spread and rolled into place (Figure 3-11). It is always applied using a larger chip than the existing surface chip, with the exception being a voidfill (Section 3.7.9).

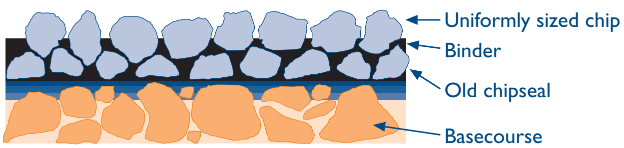


Figure 3-11 A single coat chipseal.

Category

- First coats.
- Reseals.

When to use

- Best in situations where traffic stresses are not great.
- Suitable for low to high traffic volumes.

Existing surface condition required

- When applied as a reseal, existing macrotexture variation must be within limits relative to the chip size nominated in the reseal.

- Existing surface texture must be consistent, not too coarse, with a sound surface and sound pavement condition to be successful.

Advantages

- Low cost.
- Can provide excellent waterproofing because the binder is concentrated in one layer.
- Will provide macrotexture.
- Simple to construct.
- Can perform well in most situations provided they are well constructed, including stressed sites such as steep grades provided the traffic volumes are of medium to low density.

Limitations

- Limited resistance to traffic stresses (e.g. cornering stresses).
- Should never be applied with a chip that is the same size as existing surface chip, unless it is an old worn surface.
- Not very tolerant of a wide variation in underlying texture.

Summary comments

- A straightforward standard seal.
- Single coat seals have been used extensively throughout New Zealand for as long as chipseal surfacings have been constructed.
- Their simplicity and ease of construction make them a cost-effective choice in all simple non-stressed environments.

3.7.7 Two Coat Chipseal

A two coat is a chipseal with two applications of binder and two applications of chip (Figure 3-12), applied in the following sequence:

- An application of sprayed binder is followed immediately with an application of large size chip.
- Then a second application of sprayed binder, and a second application of smaller chip.
- Both coats are applied one after the other with little or no time delay between coats.

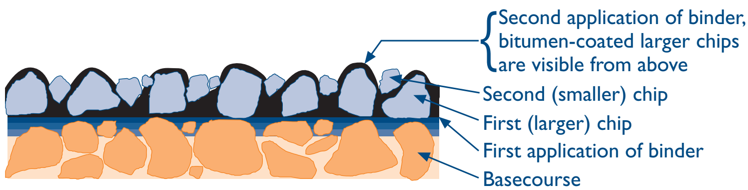


Figure 3-12 Two coat seal (two applications of chip and two applications of binder), shown here as a 'Two Coat as a First Coat seal'.

Two coat chipseals and other chipseals with more than one layer of chip are sometimes known as 'multicoat seals'.

Category

- First coats.
- Reseals.

When to use

- In areas with low or high traffic volumes.
- In difficult conditions, often where other seal types are not suitable because of site conditions, e.g. high stress areas.
- Can be used as a first coat, in which case they are called 'two coat as a first coat' seals.
- Often used when a non-conventional binder is specified, e.g. emulsions or PMBs, to aid chip retention.
- A two coat seal can be used without a pretreatment seal to seal off a porous underlying surface.
- Reasonably resistant to snow-plough damage as has less macrotexture than a single coat seal.

Existing surface condition required

- When applied as a reseal, macrotexture variation must be within limits relative to the chip size nominated in the reseal.
- Consistent underlying texture, although it is more tolerant of texture variation than a single coat.

Advantages

- Able to withstand more traffic stress than most other chipseal surfacings.
- More tolerant of texture variations in existing conditions than other chipseal surfacings.
- Can be constructed as a stress-resistant seal coat.
- Generally durable and long lasting due to chip interlock between the two layers.

Limitations

- More costly than single coat chipseals.
- During the construction of two coat seals and through their early life, loose chip can create considerable nuisance.
- Loose chip can be evident for many months after construction and regular sweeping is required.
- The appearance and performance of a two coat seal is subject to the construction techniques employed.

- Chip size compatibility and spread rates are critical, and directly affect the final outcome.
- Bitumen can be picked up by vehicle tyres (called 'tracking') because binder has been sprayed on the large chip.
- Depending on construction techniques, the seal can be rough and noisy, or smooth and quiet under the action of vehicle tyres.

3

Summary comments

- Two coat chipseals have been used in recent years as a cure to all problems and have been applied in many situations, but they are not a replacement for all seals.
- Their performance and appearance however is very dependent on construction and the selection of chip size and compatibility. (They can be rough and noisy or smooth and quiet, depending on the construction techniques that are used.)
- Construction techniques vary in rates of chip application and rolling, e.g. if the first coat is rolled (especially with a steel roller), a very different seal is constructed (because more chip realignment occurs) compared to one which is not rolled or not trafficked between coats.
- Although more complicated than a standard single coat chipseal, two coat seals have been used for some years now, and a skilled and experienced crew should have little trouble with construction of a two coat chipseal.

3.7.8 Racked-in Chipseal

A racked-in chipseal consists of one application of binder and two applications of chip (Figure 3-13), applied in the following sequence:

- A single application of binder is applied, followed by the application of a large chip which is widely spaced (with 'windows' between the chips).
- This is followed by a further application of smaller chip.
- The smaller chips fall into the windows between the large chips of the first application, and adhere to the layer of binder below.

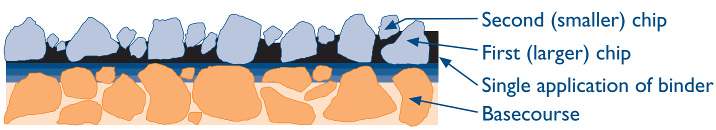


Figure 3-13 A racked-in seal (one application of binder, two of chip).

Category

- First coats.
- Reseals.

When to use

- In areas with low or high traffic volumes.
- In difficult conditions where other seal types are not suitable, and where loose chip from two coats cannot be tolerated.
- On just the high-stress intersections in a long run of single coat chipseal.
- In town centres where loose chip needs to be kept to a minimum.
- Often used where a non-conventional binder is specified, e.g. a PMB, to aid chip retention.
- Reasonably resistant to snow-plough damage as has less macrotexture than a single coat seal.

Existing surface condition required

- When applied as a reseal, macrotexture variation must be within limits relative to the chip size nominated in the reseal.
- Consistent surface texture and pavement condition are required to provide a good surface.
- Surface conditions required are similar to those for single coat seals.
- The most important objective during racked-in seal construction is to produce a first layer that ensures a surface condition with adequate windows left between the chips of the first layer when they are being spread onto the binder. This allows the smaller chip to fit between them.

Advantages

- Cost effective.
- Able to withstand more traffic stress than single coat chipseals.
- Can withstand more texture variation in existing conditions than a single coat seal.
- Less loose chip than single coat seals.
- Can be constructed quickly.
- Can use less binder than a two coat or single coat seal.
- Racked-in seals generally do not generate tracking of bitumen.

Limitations

- As with two coat seals, the construction techniques used will significantly influence the final outcome.

Summary comments

- Racked-in seals were first constructed many years ago, and in more recent times have come back into use.
- Racked-in seals are being used in moderately stressed situations where two coat seals which generate loose chips are less favoured.
- Although more complicated than a standard single coat chipseal, they have been in use for some years, so a well-trained crew should have little trouble with seal construction of a racked-in seal.

3.7.9 Voidfill Seal

A voidfill seal is a single very light application of binder, followed by a single application of small chip designed to fit into the macrotexture of an existing chipseal surface (Figure 3-14). Also known as a void seal.

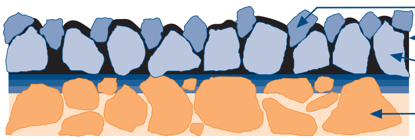


Figure 3-14 A voidfill seal (a single application of binder and small chip over existing seal).

Category

- Reseal.

When to use

- On a surface requiring resealing that has coarse texture which creates excessive binder demand (usually when sand circles, used to determine macrotexture of the surface, are 170 mm or less).
- On a surface showing early signs of chip loss. However, if the chip loss is advanced a voidfill will not fix the problem and a texturising seal should be used (Section 7.3.4.3).

Existing surface condition required

- Coarse texture.
- Not to be applied to a smoother textured surface.

Advantages

- Provides a cost-effective, smooth, consistent surface for subsequent reseals.
- Uses minimal binder.
- The chip application rate is lower than that for a single coat seal.
- When used appropriately, they can prevent cumulative development of uneven texture.

- They can prevent long-term problems caused by excess binder in the chipseal layers because proportionally more chip is present and less bitumen is required.

Limitations

- Can only be applied to coarse textured surfaces.
- As they reduce texture, the resulting smooth surfaces can influence skid resistance at high speeds in wet weather. Therefore a new voidfill should not have less than 0.9 mm macrotexture depth.
- Generally they need to be resealed in 2 to 3 years, except in areas with low traffic volumes where they can achieve a very long life.
- Incorrect chip size selection (e.g. too large) can re-create coarse texture and so defeat the purpose of the voidfill seal.
- They should not be applied where excess binder has already accumulated at the road surface (called flushing), because the binder will be displaced and rise up around the voidfill making the problem worse.

Summary comments

- A voidfill seal fills the existing coarse texture with chip and requires very little binder.
- The resulting seal is a smooth even-textured surface on which subsequent reseals can be applied, using minimal binder application rates.
- Normally a new voidfill should not have less than 0.9 mm texture depth.
- While they can last a long time in areas of low traffic volumes, generally they have a short life.
- A relatively simple seal type and comparatively easy to obtain a good job.
- Voidfills play a very important role in the life cycle of the pavement surfacing because the voids are filled with chip rather than binder. This alters the overall ratio of binder to chip (called the binder:stone ratio).
- Because more chip is present and less bitumen is required, the binder:stone ratio is lowered in the successive seal layers, and this reduces the chance of layer instability developing (more detail is in Section 4.7.4.2).
- Care is required to select the correct chip size because the aim is to fill the void as close to level with the existing chip as possible, and to avoid using a large chip that can sit higher than the existing chip.
- Design of voidfill bitumen application rates is by experience. Usually an experienced seal designer selects a relatively low binder application rate, rather than apply the design algorithm which would result in application rates that are too high.
- Voidfill seals must not be applied to flushed or bleeding wheelpaths (i.e. bitumen at the surface) as they will tend to make these problems worse. Other treatments for such distressed areas can be sandwich seals, water cutting, etc. (see Chapter 7 for treatments for flushed and bleeding wheelpaths.)

3.7.10 Sandwich Seal

A sandwich seal (Figure 3-15) is applied in the following sequence:

- A layer of large chip is spread directly on the existing surface.
- This is followed by a relatively light application of binder.
- A smaller chip is then spread directly onto the sprayed binder.
- The surface is rolled to compact the seal.

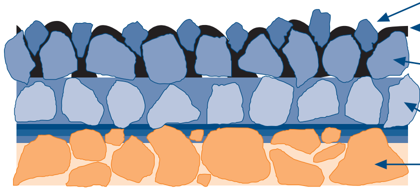


Figure 3-15 A sandwich seal.

Category

- Reseal.

When to use

- On existing sealed surfaces which are unsuitable for conventional resealing as they are rich in binder (e.g. flushed surfaces with little to no texture).
- To help correct binder:stone ratios in unstable or potentially unstable seal layers.

Existing surface condition required

- Little to no texture, and rich in binder.

Advantages

- Sandwich seals can be a cost-effective seal to restore texture to smooth binder-rich surfaces.
- They can prolong the life of a pavement surface which is nearing the unstable phase, usually related to successive build-up of seal layers.

Limitations

- Because the surface to which a sandwich seal is applied is generally nearing the unstable phase, their performance can be unpredictable.
- If the existing surface is very rich in binder, the sandwich seal may only temporarily restore texture.
- Their success is dependent on the accurate assessment of the amount of free binder in the existing surface, which is used in calculating the appropriate binder application rate.
- Success and appearance are also subject to chip size compatibility and construction techniques.

- Although good results have been achieved, sandwich seals are not suitable in all high stress situations.

Summary comments

- On flushed surfaces sandwich seals are used to absorb existing surface binder by using larger chip sizes of Grades 2 and 4. In urban environments a finer Grade 3/5 sandwich seal may be more appropriate.
- Sandwich seals have been developed in recent times as a valuable cost-effective method of sealing over unstable multiple chipseal layers.
- By nature they are considered by some as a repair, but they are becoming a valid reseal, albeit with some unpredictable results.
- It is a relatively new chipseal type on the New Zealand market that is more complicated to achieve than two coat seals.
- Sandwich seals have been used (Figure 3-16) for some years now in some parts of the country, while in other parts of the country they are little used. Therefore seal construction crews who are employed to lay sandwich seals range from skilled and experienced crews to those who are learning. This may add to the variability of the results.

Figure 3-16 A sandwich seal under construction in Hawke's Bay.
Clockwise from top left: Applying the first layer of large chip to the flushed surface without binder. Top right: Applying the binder over the large chip. Bottom right: Applying the binder over the large chip. Bottom left: Small chip being spread over binder over large chip.

Photos courtesy of Laurence Harrow, Opus

3.7.11 Wet Lock Seal

A wet lock maybe applied to a new seal to improve its durability under unexpected traffic stress. Wet locks create an interlocking seal layer using smaller chip which fits into the texture between the large chips. A light application of binder is used to make sure the smaller chip adheres to the underlying seal (Figure 3-17).

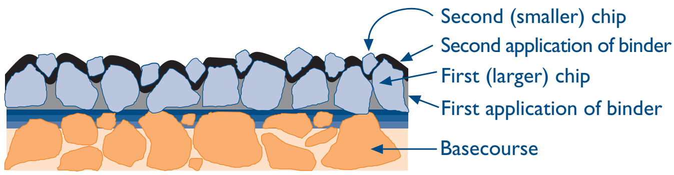


Figure 3-17 A wet lock seal.

They differ from two coat seals in that they are not necessarily constructed immediately one coat after the other, and the two coats can use different binders. Often the wet lock seal is applied after a period of time (e.g. the next day). A wet lock is not used as a first coat seal but could be applied to a first coat seal. The first coat is designed as a single coat seal and the second coat as a voidfill.

The binder:stone ratio in a wet lock is higher than that for a racked-in seal or two coat seal. This means a wet lock may increase the risk of future flushing.

A bitumen emulsion is often used as a binder as the emulsion binder application rate is typically low, reducing the risk of binder run-off.

Category

- Reseal.

When to use

- To enhance surfacing strength.
- Where a single coat is failing or about to fail (usually due to under-application of binder). Applying a wet lock avoids a seal failure.
- Can be used on just the high stressed intersections in a long run of single coat chipseal.

Existing surface condition required

- Coarse texture, to enable the small chip to fit between the large chip.
- The selection of chip size is important for the seal to be successful.

Advantages

- Wet locks can greatly enhance the strength of a seal without generating as much loose chip as does a two coat seal, because chips on the bottom layer are rolled and swept before the wet lock coat is applied.

- When designed and constructed appropriately, they can produce less traffic noise, have more consistent texture, and are more resistant to traffic stress than a two coat seal.

Limitations

- When used as a repair, care is required with binder application rates to avoid over-application which results in flushing.
- Overall macrotexture will be reduced but should still meet minimum texture requirements.
- When designed and constructed with a delay between the applications of the two layers, the risk of traffic damage and chip loss to the bottom layer is very high.

Summary comments

- Wet locks are not used often and are usually employed as a repair of a single coat which shows early signs of failure.
- Very strong, well-constructed seals can be achieved but the risk of flushing that may be caused by excess binder needs to be assessed in the design.
- When designed specifically and not used as a repair a strong seal can be achieved, but the risk of traffic damage to the bottom layer may be high if the delay between coats is too long.
- Wet locks are no more complicated to apply than a standard single coat chipseal or voidfill, and a chipsealing crew should have little trouble with its construction.
- Can be designed and used for the construction of a strong well-bound seal coat on a new pavement construction where the bottom chipseal layer is not trafficked before the wet lock is applied.

3.7.12 Dry Lock Seal

A dry lock is the application of small chip to a new chipseal (Figure 3-18), usually after some traffic has used the new seal. No binder is applied before spreading the dry lock chip. The small chip fits into the texture of the new larger seal chip (and is chosen so it only just makes contact with the binder) where it forms shoulder-to-shoulder contact to add strength and prevent damage to the new seal.

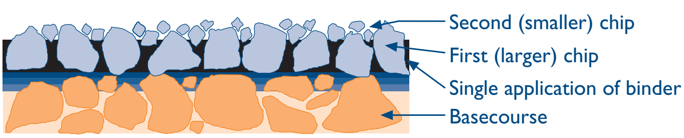


Figure 3-18 A dry lock seal.

It is used to provide a temporary running coat to protect a new seal from traffic stresses because it provides a protective layer of chip over the new seal.

3

Category

- A dry lock is not a reseal but can be applied to a reseal.
- A dry lock is not a first coat but can be applied to a first coat.

When to use

- In any circumstance where some added protection from damage caused by traffic stresses is required.
- Can be used on just the high stressed intersections in a long run of single coat chipseal.
- Usually applied to a larger size single coat chipseal where the small chip of a dry lock will help prevent the large chip from being plucked out of place.

Existing surface condition required

- Fresh seals, usually a few hours after sealing and rolling is complete.
- Coarse-textured seals with large size chips to enable the locking chip to fit into the texture.

Advantages

- Inexpensive and easily applied.
- Can resist moderate traffic stresses without the need for a two coat or a racked-in seal.

Limitations

- Applying the locking chip too early, i.e. before the large chip has been rolled and is embedded, can cause the small chip to settle beneath the large chip and prise it loose.
- A dry lock seal will reduce overall macrotexture.

Summary comments

- Dry locks are often referred to as inexpensive insurance against traffic damage for single coat seals in moderately stressed situations.
- A dry lock seal is very simple to achieve, and no binder is required.
- A dry lock seal is quite different to a racked-in seal. The small chip fits tightly between the large chip which has been rolled and bedded in. Individual single small chips fit between large chips and only just make contact with the binder.

  In a racked-in seal, more than one small chip will fit between the large chips and the small chip makes contact and embeds into the binder. The large chip will not necessarily be rolled and fully embedded before application of the small chip. This achieves a seal that is very different in both appearance and performance.

3.7.13 SAM Seal

A SAM is a Stress Absorbing Membrane. SAM seals can be single coat, two coat or racked-in seals which use a PMB (Figure 3-19).

The use of a PMB introduces properties to the seal coat which make it more resistant to reflective cracking from an underlying cracked surface. (PMBs are discussed in detail in Section 8.4.)

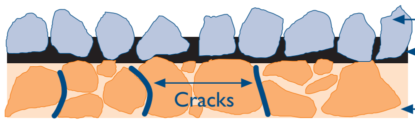


Figure 3-19 A SAM seal. Courtesy of Austroads Sprayed Sealing Guide (2004)

Category

- Reseal.

When to use

- To seal cracked pavements.

Existing surface condition required

- Pavement defects, e.g. cracking, that can be improved by the special properties of PMB.
- The same conditions as required for single coat, two coat or racked-in seals.

Advantages

- SAM seals can provide enhanced performance in cracked pavement situations (see Section 8.4.7 for uses of PMBs).
- A SAM seal will not repair a flushed surface but can prevent binder pick-up on vehicle tyres (tracking) in hot weather.

Limitations

- SAM seals are more costly than conventional binder seals.
- Construction techniques must carefully comply with best practice and the binder manufacturer's recommended procedures.
- Limitations are similar to those of PMBs (Section 8.4.10).

Summary comments

- Although SAM seals are in fact PMB seals, SAMs are specifically designed to minimise reflective cracking in a pavement, whereas a PMB seal can be used for a variety of other purposes.

- They are essentially a single coat, a two coat, or a racked-in seal with a binder that is specifically modified for a particular situation.
- As a PMB is involved, a relatively high pavement temperature (e.g. 20°C) is required at the time of chipsealing.
- The same comments for conventional single coats, two-coats and racked-in seals apply also to their PMB equivalents.
- For resisting or delaying reflective cracking, high binder application rates (>2 ℓ/m²) are used.

3

3.8 Slurry Seal Surfacings

As a slurry seal has properties of both chipseal and asphalt, it is included in this book. An in-service slurry behaves and fails like a chipseal but the technology to produce it is more like that used for an asphalt.

Slurry seals are specifically designed mixes of aggregates, an emulsified binder and additives, applied to a surface and spread to a specific depth.

Depths of slurry seals vary, depending on the aggregate sizes used, and typically they range from 5 mm to 8 mm in depth.

Where the emulsion binder is modified by adding polymer (usually up to 3% of the binder), the technically correct term for a slurry seal is microsurfacing. The term microsurfacing is well recognised overseas but has not found favour in New Zealand. Most slurry sealing in New Zealand contains polymer modified emulsion (PME) and thus meets the specified criteria for microsurfacing.

3.8.1 Slurry Seal

A slurry seal (Figure 3-20) is a surfacing comprising a specially graded aggregate (ISSA 2004a, b, Austroads 2003) mixed with an emulsion binder, a small percentage of filler (commonly cement), and water.

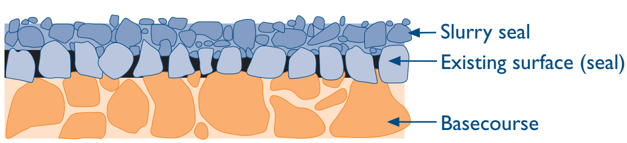


Figure 3-20 A slurry seal. Courtesy of Austroads Sprayed Sealing Guide (2004)

These components are mixed in the correct proportions, usually in a truck-mounted mixing plant (slurry truck), and the resulting slurry is spread onto the road surface by a special spreader box dragged behind the truck.

The four recognised aggregate gradings that are available for slurry seals range from Type 1 (nominal 3 mm maximum size) through to Type 4 (nominal 10 mm maximum size).

Type 1 is used where a very fine texture is required. Nominal aggregate size is 3 mm resulting in a surface texture of typically 0.3 mm. It is seldom used in New Zealand and is most suited for use on footpaths or voidfilling on airport runways.

Type 2 is most commonly used as a reseal, wearing course and/or voidfill on urban residential streets, low to medium volume roads, carparks and footpaths where fine texture, low traffic noise and lack of loose chips are desirable. It has a nominal maximum particle size of 5 mm, resulting in a surface texture of around 0.5 mm.

Type 3 offers a coarser texture for use on roads with higher traffic volumes (e.g. on state highways). It has a nominal maximum particle size of 7 mm.

Type 4 has the coarsest texture and can be successfully applied as a wearing course on high traffic volume sites. It is however most suited for rut filling and minor shape correction of the surface as a stand-alone repair or pre-reseal treatment.

Category

- Reseal (technically deemed to be a thin asphaltic surfacing).

When to use

- As a cost-effective alternative to chipseals where an asphalt-like surface is desirable.
- As a thin wearing course to restore skid resistance and to prevent chip loss (also called fretting).
- To reduce road noise.
- Slurry seal has been reported to have been used over ageing porous asphalts or similar surfaces that are beginning to fret and wear away. The slurry effectively fills the worn areas, prevents further wear and restores a smooth even surface that can extend the seal life by many years.
- Can be used to repair ruts in the pavement by applying a layer of slurry just in the rut itself.

Existing surface condition required

- The surface should be clean as mud and oil deposits will be detrimental to a good bond.
- Thick build-ups of pavement markings, e.g. thermoplastic, should be removed in advance.

Advantages

- Once cured, a properly designed slurry will withstand a high level of traffic stress. Thus slurry seals are well suited to urban and other high stress situations.
- Once cured, has low risk of binder pick-up on vehicle tyres (i.e. tracking).
- In all cases, slurry seals offer very good skid resistance properties, low traffic noise compared with chipseals, and excellent chip retention in areas where loose stones are undesirable.
- Less tyre–road noise.
- More texture than that of a dense asphaltic concrete.
- Safer for sealing crew to apply than conventional chipseals and asphalt because emulsion binder is used and so slurry is applied at less than 100°C.
- More environmentally friendly because emulsion binder is used, and so lower quantities of volatile chemicals such as kerosene are added.

Limitations

- Slurry seals generally provide good skid resistance in all situations but, because of their relatively fine textures, they may not always be suitable for high speed situations where coarse-textured surfaces are desirable to reduce braking distances in the wet.
- Slurry seals should never be applied over young (<1 to 2 years old) chipseals that contain cutbacks or diluents, as this will lead to early flushing or bleeding of the surface. The causes of flushing are explained in Chapters 4 and 6.
- Ideally, slurry seals should only be laid when average air temperatures can be expected to exceed 10°C for a few days following construction. Below this temperature the risk is that the mix will not cure properly and may result in early failure.
- Because a slurry seal is a non-structural surfacing, avoid using it on flexible pavements having deflections greater than 1.5 mm, or where cracking or other pavement failures are structural or extensive. Otherwise the cracks will soon reflect through the slurry causing early failure by cracking or delamination.
- A small degree of flushing or minor cracking can be repaired with slurry, but in moderate or extreme cases the flushing or cracking will reflect through to the surface.
- Longitudinal joints may be visible.
- Specialist slurry plant is required.
- Testing is required, e.g. compatibility of the slurry aggregate with the emulsion binder, durability and wear tests.

Summary comments

- The typical thickness of a slurry is about 5 to 8 mm so only minor levelling of the underlying surface is possible with a single coat of slurry. Some shape improvement is achievable if an initial levelling course is applied immediately before a second top coat. This is called a two-coat slurry.

- The mix hardens as the emulsion breaks and the surface is generally trafficable with care after 10 to 20 minutes. Final curing and hardening of the surface takes place over the following few days.
- The durability of a slurry is sometimes considered to be less than that of a chipseal. However its durability is highly dependent on the aggregate and binder properties, specifically how they react with each other. Many aggregate sources are unsuitable and thorough laboratory testing during the mix design process is an essential prerequisite to ensure an adequate seal life will be achieved. Accurate metering of mix components during construction is essential to ensure that mix design targets are achieved.
- Design criteria and specifications are detailed in either ISSA (2004a, b) or Austroads (2003).

3.8.2 Cape Seal

A cape seal (Figure 3-21) can best be described as a two coat seal where the first coat is a chipseal and the second coat is a slurry seal. The chipseal is constructed, and is followed soon after by the application of a slurry seal which fills the texture of the chipseal.

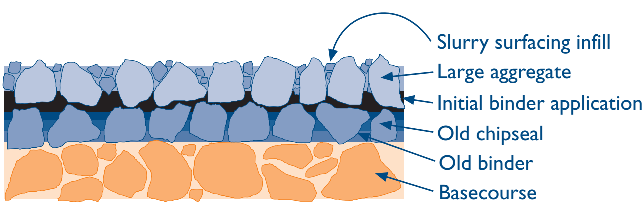


Figure 3-21 A cape seal.

The seal coat provides an effective waterproof membrane, and the slurry fills the interstices between the chips to provide a smooth surface and to lock the chips in place. This effectively combines the best properties of both these types of surfacings where either one on its own would fail to provide the desired outcome.

The chipseal typically uses a Grade 2, 3 or 4 chip and usually incorporates a PMB, with polymer levels of between 3% and 6%. The purpose of the polymer is to provide a high level of chip retention, high surface texture, and a more effective membrane to ensure the cracked surface remains waterproof through its life.

For a cape seal, the slurry is constructed in the normal manner (see Section 3.8.1). The aggregate grading for the slurry seal coat should be targeted to match the voids in the chipseal component. Typical combinations include:

- Grade 2 chip/Type 3 slurry;
- Grade 3 chip/Type 2 slurry;
- Grade 4 chip/Type 2 slurry.

Some flexibility to these combinations is possible depending on factors such as the size of chip and type of end-result texture desired.

Category

- Reseal.

When to use

- In situations where high resistance to traffic stress, reduced traffic noise and a smooth texture are required, and where chipseals or asphaltic concrete are not acceptable options.
- On moderately cracked or flexible pavements in urban and/or residential areas with moderate to high traffic stress.
- Where slurry seals cannot be used on their own as they would not fix cracking in the underlying old chipseal or provide adequate waterproofing.
- When a high level of waterproofing as well as a smooth, tough, durable surface is required.

Existing surface condition required

- Significant texture variations can be accommodated. However badly flushed or bleeding pavements may ultimately reflect through.

Advantages

- Cape seals combine the best features of both a chipseal and a slurry seal surface.
- They produce a smooth, quiet, waterproof, stress-resistant surface.

Limitations

- In very high stress areas (such as roundabouts and sharp corners), cape seals can sometimes slide on the underlying pavement.

Summary comments

- Success has been achieved when precoated chips are used, as these chips adhere well to the binder, and enable the seal to withstand traffic stress before and during the construction of the slurry layer.

- All loose chip must be swept up from the first chipseal coat immediately before slurry sealing.
- Cutback binders containing any volatile diluents, such as AGO or kerosene, must not be used in cape seals. The diluents trapped in the lower layer will cause the slurry seal to flush or bleed. (This is the key reason why precoated chips and PMBs are used in most instances.)
- Binder application rates can be reduced by up to 10%, although this requires judgement based on traffic volumes and the level of cracking in existing surfaces.
- Chip application rates should be sufficient to provide normal shoulder-to-shoulder contact. Over-chipping must be avoided at all costs.
- The slurry seal is normally constructed within one to two weeks of the chipseal being completed. This allows time for proper chip embedment.
- Some practitioners suggest that the slurry should be laid thick enough so that the tips of the underlying chips protrude from the finished surface (Figure 3-22), while others consider the slurry should completely hide the chips. The latter approach is the most common and provides a smoother and quieter running surface, although it is not a true cape seal.

Figure 3-22 Detail of a cape seal surface. (The coin is about 3 cm diameter.)

Photo courtesy of Les McKenzie, Opus

3.9 Asphaltic Concrete Surfacings

Asphaltic concrete is not discussed in depth in this book. However it is a surfacing treatment which is often applied over existing chipseals, and in many cases constructed directly over a new chipseal. In the latter case the chipseal is often referred to as a 'membrane seal' and is applied as waterproofing beneath the asphalt layer. Examples of this latter seal type are OGPA and OGEM, Membrane and SAMI seals.

3

3.9.1 OGPA and OGEM

Open-Graded Porous Asphalt (OGPA) and Open-Graded Emulsion Mix (OGEM) are special seals that allow water to drain off the surface but not let it penetrate through to the basecourse. They are used to reduce spray on motorways and other roads with high traffic volumes (Figure 3-23).

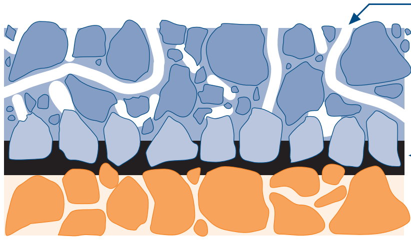


Figure 3-23 An OGPA with waterproof chipseal membrane beneath.

3.9.2 Membrane Seal and SAMI

Membrane seals are constructed to aid waterproofing beneath the asphalt layer. This seal is usually constructed with a binder having little to no cutback and a light covering of chip. They are usually covered soon after with asphalt and are only expected to carry asphalt construction equipment but not normal road traffic. A minimum application rate of 1 ℓ/m^2 is normally applied.

SAMI is a Stress Absorbing Membrane Interlayer (Figure 3-24), usually constructed with a PMB and a light covering of chip (and not to be confused with a SAM, Section 3.7.13).

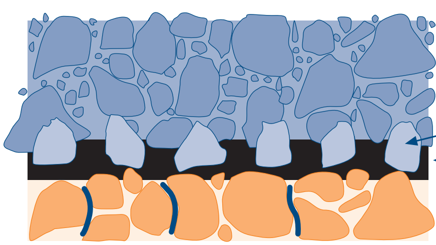


Figure 3-24 SAMI, a polymer modified chipseal membrane underlying an asphalt surfacing.

These membranes are an integral part of the asphalt pavement design and construction sequence, and therefore should not be considered a chipseal as defined in this book.

3.10 Specialist Surfacings

Many specialist surfacings exist in various forms and, as technology develops, new and innovative products are developed to meet specific needs.

Most specialist surfacings at present are associated with providing skid resistance, or with delineating uses of a pavement (e.g. coloured bus lanes). They can be types of chipseal but they can also include asphalt mixes and coloured surfacings.

Examples currently in use include high skid-resistant surfacings using Calcined Bauxite chips and synthetic binders, and coloured treatments used for cycleways or bus lanes. See Section 8.5.2 for information on synthetic aggregates, e.g. slag.

3.10.1 Fog Coat, Rejuvenating Seal or Enrichment Seal

The seals referred to as Fog Coat, Rejuvenating Seal, or Enrichment Seal are essentially all the same kind.

They are a light application of binder, with no chip applied, and usually sprayed over an ageing coarse-textured chipseal. The binders used are usually emulsions with low bitumen contents.

Category

- Reseal.

When to use

- To rejuvenate or enrich an existing seal coat.
- Usually applied to old very coarse seals, often in low traffic environments where the texture is still coarse, the chip is still in good condition, but the binder is becoming brittle and chip loss is beginning to occur.
- To prevent chip loss in new seals where binder has been significantly under-applied.

Existing surface condition required

- Coarse textured seals with low or brittle binder, where chip loss has occurred or is about to occur.

Advantages

- These seals are inexpensive and easy to apply.
- They prolong the life of the existing surfacing without significantly reducing texture.

Limitations

- These seals reduce skid resistance for a short period after spraying.
- Care is required to prevent run-off of the binder, especially when using low bitumen-content emulsions.
- Traffic speed restrictions must remain in place until the binder wears off the tops of the chips and the skid resistance increases to acceptable levels.

Summary comments

- These rejuvenating seals are a cost-effective solution to maintaining coarse-textured surfacings when they need waterproofing or more binder.
- Use where surfacings are showing signs of failure related to brittle binder.
- In the past they have been applied to chipsealed airport runways or lightly trafficked roads.
- They are not often used in New Zealand because they create low skid resistant surfaces.
- Where appropriate, the application of a rejuvenating seal (i.e. no chip is applied) can extend the life of the surfacing by rejuvenating the binder and hence maintaining the original coarse texture.
- A voidfill seal can achieve the same outcome without the loss of skid resistance.

3.10.2 Geotextile Seal

A geotextile seal (Figure 3-25) incorporates a geotextile, which is a synthetic fabric composed of flexible polymeric materials used in geotechnical or general engineering earthworks, for strengthening, and retaining or restricting movement of water or sediment.

A geotextile seal is constructed usually by a light application of binder, over which a geotextile fabric is laid. The fabric is sprayed with binder at a rate to both saturate it and leave enough binder to hold the chips. Chip is then spread, followed by rolling. The chipseal that is laid over the fabric can be a single coat, two coat, or racked-in seal.

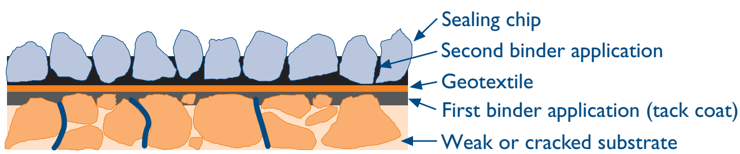


Figure 3-25 A geotextile seal. Courtesy of Austroads Sprayed Sealing Guide (2004)

Category

- First coat.
- Reseal.

When to use

- On soft, flushed or severely cracked pavements (Figure 3-26).
- To extend the life of a pavement by delaying the need for reconstruction.
- Used over a wet soft subgrade, such as a peat or sand.
- Also can be used to waterproof a bridge deck and restrict water from entering bridge joints.

Figure 3-26 Laying a geotextile on a cracked surface.
Clockwise from top left: The cracked pavement to be treated. Top right: Laying the fabric over a bitumen tack coat on the cracked pavement. Bottom right: the fabric in place. Bottom left: Saturating the fabric with bitumen. The next step is to lay chip on top as for a conventional chipseal.
Photos courtesy of Julien van Dyk, The Isaac Construction Co. Ltd

Existing surface condition required

- Used on a range of surface conditions.
- Designers use experience to determine the most appropriate chipseal type to use and the construction method required.

Advantages

- A strong, waterproof mat can be achieved which will cover cracked and stressed surfaces.
- A geotextile seal has been shown in research by Towler & Ball (2001) to prevent future flushing.
- Can be an economic alternative to reconstruction of a severely cracked pavement.

Limitations

- Geotextile seals can be costly in comparison to conventional seals.
- Success is very dependent on design and construction techniques. It is advisable to follow the manufacturer's recommendations.
- The seal can slide and move as a mat if not adhered to the underlying surface, especially in situations of stresses caused by stopping and turning traffic.
- Geotextiles that incorporate a grid give limited strength benefit in surfacing applications.
- Geotextile seals of fabric-only type do not provide strength but do provide a medium that allows increased binder thickness, suitable for repairing cracks and preventing future flushing.
- When used on a flushed binder-rich surface, the fabric has the ability to absorb binder. However, estimating the correct binder application rate so that the binder is enough to hold the chipseal as well as saturate the fabric is very difficult.

Summary comments

- Geotextile seals incorporate the use of fabrics in the seal coat to enhance performance.
- They are used in specific circumstances and care is required in the surfacing design and construction to ensure success.
- The fabric manufacturer's instructions and industry best practice must be consulted and followed in the construction of this type of seal.
- Applying the fabric evenly is difficult, with problems in areas that have many service covers or corners. A specially built jig to hold and apply the fabric helps to alleviate some of these problems, but these jigs are not common in New Zealand.
- Although some RCAs are reporting success with this technique, further research and experience is required before it should be considered low risk.

3.11 Defects in Chipseals

To continue the theme of defining the terminology related to chipseals, the following section defines the defects that are found in chipseals (which lead to resealing and repairs), and causes of the defects are touched on. Causes are covered in greater detail in Chapter 4, while the repair of defects are covered in Chapters 7 and 12.

Some of the defects listed below are pavement faults as distinct from chipsealing faults. Definitions of these are included as well so that the reader can understand the terminology when it is used in later chapters.

3

In New Zealand, the definitive reference relating to defects of the road surface, footpath surface, and kerb and channel is contained in the *RAMM Road Assessment and Maintenance Management System Road Condition Rating Manual, National Roads Board New Zealand, June 1988* (prepared by the Local Government Training Board, for NRB 1988). Commonly referred to as the *RAMM Rating Manual*, this book is currently out of print, so key portions of it relating to road surface defects are reproduced below. The word 'rating' refers to the activity of collecting road surface condition data for input to the RAMM system, or other pavement management system (see Chapter 5). Rating is also a name given to road surface condition data (e.g. the Rating Table in the RAMM database (CJN Technologies 2004)).

3.11.1 Deformation

3.11.1.1 Rutting

Rutting is deformation (Figure 3-27) of the pavement surface. A rut has a regular shape (saucer shaped in cross-section) and looks as though the pavement surface has sunk downwards, or depressed, with no other apparent signs of pavement distress. Rutting may be caused by any of the following:

- Water in or beneath the pavement layers, or the collapse of an underground pipe or other service.

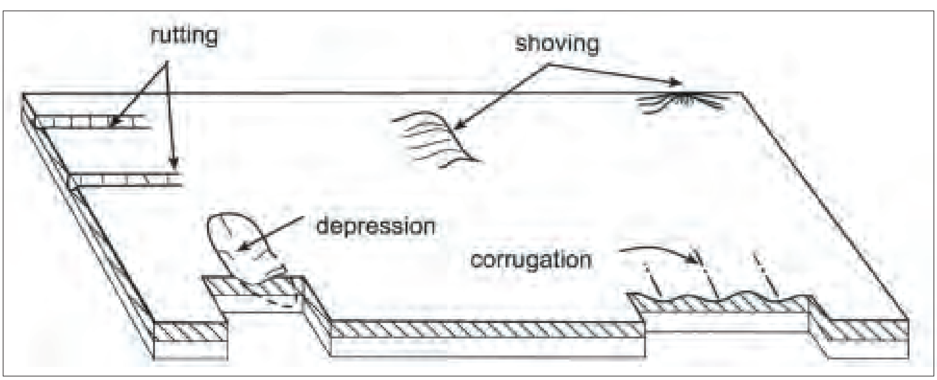


Figure 3-27 Types of pavement deformation. Courtesy of Austroads Sprayed Sealing Guide (2004)

- Within-pavement densification, e.g. it can often be seen where excessive heavy vehicles have caused depressions in the wheelpaths. This would indicate pavement deterioration and may be the normal end-of-design-life failure mode.
- As a result of construction faults, when it occurs in a relatively short time from construction.
- Contamination or deterioration of the structural layer.
- As a result of subgrade deformation which is a structural weakness of the pavement layer.
- When a deep layer of bitumen-rich surfacing has accumulated during the life of the pavement (although this usually results in shoving and shallow shear, see below).

To record the extent of rutting, the RAMM Rating Manual (NRB 1988) states:

> *the length of wheelpath which has rutted to a depth of 30 mm or greater as measured from a 2 m straight edge placed across the wheelpath. If the whole carriageway area or a large part of it is shaped so it holds water then it is rated as if all the wheeltracks in that area are rutted, e.g. for a two lane carriageway holding water over 20 m of the inspection length the rating for rutting would be 4 x 20 = 80 m.*

Note that some RCAs require rating of ruts of as little as 20 mm depth.

The RAMM Rating Manual also states "Rutting has occurred when traffic has caused wheeltracks in the carriageway to be depressed with no bulging in the adjacent pavement."

3.11.1.2 Shoving

Shoving, also called shallow shear, is deformation of the pavement surface where the pavement itself or just the surfacing layers have been deformed and misshapen, with accompanying pavement distress such as alligator cracking, pumping or potholes. Figure 3-28 shows shoving, which may be caused by:

- water in or beneath the pavement layers;
- excessive shear stresses in the surfacing layers by heavy vehicles on corners;
- the disintegration of the granular basecourse layers of the pavement after excessive and repetitive loading.

To record the extent of shoving, the RAMM Rating Manual states:

> *This rating records the length of wheelpath showing shoving in the inspection length. Where there are other defects in the length of shoving being rated, they are to be ignored for rating purposes; e.g. if both alligator cracking and potholes are present in a length of shoving, they would not be rated.*
>
> *Shoving occurs when material is displaced to form a bulge or heave alongside the depressed area… Shoving frequently occurs in the outside wheeltrack often as a result of poor drainage. It can also occur as the result of a poorly designed asphaltic concrete or as a result of moisture entering the pavement through cracking.*

3.11.2 Cracking

Cracks in a bituminous surfacing allow surface water to infiltrate the underlying pavement layers and, with time, to filter through to the foundation (subgrade). This can cause a significant reduction in pavement strength and can very quickly lead to pavement deformation and shear failure unless the cracks are sealed.

There are many types of cracking (Figure 3-29), but the three types of crack recorded in the RAMM system are Alligator, Longitudinal and Transverse, and Block cracking.

3

Figure 3-28 Shoving in a pavement. Photo courtesy of Les McKenzie, Opus

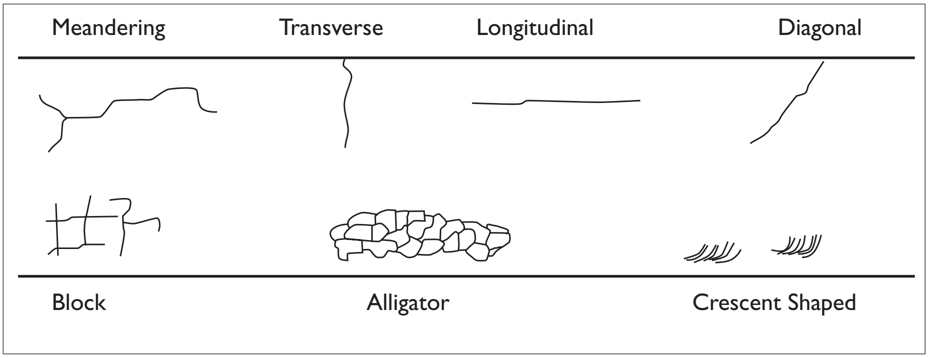


Figure 3-29 Types of cracking in a pavement. Courtesy of Austroads Sprayed Sealing Guide (2004)

The crescent-shaped cracks in Figure 3-29 are caused by shear of the surfacing layers, and the pavement would normally be rated as 'shoved' in New Zealand. The front of the crack points in the direction of the traffic stream.

Alligator Cracking – so named for its semi-regular polyhedral shapes, reminiscent of the pattern on an alligator's skin (Figure 3-30). It is also know as chicken wire cracking as it has the appearance of chicken wire mesh.

Figure 3-30 Alligator cracking has a cracking pattern like an alligator skin.

Photo courtesy of Les McKenzie, Opus

To record the extent of alligator cracking, the RAMM Rating Manual states:

> *This rating records the length of alligator (fatigue) cracking showing in the wheelpaths of the carriageway…. Fine cracking often found at the edge of the seal is not to be rated as alligator cracking. Alligator cracking is to include all polygon-shaped cracking irrespective of the size of the polygons formed by the network of cracks.*

Alligator cracks are easiest to observe in the coldest months of the year as the surface contracts and the cracks open up. After light rain the cracks are more obvious as the surface dries leaving moisture in the cracks. If the rating survey is done over the summer months then fine alligator cracks are much harder to see due to expansion of the carriageway surface and glare off the surface. But looking into your shadow, cracks can usually be observed.

Longitudinal and Transverse Cracks – long cracks that run along or across the road (also includes diagonal and meandering cracks). This type of cracking (Figure 3-31) can occur in overlays over cement-stabilised bases, and also in overlays over bituminous bases wherever cracks in the old pavement have not been properly repaired, and this is known as reflective cracking.

3

Figure 3-31 Longitudinal and transverse cracks run along or across the road.

Photo courtesy of Les McKenzie, Opus

To record the extent of longitudinal and transverse cracking, the RAMM Rating Manual states:

The rating for longitudinal and transverse cracks records the length of cracking in the carriageway…. Large rectangular cracks are to be included as these are generally a more severe form of longitudinal and transverse cracks which have extended sufficiently to form a network.

Block Cracking – cracks found, for example, around service covers (service holes, etc.) where the rigid concrete mounting ends and the chipseal begins. Block cracking in thin surfacing mixes may lead to alligator cracking. Block cracks are often caused by the reflection of cracks in an underlying layer, e.g. from a cement-bound basecourse.

To record the extent of block cracking, the RAMM Rating Manual states:

> *This rating records the length of cracks present at joints in the surface of the pavement. These cracks would typically be found at construction joints in asphaltic concrete or at joints in the pavement surface where underground services have been laid.*

Shrinkage Cracks – are not recorded in RAMM but can occur in very old bituminous surfaces (especially in thin surfacing mixes) as a result of shrinkage. These shrinkage cracks are not usually associated with pavement deterioration but, if left unsealed for too long, moisture may filter through to the pavement foundation. This causes loss of strength which may result in surface deformation. Shrinkage cracking can also occur because tree roots have contracted, pulling the pavement during a drought, especially alongside windbreaks.

3.11.3 Chip Loss

3.11.3.1 Scabbing

Scabbing is chip loss from a chipseal. Chip loss may occur if there is not enough binder or if the binder does not adhere to the chip (Figure 3-32) because the chip was wet, dirty, or wetting and adhesion agents were not applied correctly. Chip loss can also occur on older surfacing when the binder oxidises or becomes hard and looses its grip on the chips. See Chapter 4 for discussion on causes of chip loss.

To record the extent of scabbing, the RAMM Rating Manual states:

> *This rating records the area of carriageway where the seal has lost more than 10% of the sealing chip. In the case of asphaltic concrete surfaces, this is the area of pavement showing signs of ravelling (surface attrition).*
>
> *Scabbing occurs when sealing chips become separated from the bitumen in a chipseal. In an asphaltic concrete pavement the aggregate loss from the mix is called ravelling and is rated as scabbing.*

3.11.3.2 Ravelling

Ravelling is the loss of chip from an asphaltic concrete or a slurry surface. It occurs where the binder has oxidised and is loosing its grip on the large- and small-sized aggregate of the surfacing. In a way, the asphalt or slurry is unravelling. If it is not halted, ravelling may cause deterioration to the extent that the surfacing mix no longer performs competently, resulting in a lack of waterproofing, and it can cause an uncomfortable ride.

Figure 3-32 Chip loss caused by dirty chip. Photo courtesy of Les McKenzie, Opus

3.11.4 Potholes

Potholes are formed when the pavement surfacing is lost so that the underlying basecourse is exposed (Figure 3-33). Often potholes become filled with water or even grass.

Figure 3-33 Potholes and cracks form where water gets under the pavement.
Photo courtesy of Les McKenzie, Opus

To record the extent of potholes, the RAMM Rating Manual states:

> *This rating records the number of potholes in the inspection length of carriageway. A pothole is an area where the carriageway surface has deteriorated, resulting in the cracking and eventual breaking up of the surface to form a cavity.*

Pothole Repairs

These are small (usually asphaltic) patches over potholes that have been filled in (i.e. repaired) and are considered just as important an indication of pavement failure as the potholes themselves. As repairs mean that the pavement surface has been compromised, the number of pothole repairs is counted along with potholes by the pavement management system when determining the need for resurfacing.

To record the extent of pothole patches, the RAMM Rating Manual states:

> *The same criteria and ratings apply here as for potholes except that the holes have been patched. A patch is to be rated as a pothole patch if it is less than 0.5 m^2 in area. If a patch is greater than 0.5 m^2 it is to be considered part of the pavement.*

3.11.5 Edge Break

Edge break is where the edge of the road has started to crack and fall away (especially on rural roads with unsealed shoulders). Edge break is defined when at least 100 mm of road edge has disappeared. It can leave a dangerous drop at the edge of the seal, and wheels of any vehicles that leave the road could become trapped over the side of the edge break, making it hard for the vehicle to easily make it back onto the carriageway.

To record the extent of edge break, the RAMM Rating Manual states:

> *This rating records the length of carriageway edge showing signs of edge break where there is no surfaced channel. Edge break is the reduction of the seal coat by more than 100 mm from the original line of the seal edge. If a channel is present then any break in the carriageway/channel boundary should be rated as ineffective surface water channel.* (Note: the topic of ‘ineffective surface water channel’ is not discussed in this book.)

Edge Break Repairs

To record the extent of edge break repair patches, the RAMM Rating Manual states:

> *… the same criteria and ratings apply here as for edge break except that the edge break has been patched.*

3.11.6 Flushing

Flushing creates a solid, smooth, black, slick surface caused by an excess of binder. Flushing may occur as the natural end-of-life condition of a well-designed chipseal, or as a seal design or construction fault. In hot weather a flushed surface may soften and bleed (Figure 3-34).

To record the extent of flushing, the RAMM Rating Manual states:

> *This rating records the length of wheelpath where the carriageway surface has flushed. A flushed surface is where the binder is level with or above the surfacing aggregate.*

Current definitions of flushing in use by various RCAs include:

- When the chipseal's texture depth is less than 0.5 mm.
- When the chipseal's texture depth is
  - less than 0.7 mm (for areas where the posted speed limit is <70 km/h) or
  - less than 0.9 mm (where the posted speed limit is >70 km/h).
- When the binder is half way up the chip.

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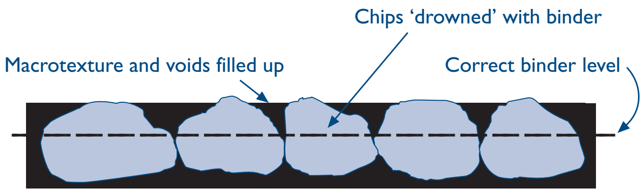

Figure 3-34 A flushed chipseal, in which excess binder rises over the chip and reduces macrotexture.

Figure 3-35 This road shows a slick, bleeding or flushed surface that has low friction and therefore low skid resistance.
Photo courtesy of Mark Owen, Transit NZ

Figure 3-35 shows a slick bleeding or flushed surface that has low friction and therefore low skid resistance. It is unacceptably slippery and unsafe as the tyres cannot grip the sealing chip. Also the surface does not have any texture.

Insufficient binder causing areas of chip loss leads to exposed binder and thus to a slick surface which is also classed as flushing.

3.11.7 Bleeding

In hot weather when the binder is soft, it will adhere to the vehicle tyres and be spread (tracked) over the surrounding road. This soft state is called bleeding and is undesirable because the binder coats the microscopic surfaces of the chips (the microtexture), creating a slick surface with a lowered skid resistance.

At a critical texture (which depends on chip size), the tyres can reach down into the spaces between the chips and touch the surface of the binder. There is also a critical viscosity (related to temperature and additives in the binder) at which the tyres are able to adhere to the bitumen. Although tracked bleeding binder may eventually wear off chips, it presents a hazard while it is present.

> To remember the difference between flushing and bleeding, a flushed road surface is solid in cold weather but may still bleed in hot weather.

3.11.8 Roughness

Roughness is a measure of the comfort of the ride (i.e. bumpiness of the road). Originally it was measured with a ‘roughometer’ or NAASRA roughness response meter, which literally counted the number of bumps recorded by a standard vehicle when it was driven over a certain length of road. Today, roughness is more usually measured by a set of lasers mounted on a vehicle, the data being analysed at the correct wavelength to correspond to road bumps. (A different wavelength is analysed from the same data to measure chip texture depth, and hence flushing.)

3.11.9 Loss of Texture

Loss of texture through flushing or other causes is measured by either sand circle measurements (TNZ T/3:1981) or by High Speed Data (HSD) collection. The texture output of HSD is the Mean Profile Depth (MPD). The principles of MPD measurement are shown in Figure 3-36.

$$\text{Mean Profile Depth (MPD)} = \frac{\text{Peak level (1st)} + \text{Peak level (2nd)}}{2} - \text{Average level}$$

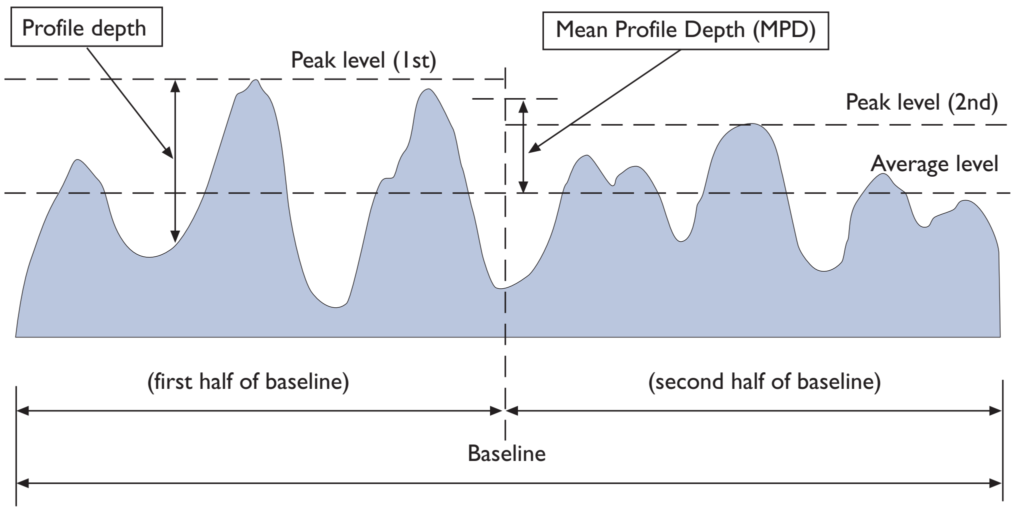

Figure 3-36 How the MPD (mean profile depth) is calculated from HSD (high speed data).

3.11.10 Loss of Skid Resistance

Skid resistance is measured as the wet-road skid resistance by the Sideway Coefficient Routine Investigatory Machine (SCRIM). (SCRIM and skid resistance are explained in Section 4.9.) Low skid resistance recorded by SCRIM may have been caused by polishing of the chip or related to bleeding and flushing masking the microscopic surface of the chip (the microtexture).

3.11.11 Conclusion

Shear failures (which cause shoving), depressions (rutting), and potholes form as a result of pavement ageing and loss of waterproofing. As the pavement gets older, and weaker or softer because water is leaking into the underlying layers or is not draining away, it deforms and the seal cracks, letting in more water which accelerates the damage.

Also the action of traffic causes pumping, which is the movement and ejection of fine particles in suspension through joints or cracks. This removes fine particles from the basecourse, which weakens it further, and the hydraulic pumping effect itself will eventually lift the seal.

To counter this natural deterioration, a well managed network will have a Pavement Management System in place for which the road condition rating data is collected and fed in, as described in Chapter 5. This means that the available budget is targeted to achieve the maximum return.

3.12 References

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CHAPTER FOUR

Typical Chipseal Performance

Chapter 4 Typical Chipseal Performance

Previous page: A chipseal performing well on State Highway 73, through Porters Pass, Canterbury.

Photo courtesy of Terry Hann, Wreford Hann Photography Ltd

Chapter 4 Typical Chipseal Performance

4.1 Introduction

A chipseal surfacing does not remain static once it is constructed. Traffic flexes the pavement, compacts and polishes the chip; loss of diluents (or of water in an emulsion) and oxidation cause the binder to harden; temperature changes result in the seal expanding and contracting; and moisture can penetrate the seal and damage the base.

Chipseal performance can be considered in two distinct phases:

- Post-construction or settling-down period;
- In-service performance during its expected life.

During the relatively short period immediately after construction, i.e. post-construction, which is the settling-down period, chipseal performance is affected by construction conditions and techniques. During this stage typical failure symptoms are chip loss, bleeding and chip rollover. Factors which can cause the onset of these types of failure generally relate to:

- the amount of kerosene used as cutback in the construction;
- binder application rate, and binder properties;
- chip application rates;
- weather conditions; and
- how well the layer has been compacted.

After the post-construction period, the in-service performance and expected life of the seal are affected by:

- binder application rates;
- chip application rates;
- inadequacies occurring at the time of construction;
- adequacy of the substrate;
- ageing of each component of the construction;
- effects of traffic and environment;
- binder properties.

Typically a seal will either fail early in its life (i.e. in the first days or months) or last many years.

Initial seal failure early in its life is usually associated with chip loss because the binder loses its grip on the chip before the chip has had time to embed adequately.

Ultimate failure (i.e. the end of its life) is typically associated with loss of skid resistance, texture, or waterproofness. Loss of skid resistance is associated with chip polishing or surface flushing whereas loss of waterproofness is associated with cracking or chip loss.

4.2 Post-Construction Performance

This section focuses on factors impacting on the performance of seals during the settling-down period immediately following their construction. Effects of these factors also carry on into the long-term performance of the seal.

4.2.1 Loss of Diluent

Diluents are substances that reduce the viscosity of a bituminous binder, making it more fluid and easier to apply. Diluents are called cutters if the lower viscosity is required only temporarily for the time while applying the binder, or fluxes if the viscosity needs to be permanently (or semi-permanently) reduced. The other technique of reducing the viscosity of a bituminous binder by converting it to an emulsion is covered in Chapter 8.3.

Kerosene is used as a cutter to reduce its viscosity by modifying the viscoelastic properties of the binder at the ambient pavement temperature so that it will wet and adhere to the chip. It affects both the short-term performance of the seal during the immediate post-construction period and the longer term performance, particularly as it affects the tendency of a seal to bleed.

In the construction process the binder (in this case bitumen that has been cutback with kerosene) is sprayed onto the pavement and covered with sealing chip. A significant issue then is the rate at which the kerosene evaporates from the binder. In 1988 a sealing trial carried out on roads in Lower Hutt (Ball 1999) demonstrated the rate of loss of kerosene. The trial used samples of chipseal composed of cutback bitumens containing 10 pph and 5 pph of kerosene. An estimate of decrease in kerosene content over time was made by measuring weight loss from samples regularly over a period of 5 years. The results adapted from this research are shown in Figure 4-1. Approximately 20% of the added kerosene evaporated while being sprayed, and 30% within 2 hours following application. The results of longer term monitoring indicated that 30-35% of the kerosene remained by the end of the following winter.

One year after chipsealing, all the kerosene had evaporated from the chipseal's binder except for the last 20% which remained in the binder for the rest of the chipseal's life.

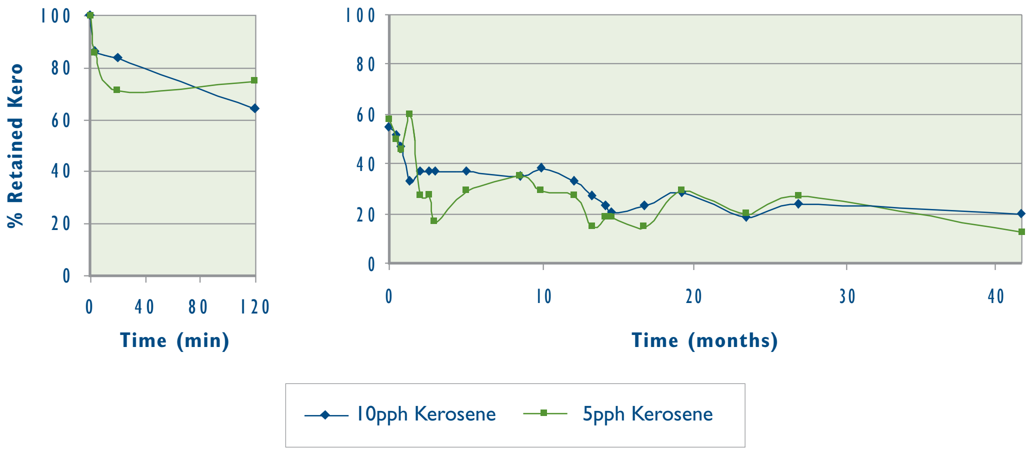

Figure 4-1 Estimate of kerosene content made by measuring weight loss from samples over a period of 5 years (Ball 1999). Approximately 20% of the added kerosene evaporated while being sprayed, and 30% within 2 hours.

This slow down in kerosene loss over the winter is consistent with laboratory trials (Patrick 1987) which indicated that the rate of loss of kerosene, mineral turpentine and AGO was controlled by the diffusion of the diluent to the seal surface, not by its volatility. This means that the diluent needs to diffuse through the binder film to the surface before it will evaporate. Therefore the diluent lower down in the chipseal takes a longer time to diffuse to the surface and evaporate. Patrick also found the following relationship.

The rate of evaporation is related to temperature. For example, a 50% loss in kerosene takes 2 to 2.5 times longer to achieve if the temperature drops by 10°C.

AGO (Automotive Gas Oil) or diesel has been traditionally used as a flux to bitumen in the belief that it remained permanently in the bitumen, resulting in an overall softening of the binder. However, research on seals in Dunedin found that, after 5 years, 70% of the AGO had evaporated. Thus the expected long-term softening effect is not being obtained and subsequently the practice of fluxing bitumen is now used less often in New Zealand.

4.2.2 Effects of Rolling

Use of a pneumatic-tyred roller to roll the chip assists in adhesion between chip and binder and begins the compaction process. After rolling, traffic will continue the compaction process and the binder will be forced up around the chip, thus increasing the seal strength. As a result of 'compaction rolling' the chips tend to roll onto their Average Greatest Dimension (AGD) as illustrated in Figure 1-2.

The change in texture depth (which is a measure of compaction of the seal) that occurs in the early life of a seal is illustrated in Figure 4-2 adapted from a 1989 NRB RRU report.

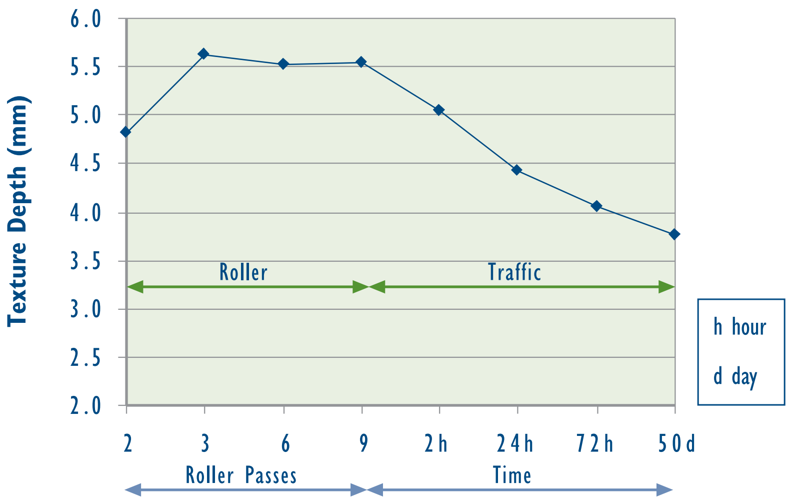

Figure 4-2 The change in texture depth (which is a measure of compaction) that occurs in the early life of a seal (adapted from NRB RRU 1989).

Figure 4-2 shows an apparently very slow change in texture under the roller during construction, followed by a rapid decrease in texture depth under normal traffic. This pattern was confirmed in other roller trials on single coat seals, results of which are given in Figure 4-3. In this research Hudson et al. (1986) used rollers of three different weights (8.3 tonnes, 10t, 13t).

As shown, no significant change in texture took place between roller passes 3 to 9, or between different weights of rollers.

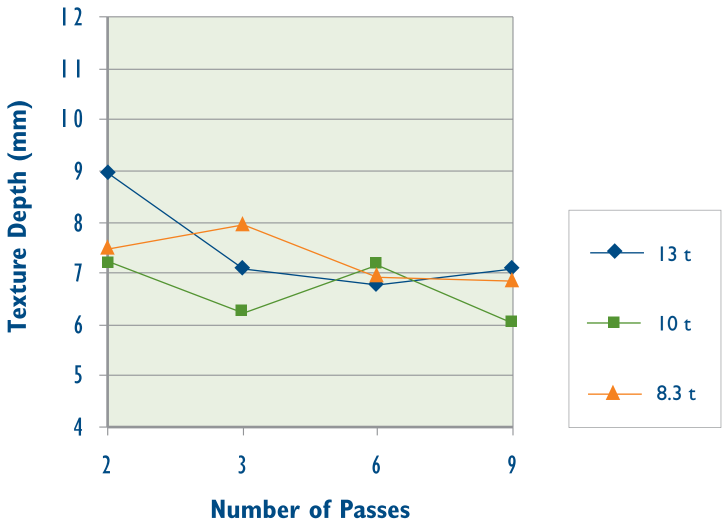

Figure 4-3 Effect of roller mass (8.3 tonnes, 10t, 13t) and number of passes on the compaction of a single coat chipseal (Hudson et al. 1986).

When the final rolling has been completed for the construction, the seal is opened to traffic. At this time the bond between the chip and binder has not been fully developed, and chip can be easily displaced by a combination of rain and traffic. The binder viscosity and application rate must be optimised to achieve a binder that has sufficient strength to resist rain-related chip loss after the seal is subjected to normal traffic. To minimise risk of such chip loss, adhesion agents are used (see Chapter 8.2.2). As time progresses, the chipseal continues to gain strength through chip interlock, binder rise and binder curing.

A fault known as chip rollover may occur during the compaction of the chipseal by traffic. The twisting action of power steering can lead to chip loss or to the chip being inverted so that the binder-coated surface is facing up instead of down. The binder-coated chip can then be tracked away from its initial position on vehicle tyres.

4.2.3 Effects of Temperature

The interactions between temperature, viscosity, rolling and traffic have been investigated by Ball et al. (1999). Figure 4-4 adapted from the research illustrates the results where samples of seals using 180/200 grade bitumen were manufactured in the laboratory and then subjected to impacts to simulate traffic stresses. Although the temperatures at which failure occurred are not expected to model the field conditions exactly, the trends do reflect field behaviour.

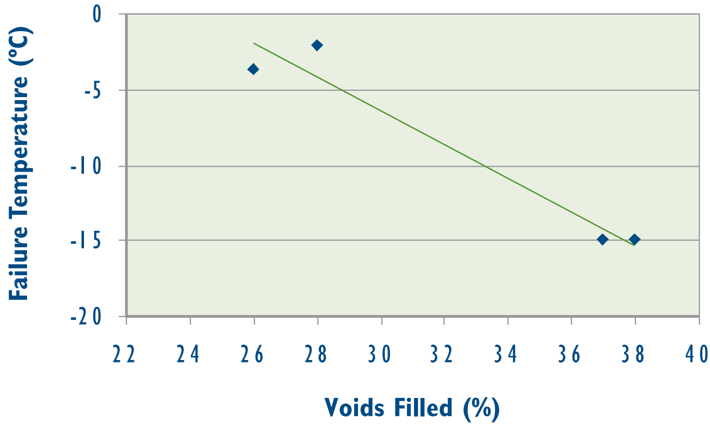

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Figure 4-4 Temperatures at which failure by chip loss occurs in seals using 180/200 grade bitumen and subjected to impact as for traffic stress. The trends reflect field behaviour (from Ball et al. 1999).

Houghton & Hallett (1987) analysed seal failures occurring on roads at the beginning of winter in Lower Hutt and Dunedin. They concluded that the voids needed to be filled to at least 35% at the beginning of winter to avoid chip loss. Road emulsion trials reported in Patrick (1998) support this concept, although the 35% voids filled is considered not to be an exact value but rather to be an indication that significant binder rise needs to occur or, if it is not likely to occur, to use a softer binder.

If the low temperature properties of the binder and its durability cause it to get very hard at the prevailing pavement temperature, then chip loss caused by traffic can occur. The variation in temperature experienced in New Zealand is illustrated in Figure 4-5. It shows that pavement surfaces in Napier do not experience temperatures below 0°C, while those in Dunedin have surface temperatures below 0°C for 7% of the year. In Central Otago (one of the coldest regions of New Zealand) the surface can be below 0°C for 14% of the year.

In the past, it was assumed that different grades of bitumen should be used in different climatic zones in New Zealand. However testing of the different bitumen grades produced by the New Zealand Refining Company, at Marsden Point, Whangarei, showed they tend to have a similar modulus at temperatures below zero (discussed in Section 8.1.2.8). Harder bitumens (e.g. 80/100) and softer bitumens (e.g. 180/200) therefore behave about the same below 0°C, which means harder grades (e.g. 80/100) can be and are used successfully in colder areas.

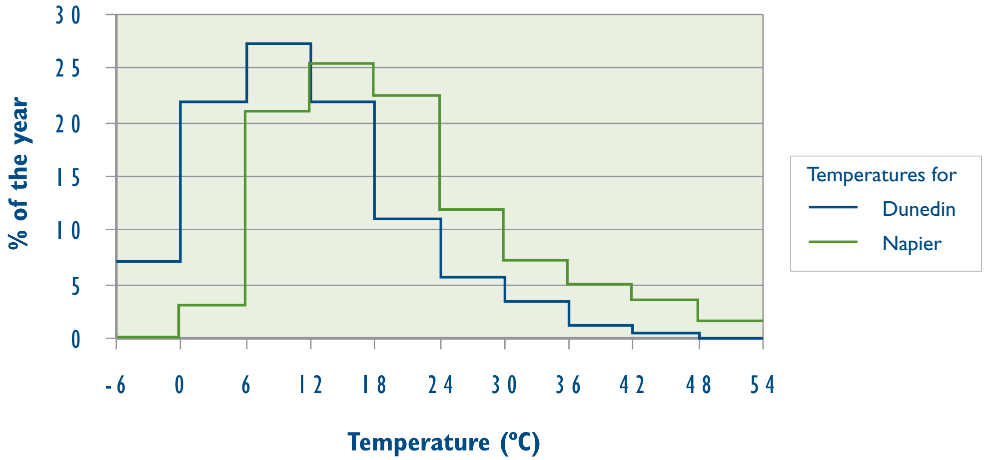

Figure 4-5 A comparison of pavement surface temperatures for Dunedin and Napier to show why chip loss is more likely to occur in Dunedin pavements.

High pavement temperature also affects seal strength by affecting binder viscosity and chip interlock. Figure 4-6 taken from Ball et al. (1999) illustrates the effect of binder viscosity and % voids filled on the strengths of seals compacted in the laboratory. The range in viscosity is equivalent to a change in temperature from 40°C to over 60°C.

The laboratory tests performed used a similar apparatus as used for the low temperature tests, and failure was defined when the seal sheared under impact loading. Figure 4-6 shows that the seal would fail at 40°C when approximately 22% of the voids are filled, but at 60°C when over 35% of the voids are filled.

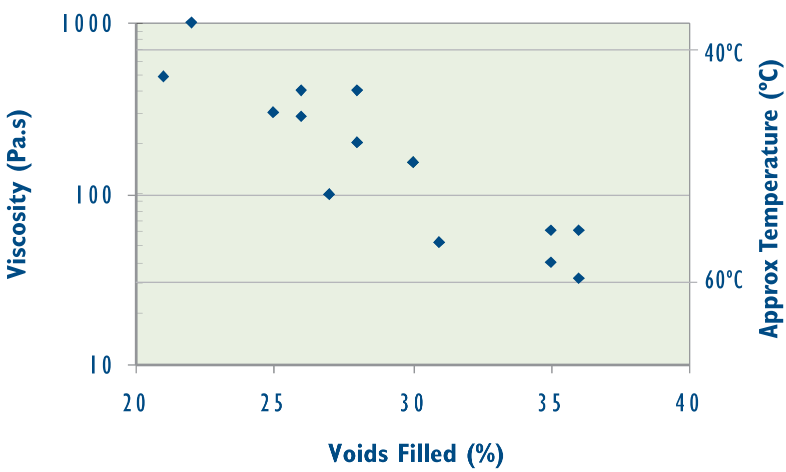

Figure 4-6 The effect of binder viscosity and % voids filled on the strengths of seals compacted in the laboratory (from Ball et al. 1999).

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Unless the seal is subjected to a major change in use after the first year, the seal would be expected to slowly lose texture (i.e. becoming smoother through a combination of chip embedment and binder rise) until it reached the end of its life, signalled by flushing, cracking or chip loss associated with binder embrittlement. This concept has been used to develop the contractual model detailed in TNZ P/17 *Performance-based specification for bituminous reseals,* where the contractor is responsible for the performance of the seal for the first 12 months. After that the seal is 'handed over' to the client with all its chips in place and sufficient texture. The absolute value of texture is dependent on chip size and traffic volume and is based on ensuring that the seal will not flush before achieving its design life.

4.3 Long-term Performance

This section focuses on issues affecting the normal in-service performance of the chipseal until its ultimate failure and the need for its replacement.

The chipseal can fail through a number of causes, such as:

- traffic continuing to re-orient the chip and to push it into the base or underlying seal, leading to flushing;
- oxidation of the bitumen so that it hardens, leading to cracking or chip loss;
- loss of skid resistance, related to polishing of the chip;
- repetitive flexing of pavements with high deflections that can lead to cracking, especially on pavements with a weak base or inadequate pavement thickness.

A conceptual representation of the process is shown in Figure 4-7 on a pavement with low deflections where the traffic level in curve 1 is lower than that in curve 2. The surface texture initially decreases quickly and over time tends to flatten out. This example shows that the pavement experiencing higher traffic loading (curve 2) would have texture low enough to be considered flushed in about 8 years. The lower traffic volume pavement (curve 1) however is still well above this level at year 15. The binder-hardening curve has a similar shape in that, after an initial rapid hardening, it tapers off. This curve shape (where bitumen hardening slows down after 4 to 5 years) has been confirmed from field trials by Ball (1999). Depending on the chemistry of the bitumen and the temperature environment, the binder will ultimately reach a level of hardness at which cracking will occur, or traffic will dislodge the chip. In the conceptual example this is at about year 15.

Therefore the pavement under higher traffic loading (curve 2) would fail through flushing while the pavement with lower traffic loading (curve 1) would fail through cracking. This cracking could be thermally induced as the binder would not be able to accommodate the thermal expansion and contraction cycles it undergoes every day and night.

In the above example the pavement was assumed to have low deflection so that effects of load-induced cracking or fatigue were not significant.

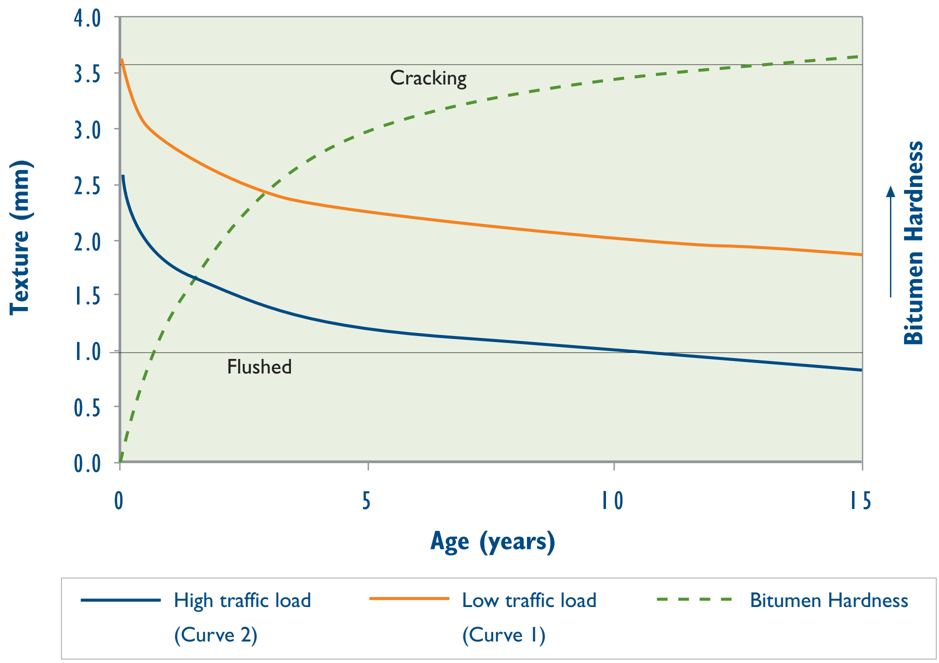

Figure 4-7 Over 15 years the ageing process related to oxidation of the bitumen causes hardening, leading to cracking or chip loss, or loss of texture by traffic compacting the chip, leading to flushing. Bitumen hardness and texture depth (mm) are shown for a low deflection, less flexible pavement, under low (curve 1) and high (curve 2) traffic loadings.

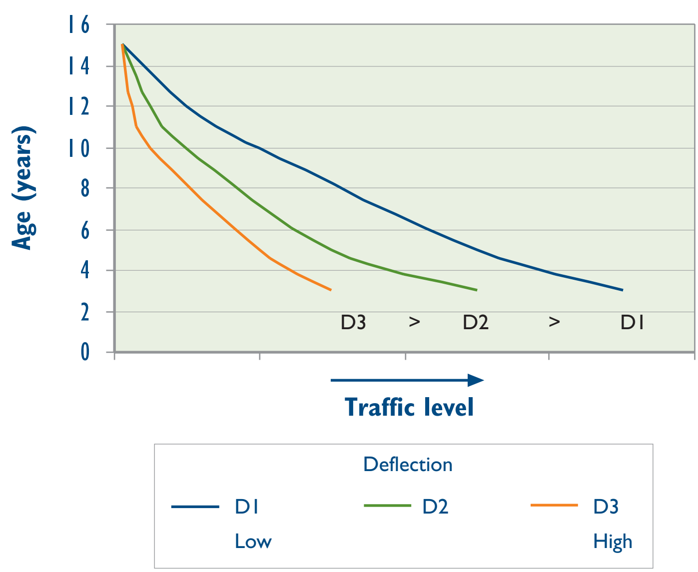

Figure 4-8 The time taken for a chipseal to crack under the effect of 3 levels of deflection: D1 (low), D2, D3 (high). (Deflections 1, 2, 3 are relative units.)

Figure 4-8 illustrates the effect of pavement deflection on the time a seal takes to crack. The three deflection levels converge under low traffic to a single point at 15 years. As the traffic increases the increased flexing of the seal will lead to fatigue cracking. The age at which this occurs is affected by the deflection of the pavement and the traffic volume. At the same traffic volume, seals on low deflection pavements will take longer to fatigue crack than those subjected to higher deflections.

The life of a chipseal is therefore affected by a large number of factors and its life can be considered to have ended or the chipseal to have failed when waterproofing or skid resistance has been lost.

End of seal life can be caused by:

- Cracking, either thermal- or traffic-induced;
- Fretting or chip loss, also called scabbing, ravelling;
- Texture loss;
- Polishing.

Increased seal life can be affected by:

- Lower traffic loadings;
- Thicker binder films to reduce the rate of binder oxidation and increase resistance to cracking;
- Binders which are more oxidation-resistant;
- Larger chip to increase the time until chips are embedded;
- Lower pavement deflections;
- Harder substrates to reduce chip embedment;
- Polish-resistant chip.

Some of the above factors are controlled by material specifications, e.g. bitumen durability, chip polishing resistance. Some are outside the control of the seal designer, e.g. substrate hardness, pavement deflection and traffic loading. The designer is thus left with the choice of chip size, binder type, binder application rate, and its properties, and seal type. This choice needs to take into account the life cycle assessment of the pavement, traffic stress, community and environmental factors (which are discussed in more detail in Chapters 5 and 6).

When all these factors are considered, no one chipseal system can be suitable for all roads, and combinations of different chip sizes and seal types need to be used.

4.4 Texture Change

As shown in Figure 4-2, after compaction the texture of a seal continues to decrease under traffic. In order to correlate or compare data from different pavement sections using different chip sizes and traffic volumes, results are presented typically in terms of volume of voids (Vv) over chip Average Least Dimension (ALD) expressed as $\frac{Vv}{ALD}$ and total traffic passes.

4.4.1 Single Coat Seals

The basic voids concept of a single coat seal is illustrated in Figure 4-9. The spaces between the sealing chips are taken up by air, binder and by embedment of the chip into the underlying substrate. Under traffic the total voids decrease through chip re-orientation and embedment, at different rates related to the traffic load.

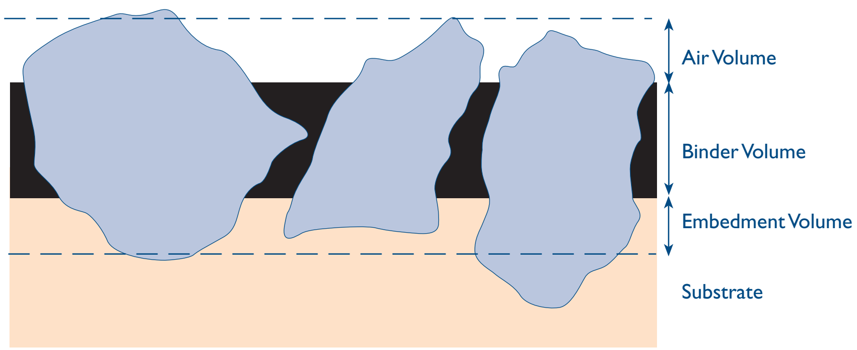

Figure 4-9 The voids concept as it applies to a single coat seal: spaces between chips are taken up by air, binder or embedment in the underlying substrate (from Potter & Church 1976).

A summary of the relationships found between Vv/ALD and traffic volume is given in Patrick (1999). The most comprehensive set of data that is available was obtained for single coat seals in Lower Hutt, and is shown in Figure 4-10. As the extent of chip embedment into the substrate is a function of the substrate hardness, and as soft substrate and chip embedment are regular causes of flushing, a discussion on soft substrate is included in Section 4.7.4.1. Chapter 9 also covers it as part of chipseal design.

The traffic has been converted to equivalent light vehicles (elv), a concept which was developed in South Africa to equate heavy vehicles to light vehicles. Currently in New Zealand an equivalence factor of 10 is used, i.e. one heavy vehicle is considered to be equivalent to 10 cars. Very little data are available in New Zealand to robustly determine what the factor should be.

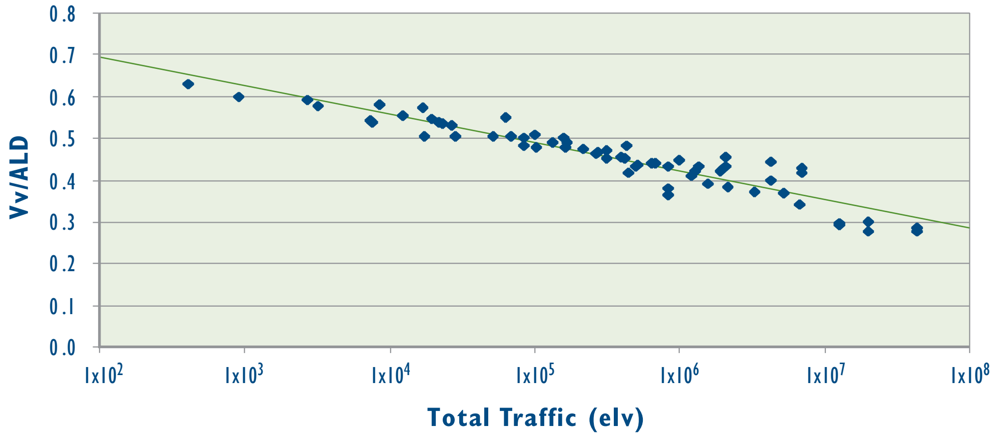

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Figure 4-10 Relationships between volume of voids (Vv), chip ALD, and traffic volume (elv) for single coat seals on roads in Lower Hutt (from Patrick 1999).

Results from trials that have been performed on roads around New Zealand are given in Table 4-1. The basic equation used to represent these results is:

$$\frac{Vv}{ALD} = A - B \log_{10} (\text{cumulative elv}) \qquad \text{Equation 4-1}$$

where:
- Vv = volume of voids in the chipseal
- ALD = Average Least Dimension of chip
- elv = equivalent light vehicle
- A, B = constants

The constant A gives a measure of the initial state of the seal. Constant B is a measure of the rate of change of texture, and the greater the value of B the faster the texture will change under traffic.

Table 4-1 Typical constants used in Equation 4-1, obtained from trials on single coat seals around New Zealand.

Location	Lower Hutt	Bay of Plenty	Canterbury	Whangarei	Rotorua
No. of Tests	64	28	48	367	60
r^2	0.88	0.74	0.66	0.45	0.30
A	0.83	1.08	0.95	0.82	0.085
Standard error	0.02	0.07	0.04	0.02	0.119
B	–0.068	–0.110	–0.074	–0.061	0.100
Standard error	0.003	0.013	0.008	0.003	0.020
elv min	4×10^2	2.2×10^4	1.0×10^4	1.2×10^4	1.2×10^5
elv max	4.4×10^7	1.1×10^6	1.5×10^6	3.6×10^7	1×10^7

4.4.2 Two Coat Seals

To develop a relationship of texture change with traffic for two coat seals, the basic concept used for single coats (in Section 4.4.1) was followed, but using the ALD of the larger chip. Data from research on roads in Lower Hutt, Rotorua, and Western Bay of Plenty were used.

Results from the regression analysis of the main data sets are given in Table 4-2, in which both the constant (A) and the slope (B) are seen to be similar to the single coat seal results. Figure 4-11 illustrates these results.

Table 4-2 Typical constants which could be used in Equation 4-1, obtained from trials on two coat seals in Hutt Valley, Rotorua and Western Bay of Plenty (WBOP), New Zealand.

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Location	Hutt Valley	Rotorua	WBOP
Number of tests	8	10	15
r^2	0.76	0.41	0.82
A	0.99	0.80	1.05
Standard error	0.12	0.16	0.07
B	–0.083	–0.058	–0.110
Standard error	0.019	0.024	0.014

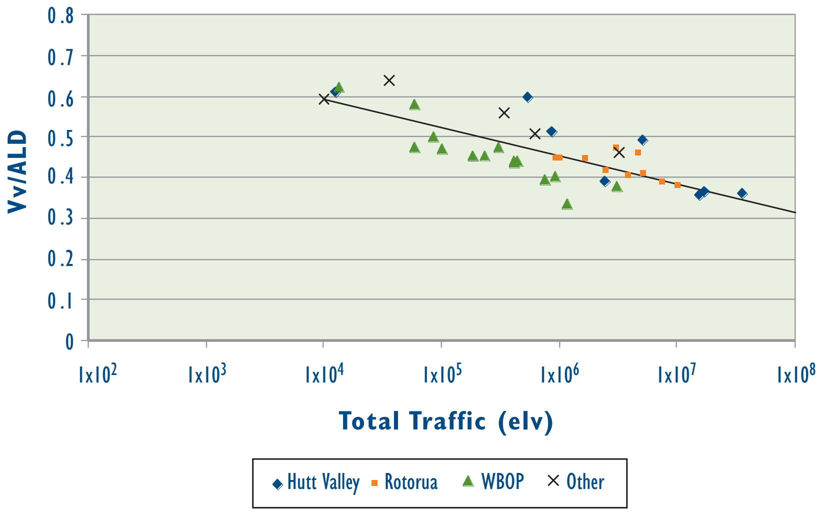

Figure 4-11 Relationships between volume of voids (Vv), chip ALD, and traffic volume (elv) for two coat seals on roads in Hutt Valley, Rotorua, Western Bay of Plenty and other areas in North Island (from Patrick 1999).

4.5 Reasons for Resealing

The reasons for resealing New Zealand state highways, as shown by 2003 data, are illustrated in Figure 4-12. It shows that the predominant reason for resealing for that sealing season was flushing (loss of texture) of the existing surface.

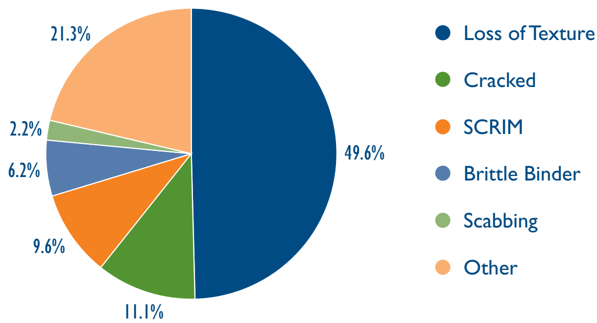

Figure 4-12 Reasons for resealing pavements on New Zealand state highways during the 2003 sealing season.

The above data do not coincide with the results of a survey by Oliver (1999) of the performance of sealing in Australia and New Zealand. Oliver's survey was based on respondents answering a questionnaire that was sent to Australian State Roading Authorities, Transit NZ, and local authorities in Australia and New Zealand. The reasons for resealing obtained are ranked in Table 4-3, in which the highest ranking is 1, decreasing to 6 for the least important reason.

Flushing (called Loss of Texture) was found to be the predominant reason for resealing on New Zealand's state highways (Figure 4-12) but was ranked at number 3 (by New Zealand authorities) for New Zealand state highways in Oliver's research (Table 4-3).

Table 4-3 Rankings of reasons for resealing (from Oliver 1999).

Reason	Aust SRA	Transit NZ	Aust LG	NZ LG
Cracking	1	1	1	1
Pavement Deterioration	5	4	2	2
Age	2	5	4	6
Loss of Aggregate	3	6	3	3
Loss of Texture	4	3	5	5
Skid Resistance	6	2	6	4

SRA State Roading Authorities LG Local Government

It should be noted that reasons for resealing on state highways in New Zealand are affected by the priority assigned to SCRIM by Transit, and is very dependent on pavement properties (e.g. moisture-sensitive soils need more diligent waterproofing).

Figure 4-13 gives an estimate of the distribution of traffic volumes on New Zealand roads in 2000. The data have been taken from the National Traffic Database which contains an estimation of the traffic volumes on New Zealand roads. Figure 4-13 also shows that approximately 50% of state highways have traffic volumes below 2000 AADT.

Ball in 1997 performed an analysis of seal performance on state highways and found that, at traffic volumes less than 2000 vpd, cracking became a more dominant factor than flushing. When this traffic data is compared with the reasons for resealing, that reseals are used on state highways for loss of texture is understandable when 50% of the traffic is greater than 2000 AADT.

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The data also help explain why the predominant reason for resealing local roads given in Oliver's (1999) report is cracking. Figure 4-13 shows that 90% of them had traffic volumes less than 2000 vpd.

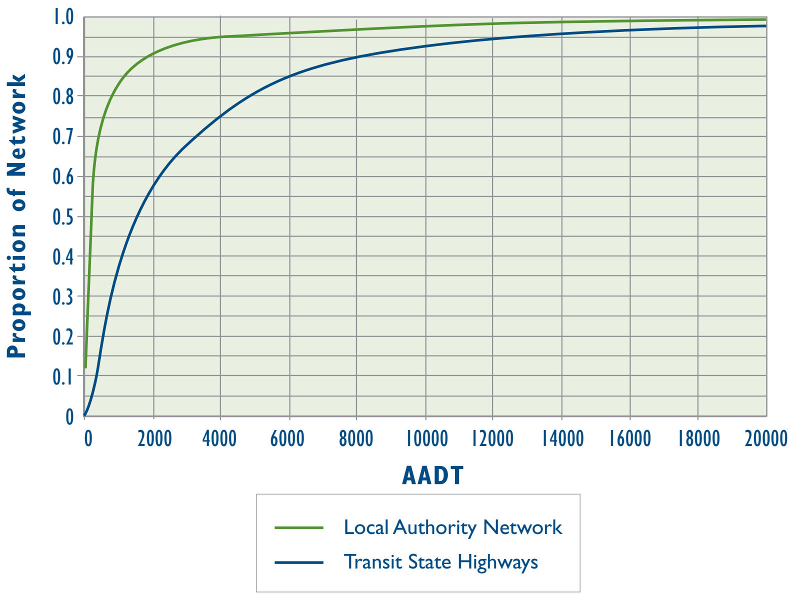

Figure 4-13 An estimate of the distribution of traffic volumes on New Zealand roads in 2000 (from National Traffic Database).

Over the last ten years the increase in the use of multicoat seals, e.g. two coat and racked-in, has been significant, as illustrated in Figure 4-14 by the state highway data.

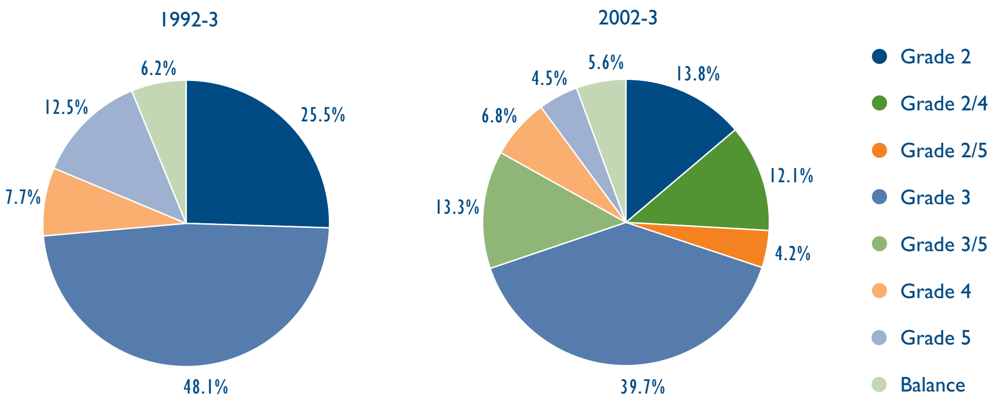

Figure 4-14 The use of multicoat seals, e.g. two coat and racked-in, has increased significantly over the last 10 years on state highways in New Zealand.

It appears however that the choice of the maximum chip size has not changed significantly, with Grade 3 chip being the predominant grade but now being increasingly used as a Grade 3/5 seal.[1]

The typical reseal cycles used on local authority roads and state highways also reflect the different failure mechanisms. Using the Transfund resealing statistics, the average reseal cycle in 2001 for a state highway was 8.4 years and for local authority roads was 13.7 years.

It should be noted that since 1998 Transit has placed a high priority on SCRIM treatment. This has had a significant effect on seal life statistics (see discussion in Section 4.7.1).

4.6 Expected Seal Lives

The RAMM system (explained in Section 3.11) has proposed default seal lives for different traffic levels, although some practitioners consider some of these seal lives are quite generous. These values, except for slurries, are given in Table 4-4.

The typical life of a properly designed slurry over a good pavement surface is between 7 and 12 years, depending on traffic volumes.

[1] The convention for naming grades of chip for a seal is to give the grade of the first chip used in the lower layer or first seal, and then the grade of the second layer or seal, e.g. Grade 2/4 is a Grade 4 over a Grade 2 chip.

Table 4-4 Default seal lives for different traffic levels, based on typical New Zealand pavements, and proposed for use in designing pavements.

Surfacing Type	Use 1 (<100 vpd)	Use 2 (100 - 500 vpd)	Use 3 (500 - 2,000 vpd)	Use 4 (2,000 - 4,000 vpd)	Use 5 (4,000 - 10,000 vpd)	Use 6 (10,000 - 20,000 vpd)	Use 7 (>20,000 vpd)
	Life in Years						
Voidfill Seals							
Grade 6	6	5	4	3	2	1	1
Grade 5	8	7	6	5	4	3	2
Grade 4	12	10	8	7	6	5	4
Grade 3	14	12	10	9	8	7	6
First Coat Seals							
Grade 5	1	1	1	1	1	1	1
Grade 4	3	2	1	1	1	1	1
Grade 3	4	3	2	1	1	1	1
Grade 4/6	6	4	3	2	2	1	1
Grade 3/5	8	6	5	4	3	2	1
Grade 2/4	10	8	6	5	4	3	2
Reseals							
Grade 5	8	7	6	5	4	3	2
Grade 4	12	10	8	7	6	5	4
Grade 3	14	12	10	9	8	7	6
Grade 2	16	14	12	11	10	9	8
Grade 4/6	14	12	10	9	8	6	4
Grade 3/5	16	14	12	11	10	8	6
Grade 2/4	18	16	14	13	12	10	9

RAMM and Asset Management are discussed in Chapters 1, 3 and 5.

4.7 Reasons for Shorter Life

The above discussion of seal lives suggests that the 'design life' or average life of seals is relatively predictable. However in practice, the distribution of seal lives in any traffic volume band is not a normal distribution. Figure 4-15 illustrates the distribution of seal lives for a Grade 3 chip on New Zealand state highways.

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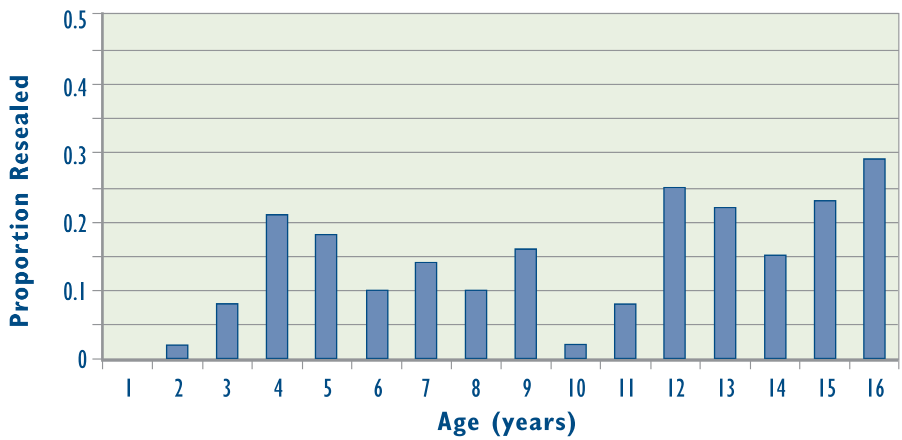

Figure 4-15 Distribution of seal lives for Grade 3 chipseals on New Zealand state highways at 2000 to 4000 vpd traffic volumes.

Figure 4-15 shows that the distribution of failure is relatively flat and there is an almost equal probability that a seal will last 3 years as it will for 10 years. Some of the reasons for seals to not attain their expected life are:

- Polishing
- Chip loss
- Cracking
- Flushing

4.7.1 Polishing

If the chip used for the seal has a PSV (polished stone value) below that required for the traffic volume or site stress, then the skid resistance of the chip could attain an undesirably low plateau value for skid resistance well before the end of its design life. When chipseals reach an undesirably low skid resistance, the only fix is to reseal them with a chip having a higher PSV. Therefore because of Transit's skid resistance policy, reseals have been required on polished pavement sections that are as young as two years old. The relationship between PSV, traffic, site stress and resultant skid resistance value is discussed in Skid Resistance (Section 4.9).

4.7.2 Chip Loss

Premature chip loss can also be a reason for early resealing. This can occur through the choice of the wrong seal type, construction faults, or unexpected cold wet weather. Construction faults normally would result in chip loss within the first few months, and in this case repairs should be carried out rather than a reseal. A repaired reseal will generally not achieve the normal expected seal life.

4.7.3 Cracking

Seal failure through premature cracking can be caused through pavement deflection or binder hardness, as discussed in Section 4.3.

Once cracking has occurred, and water enters the pavement layers, water damage can accelerate the pavement distress leading to shear failure in the basecourse and the need for major repairs to the pavement.

According to the RAMM system, a reseal should be applied within a year after more than 3% of the area has cracked. This shows that uniformity of the pavement strength is more important than average strength as the worst 3% of the pavement will control the seal life of the entire pavement.

High deflections, which can cause cracking, can also be associated with a pavement drainage fault. Water entering the base will result in a reduction in strength and lead to cracking of the seal.

Premature failure through cracking can also occur through binder hardness. This can be evident on pavements which are subject to freeze-thaw cycles, such as the Desert Road in central North Island. The cracks that can occur in winter often self-heal in the warmer seasons. If the base is moisture-susceptible however, then water entering through the cracks can lead to rapid pavement failure. See discussion about low temperature properties of binders in Section 4.2.3.

4.7.4 Flushing

Reduced seal life through premature flushing can occur through one of the following mechanisms:

1. Chip being forced into a soft substrate.
2. Layer instability of a pavement, with build-up of successive seals and excess binder.
3. Binder rising because of moisture vapour.

A premature failure of a first coat seal through flushing is normally associated with a construction fault, i.e. either water in a poorly prepared basecourse with excess fine material on its surface, or excess binder application.

4.7.4.1 Soft Substrate

A soft substrate increases the rate of chip embedment in terms of the model (Equation 4-1) discussed in Section 4.4. The constant (B) represents the texture changes with increases in traffic volume, shown by the slope of the best fit line in Figures 4-10 and 4-11.

A soft substrate can occur because of sealing

- on granular bases (first coat seal);
- over hot mix asphalt;
- over pavement repairs; or
- on a pavement weakened by water.

On granular bases
Where new pavements are not adequately compacted, first coat seals may become embedded in the soft base causing flushing.

Over hot mix asphalt
If the hot mix asphalt is relatively new (less than one year), then the new chip can be forced down into it. Even on an older hot mix in a period of hot weather, rapid embedment can occur.

Figure 4-16 illustrates the rate of change of texture of a chipseal over hot mix asphalt under laboratory rolling. This figure shows that the rate of change has increased by a factor of 5 as the temperature is raised from 40°C to 50°C as the chip embeds.

A chipseal can appear to be in a stable condition but, as Figure 4-17 illustrates, if successive days of warm weather occur, then the pavement does not cool down overnight and the temperature builds up in the pavement. This temperature build-up can result in the acceleration of chip embedment and in flushing.

Over pavement repairs
Chapter 7 stresses the need to perform pavement repairs well in advance of the sealing operation. If the pavement repair is made with a hot mix, flushing caused by the failure mechanism described in the paragraphs above can occur. If the repair is a stabilised or granular treatment, then normally it will have a seal coat applied. All the defects associated with resealing over a first coat seal can occur, e.g. diluent in the first coat can diffuse into the reseal binder making it soft (Figure 4-18), because the first coat seal may not have settled down to become stable.

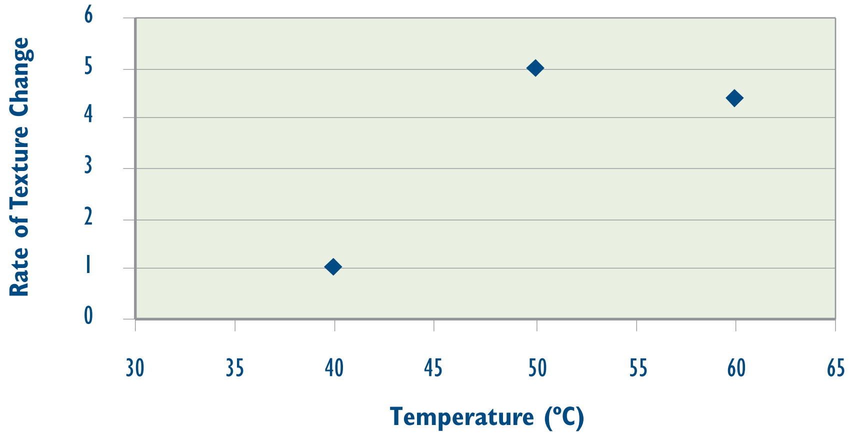

Figure 4-16 Rate of change of texture of a chipseal over hot mix asphalt under laboratory rolling.

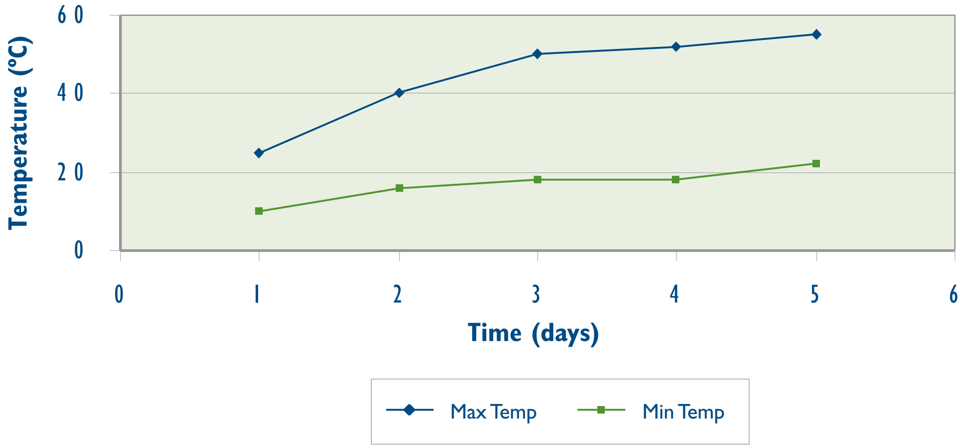

Figure 4-17 Temperature build-up over a number of sequential days in a pavement surface accelerates chip embedment.

Over weak pavements

A seal can fail rapidly where the base has been weakened by ingress of water. This can cause cracking or premature flushing because the weakened basecourse can lead to rapid chip embedment.

4.7.4.2 Layer Instability

The term 'layer instability' has been coined to cover inadequacies in the structural performance of surface layers that is often associated with the build-up of multiple seal layers until the combined thickness is greater than 40 mm with an excess of binder. Many variables related to this build-up of thick seal layers determine whether layer instability may become the mode of failure.

Figure 4-18 A flushed and tracked repair patch. Photo courtesy of Les McKenzie, Opus

In many instances these thick layers of old seals tend to perform like poorly graded, bitumen-rich asphalt mixes. Given that they comprise a matrix of mostly single-sized chip applied with a reasonably high binder content (in terms of volume), this is not surprising.

To illustrate this concept, Figure 4-19 shows a shallow shear failure that would usually be associated with poor performance of the basecourse layer of the pavement structure. The wider view of this shear failure shows that it has occurred in a number of seal layers above the concrete bridge deck. As the concrete bridge deck is rigid it cannot have sheared in this way, and the failure can only be attributed to the structural performance of the seal layers.

Figure 4-19 Shear failure on a bridge deck. Photo courtesy of Gordon Hart, Transit NZ Napier

Symptoms

The common symptoms of pavements affected by layer instability are

- shortening reseal cycles;
- routine maintenance costs that are increasing at an abnormal rate; and
- flushing, which is almost always the failure mechanism.

In many cases other near-surface maintenance problems such as shallow shear and cracking may be observed. Rutting can also be attributed to the deteriorating performance of the surfacing layers, but before treatment it must be verified that such deformation is not evident in the pavement structure below. (See Chapter 7 for information on treatment for rutting.)

Contributing Causes

Not every combination of multiple seal layers will become unstable in terms of performance under load when the total depth reaches 40 mm or more. Many other variables will determine whether layer instability may become the mode of failure. Currently the state of research on the issue is not sufficiently refined to be concise about these variables, or of their interdependence. However practitioners working with the issues have developed a practical awareness of the factors that include:

- The penetration grade of the binders used: softer penetration grades are more susceptible to layer instability.
- The use of fluxes and cutters: these permanently affect viscoelastic properties of the binder.

  As the volume of binder in the layer approaches levels where layer stability will cause flushing, the viscosity of the binder becomes critical. Diluents applied to the surface may permanently affect the viscosity of the binder near the surface and accelerate deterioration of the layer, and therefore onset of flushing.
- Chip grading: using voidfills between seals will introduce a more balanced grading of the entire layer, reducing the likelihood of layer instability.
- Climatic effects: the surfacing material accumulates heat in summer conditions, with low rates of heat loss in cooler periods. As flushing develops, the surface blackens and accelerates this temperature accumulation, which affects structural performance. Sustained pavement temperatures exceeding 50°C are not uncommon (see Section 4.2.3).
- The frequency of resurfacing: shorter chipseal lives result in lively binder (i.e. not influenced by the stabilising effect of oxidation) being sandwiched in the total layer.
- Binder application rates: where conservative binder application rate design results in small quantities of additional binder being applied to prevent chip loss, this may have little effect on the texture achieved for an individual seal layer. However, even small increases in application rate accumulate until the total binder in the layer has increased significantly in terms of the binder:stone ratio.

4.7.4.3 Binder Rise

Binder rise associated with water vapour pressure was first described by Major (1972). It is characterised by the development of 'volcanoes' (as they are called in the industry) illustrated in Figure 4-20. The binder rises as a bubble between the chip and, when pricked, a drop of water is inside it.

Although research into the phenomenon of volcanoes has demonstrated the physics, it has not been able to reproduce it in the laboratory. In the field, volcanoes show up initially as small 20¢-size 'blobs' of bitumen (Figure 4-20), which then tend to join together, ultimately resulting in a large area of flushing. This water vapour binder rise can normally be distinguished from flushing from other causes, such as trafficking, as it occurs in significant areas outside the wheelpaths.

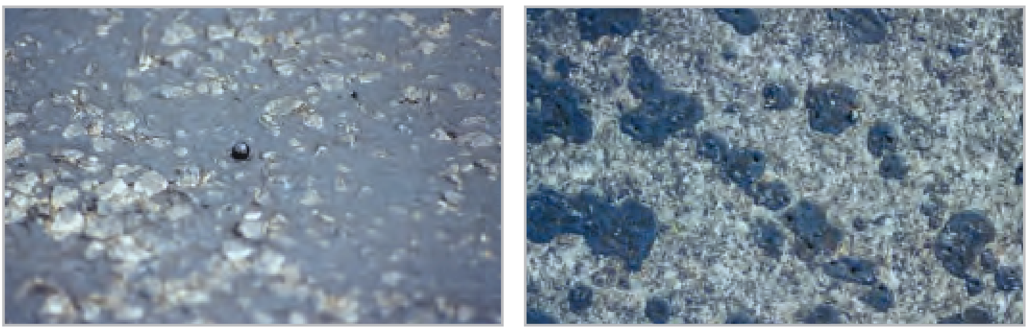

Figure 4-20 Binder rise showing vapour venting.
Left: Vapour venting shown by presence of a volcano forming on a flushed surface. Right: Over time, more volcanoes will appear and coalesce to form a flushed surface. Photos courtesy of Les McKenzie, Opus

Whether the water is coming from the base or entering from above through small cracks in the seal is unclear. Figure 4-21 shows a chipseal constructed on a steel plate, and binder rise appeared after 5 years of exposure in a bitumen durability trial. In this case the water must have come from the atmosphere through the seal.

On reseals the phenomenon normally occurs after the seal is at least 5 years old, but binder rise can occur quickly on first coat seals over a moist basecourse. The application of a seal over a basecourse that has a relatively high degree of saturation (>80%) can lead to binder rise or shear failure of the basecourse.

Figure 4-21 Binder rise in a chipseal constructed on a steel plate, for bitumen durability trials at Opus Central Laboratories, Lower Hutt. Samples have been taken from the bare sites.

Photo courtesy of Joanna Towler, Transit NZ

4.8 Reasons for Extra Long Life

As well as a high percentage of seals not attaining their design life, a large number also exceed this life. This balance results in the average design lives, given in Table 4-4, that are close to the average achieved in practice.

As discussed in Section 4.3, the decision to reseal is based on loss of waterproofness (cracking) or skid resistance (flushing or polished aggregates, discussed in Section 4.9). Seals that significantly exceed the design life are often associated with lower traffic volume pavements where loss of texture has not occurred. If the substrate is harder than normal (e.g. concrete), then a longer life could be expected under heavy traffic.

For low traffic volume roads, the asset manager is advised to inspect the seals at regular intervals and reseal if cracking or chip loss has occurred.

If visible distress has not occurred, in theory the seal should be left. In practice however, the asset manager may decide to reseal on the early side because rapid base-layer failure could occur if waterproofness is lost, especially over a water-susceptible pavement. The decision to reseal is often made before the seal has cracked because the engineer considers that cracking is imminent.

If the danger of rapid pavement failure is considered to be low, then the asset manager is more inclined to leave the seal. Because of this practice, seal lives of over 20 years have been recorded in New Zealand but are not common.

Binder hardness can play a significant part in a seal's performance and may explain how long lives have been obtained. Bitumen tends to harden quickly for the first 5 years (Figure 4-7), after which the rate of hardening becomes relatively slow and very little change occurs from 10 to 15 years.

4.9 Skid Resistance

4.9.1 Introduction

It has long been known that improving the skid resistance of a road can reduce the risk of certain types of crashes, and many countries including New Zealand have a policy of measuring and setting minimum standards for the skid resistance of roads (Austroads 2005).

Almost all dry road surfaces have a skid resistance which is adequate for the frictional demands arising from the routine braking, accelerating and manoeuvring of vehicles if they are using the road within its posted speed limit. Frictional demand is much greater in emergency situations however, where a driver brakes sharply or swerves to avoid a collision, or where a driver attempts to negotiate a bend at too high a speed.

A high skid resistance will neither prevent the emergency braking situation from arising nor improve driver judgment, but it can often alleviate the effects of driver error and reduce the risk of a crash occurring or at least reduce the severity of a collision.

In the United Kingdom (UK), research into skid resistance has been undertaken for over 60 years. This has led to the development of machines to routinely measure the skid resistance of the surfaces of in-service roads while travelling at normal road speed. One particular machine is known as SCRIM, or Sideway-force Coefficient Routine Investigation

Machine. Other machines sometimes used in New Zealand are the GripTester, Norsemeter RoAR (Road Analyser and Recorder) and British Pendulum Tester (BPT) (Figure 4-22).

Figure 4-22 Machines used in New Zealand for measuring skid resistance.
Clockwise from top left: SCRIM. Top right: RoAR. Bottom right: GripTester.
Photos courtesy of Mark Owen, Transit NZ
Bottom left: British Pendulum Tester. Photo courtesy of Shirley Potter, Opus

New Zealand has also developed and introduced a skid resistance policy. The policy was introduced in 1998 and is based on the use of a SCRIM to monitor the wet road skid resistance of the state highway network. The benefits of introducing this skid policy have been significant, with reductions of 35% in wet skidding crashes and benefit/cost ratios[2] in excess of 40 achieved.

There are therefore compelling reasons for Road Controlling Authorities (RCAs) to introduce a skid policy because not only will it reduce crashes, it also produces very high rates of return (in crash savings) on funds invested.

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2 This means 40 times the benefit in terms of crash savings are achieved for each dollar (NZ$1) spent on improving skid resistance to the level required by the policy.

4.9.2 Relationship between Skid Resistance and Crashes

Research has shown that as the skid resistance of the road surface decreased, the rate of wet skidding crashes increased. It also found that different sites presented different risks. It is desirable to have a 'constant risk' of wet skidding crashes across a road network, and therefore different skid resistances are needed on different types of sites. This is done by establishing a number of site categories describing the situations found on a road network, and developing a relationship for the wet skidding crash risk at these sites.

After completing the above procedure, Transit NZ published TNZ T/10:2002 *Specification for skid resistance investigation and treatment selection* (from which the Investigatory Levels are reproduced as Table 4-5). The investigatory level (IL) is a trigger level for identifying sites that may need inspection.

The present New Zealand skid resistance investigatory levels used in TNZ T/10 are based on those adopted by the UK, with some adjustments made that were based on an analysis performed in 1997 involving wet skidding injury crashes in New Zealand over the period 1990-1994. Recent developments include the Austroads 2005 *Guidelines for the management of road surface skid resistance (Skid Resistance Guide)*.

Table 4-5 Investigatory Levels (IL) for identifying sites requiring inspection (from TNZ T/10).

Site Category	Site Definition	Investigatory Level (IL)	Threshold Level (TL)
1	Approaches to: • Railway level crossings • Traffic lights • Pedestrian crossings • Roundabouts • Stop and Give Way controlled intersections (where the State Highway traffic is required to stop or give way) • One Lane Bridges (including bridge deck)	0.55	0.45
2	• Curve < 250m radius • Down gradients > 10%	0.50	0.40
3	• Approaches to road junctions (on State Highways or side roads) • Down gradients 5-10% • Motorway junction area including On/Off Ramps	0.45	0.35
4	• Undivided carriageways (event-free)*	0.40	0.30
5	• Divided carriageways (event-free)*	0.35	0.25

* Event-free – where no other geometrical constraint, or situations where vehicles may be required to brake suddenly, may influence the skid resistance requirements.

4.9.3 Road Factors Influencing Wet Road Skid Resistance

While a great many variables are known to be involved in wet-road skid crashes, only the road factors are dealt with here since the other factors such as driver experience, tyre tread depth, suspension system, etc., are beyond the scope of this book. For further discussion on these topics refer to the Austroads 2005 *Skid Resistance Guide*.

The principal road factors influencing wet-road skid resistance are:

- Macrotexture and microtexture;
- Water film thickness;
- Vehicle speed;
- Equilibrium skid resistance;
- Seasonal variation;
- Chip properties;
- Traffic volume and type;
- Other road factors.

4

4.9.3.1 Macrotexture and Microtexture

Wet-road skid resistance is the coefficient of dynamic friction between a tyre and the road surface. It is influenced by texture at two scales: macrotexture, and microtexture.

Macrotexture is the overall texture of the road surface and is given by the spaces in-between the chips. Macrotexture is often referred to as the texture depth.

Microtexture is the fine texture caused by irregularities or asperities on the surfaces of each individual chip. This is shown diagrammatically in Figure 4-23.

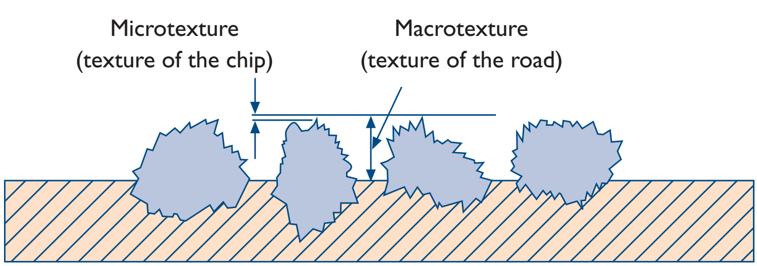

Figure 4-23 The relationship of macrotexture and microtexture of a road surface.

Figure 4-24 shows the interface between a moving tyre and a wet road. When a vehicle is running on a wet road surface, the layer of water between the tyre and the road has to be dispersed before dry contact can be established and adhesive forces developed. There are three distinct zones at the tyre–road interface:

- Zone 1, at the leading edge of the tyre, where the bulk of the water is dispersed, leaving a thin film which is penetrated in
- Zone 2 by some of the surface texture, so that in
- Zone 3, substantially dry tyre–road contact is achieved.

The microtexture is the most effective factor in breaking through thin water films to achieve dry contact which gives the necessary adhesive force.

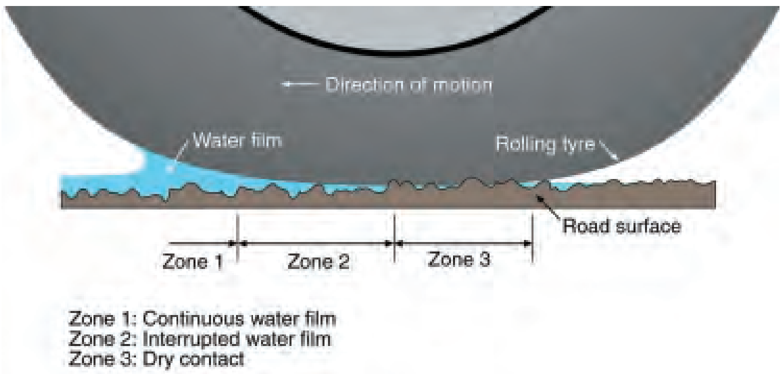

Figure 4-24 Tyre interface on a wet road.

At low vehicle speeds the bulk of the water film is readily dispersed, zone 3 (the area of dry contact) is large, and the maximum adhesive force can be developed. As the vehicle speed increases, less time is available for removal of the water and zone 3 becomes smaller with a consequent reduction in adhesive force. The reduction can be minimised by providing drainage channels to facilitate the removal of the bulk of the water. One way of doing this is to provide drainage grooves in the tyre tread.

The pavement surfacing contribution is through adequate macrotexture which not only provides drainage paths, but also produces greater tyre deformations. As vehicle tyres are not perfectly elastic, some energy is dissipated as the tyre is deformed by the macrotexture and rebounds. This imperfect elastic recovery is known as hysteresis and reduces effective braking distances in both wet and dry conditions.

At all vehicle speeds, the influence of microtexture is important. At low speeds (up to about 50 km/h) it is the predominant influence on skid resistance. As vehicle speeds increase the macrotexture becomes increasingly important (Figure 4-25). If a vehicle increases its speed from 50 km/h to 130 km/h on a conventional bituminous surface with texture depth of 0.5 mm, the reduction in skid resistance is about 30%, whereas for a texture depth of 2.0 mm there is very little reduction.

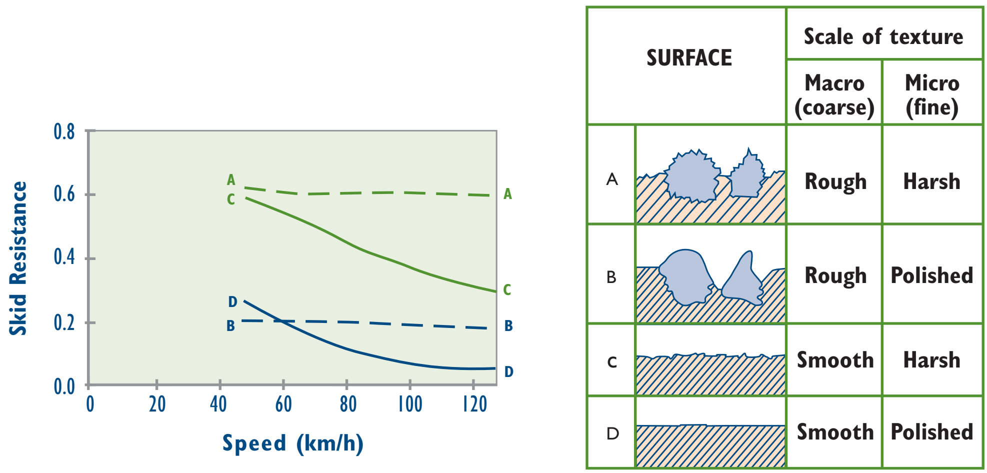

Figure 4-25 Effect of microtexture, macrotexture, and speed on skid resistance.

4.9.3.2 *Water Film Thickness*

When a road surface passes from a dry to a slightly wet condition, a sharp reduction in the skid resistance occurs because of the presence of the water film. As the thickness of the water film increases, the skid resistance decreases further but at a much less rapid rate. Before measuring skid resistance, a water film of thickness of 0.25 to 1.5 mm is applied to the road (the actual thickness depends on the test method used) to simulate the wet condition.

4.9.3.3 *Vehicle Speed*

Since the removal of bulk water between the tyre and the road is a time-dependent process, the area of dry contact decreases as the vehicle speed increases, with a consequent decrease in the effective skid resistance. The rate at which the skid resistance reduces with increasing speed depends mainly upon the macrotexture, and is of most influence at speeds above 50 km/h. It is important to consider this effect when measuring skid resistance. Although it is customary to survey a network at a standard speed, tests are sometimes carried out over a range of speeds or at the speed that is characteristic for individual sections. If texture depth measurements are also made at that time, the effective skid resistance at other speeds can be estimated.

4.9.3.4 Equilibrium Skid Resistance

Almost all new road surfaces constructed with chip from crushed aggregate have a high skid resistance initially because the exposed aggregate particles have good microtexture and sharp edges. However, under the polishing action of vehicle tyres the microtexture is reduced, the edges become worn, and the skid resistance decreases. Eventually the skid resistance stabilises at an equilibrium level, as shown in Figure 4-26, and thereafter only small fluctuations take place if the traffic level remains constant and no structural or other deterioration of the surface occurs. The time to reach this state of equilibrium is related to the amount of traffic, and can range from 6 months to several years. There is also a steady deterioration in macrotexture on road surfacings as chips either become embedded or worn away by the abrasive action of the traffic.

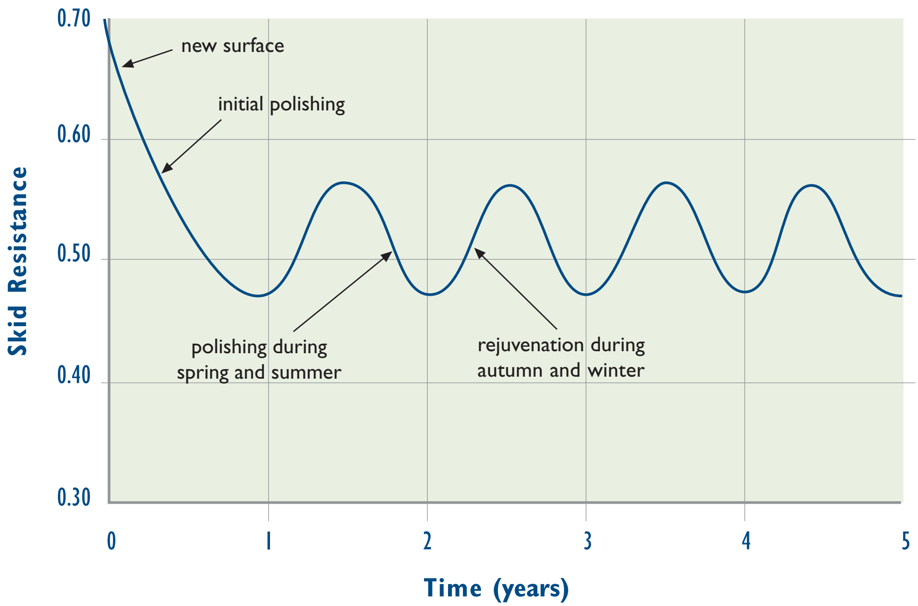

Figure 4-26 Effect of polishing on a new surface, showing initial high skid resistance followed by stabilisation at an equilibrium level.

4.9.3.5 Seasonal Variation

As shown in Figure 4-26 by the fluctuations in the skid resistance after an equilibrium level had been reached, the skid resistance tends to increase in winter and decrease in summer.

Tests carried out at a series of trial sections between 1988 and 1992 on New Zealand roads showed very pronounced seasonal changes in skid resistance, with minimum summer values being approximately 30% lower than peak winter values. A study in Australia showed that seasonal variation was evident in all states except Queensland. UK studies have shown that the variation is related mainly to seasonal changes in the grading of the abrasive material lying on the road or embedded in vehicle tyres. Polishing of the road surface chip can also be caused by action of small particles caught in vehicle tyres.

During the summer months, particularly during long dry spells, small particles of road surface chip are ground down by the action of vehicle tyres to produce a very fine flour which acts as a polishing agent. During times of prolonged rain (e.g. winter months), the very fine material is washed away leaving a coarser grit at the surface. This consequently increases the skid resistance by roughening and thus 'replenishing' the microtexture of the chip surfaces. Natural weathering of the chip caused by prolonged wetting and frost action also contributes to the improvement in microtexture during the winter months. Seasonal variation has been reported to occur to a greater degree on more heavily trafficked roads.

Effects of Seasonal Variations on Measuring Skid Resistance

Thus wet road skid resistance fluctuates throughout the year, with the lowest values occurring towards the end of the summer and the highest values during the winter. To minimise this seasonal effect, skid testing is carried out only in the summer months each year. Nevertheless, this within-year, or more correctly within-summer, variation means that parts of the highway tested at different times during the summer can record different levels of wet road skid resistance. If they had been tested on the same day however, the values would have been near identical (within the inherent variation of the test equipment).

The within-year variation could therefore lead to an inefficient use of maintenance resources because those sections tested towards the end of the summer would be more likely to be identified for treatment than those tested early or late in the summer.

New Zealand Mean Summer SCRIM Coefficient

When measuring skid resistance on the New Zealand State Highway network, and to minimise the seasonal variation as described above, a number of seasonal control sites have been set up across the network. Data from the seasonal control sites are used to normalise the SCRIM data obtained for the network to account for seasonal variation.

The sites have been selected to represent what are considered to be climatologically similar areas. These sites are tested three times each summer and the measurements used to give a Mean Summer SCRIM Coefficient (NZ MSSC) for each site. The three surveys are spread across the summer season with one survey at the start of the survey programme, one survey when the adjacent highways are being tested and one survey at the end of the survey programme. The procedure is shown diagrammatically in Figure 4-27.

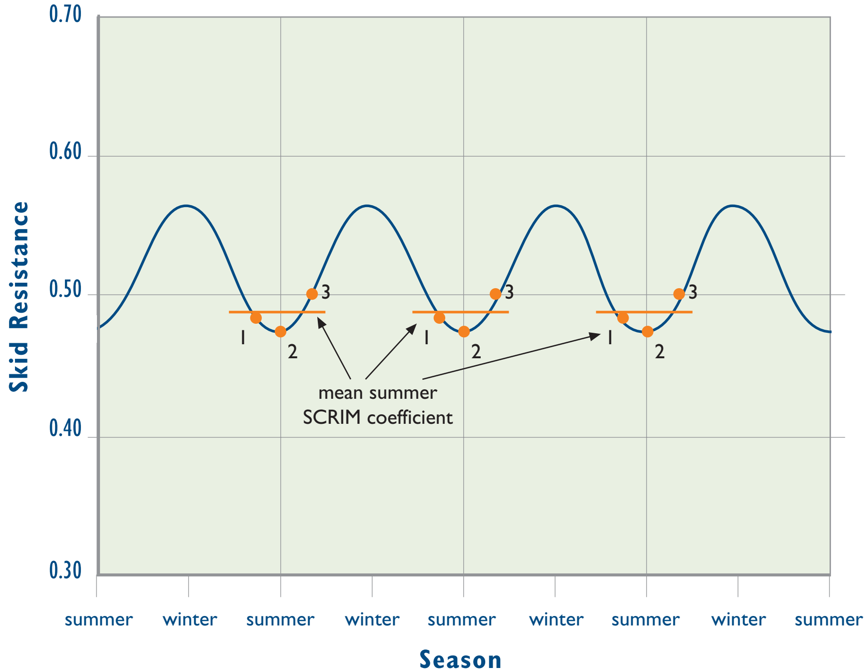

Figure 4-27 At each seasonal site, three SCRIM measurements (1, 2, 3) are made at different times during the summer. The average skid resistance for the summer for each site is calculated to obtain the Mean Summer SCRIM Coefficient (MSSC).

At each seasonal site three SCRIM measurements (1, 2 and 3 in Figure 4-27) are made at different times over the summer. The average skid resistance for the summer for each of the seasonal sites is calculated. This is the Mean Summer SCRIM Coefficient (MSSC) and is used as a correction factor. The skid resistance data from other nearby sites are corrected using the MSSC correction factor to also become the average 'worst' skid resistance for the summer, for each other site. This is reported as the MSSC for each site, and is loaded into RAMM.

Equilibrium SCRIM Coefficient

For New Zealand, the within-year variation was considered to be the most significant source of seasonal variation that could lead to differences in the identification of potentially defective skid resistance areas over the network.

However, with data available for 3 years on some seasonal control sites, the results have clearly shown that the year-on-year variations in New Zealand's weather patterns are also affecting skid resistance (Figure 4-28).

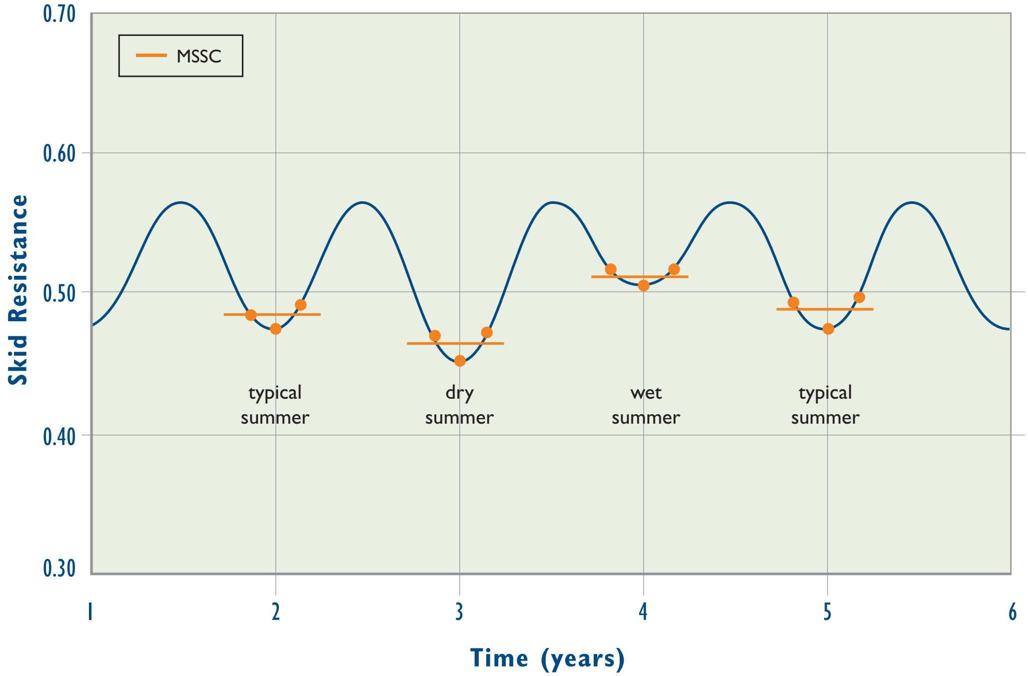

Figure 4-28 Year-on-year variations in weather patterns reduce the effectiveness of skid resistance policy in wet summers and cause over-reaction in dry summers.

This factor has also been observed in other countries, notably the UK. This means that, although the within-year variation is still dominant, the between-year effects could have a significant secondary role in the correct allocation of funds for the maintenance of surfacings with low skid resistance. If extreme weather conditions occur in any year, then in a wet summer an unusually small number of sites would be below the investigatory level. Conversely in a dry summer, long lengths of normally acceptable skid resistance could be considered deficient and require investigation. For the former situation, sites will not be identified that in a normal year could fall below the investigatory levels established for use in New Zealand. This would leave the network in a situation that is less safe than normal. On the other hand, after a dry summer excessive funds would be allocated to fix a temporary problem.

To overcome the potential problems of year-on-year variation, Transit NZ uses a correction factor to allow network results to be corrected to compensate for between-year climate changes. SCRIM data corrected for both within-year and between-year variations in skid resistance are termed Equilibrium SCRIM Coefficients (ESC).

The principle used to produce the ESC factors (Figure 4-29) shows that the mean of the three previous annual MSSCs is calculated, and this mean is used to produce an ESC factor for the year in question, in this case the fourth year. The fourth year MSSCs are corrected for between-year variations by multiplying by the ESC Correction Factor. There are no hard and fast rules regarding the number of years to be used to produce the ESC. In Figure 4-29 for example, it is three but could be possibly four or five years. The number of years used should be a balance between allowing for atypical years but not masking actual changes in the condition of the network, and maintaining a reasonable pool of calibration sites after reduction in the data because of reseal programmes. This can only be done by reviewing the actual data.

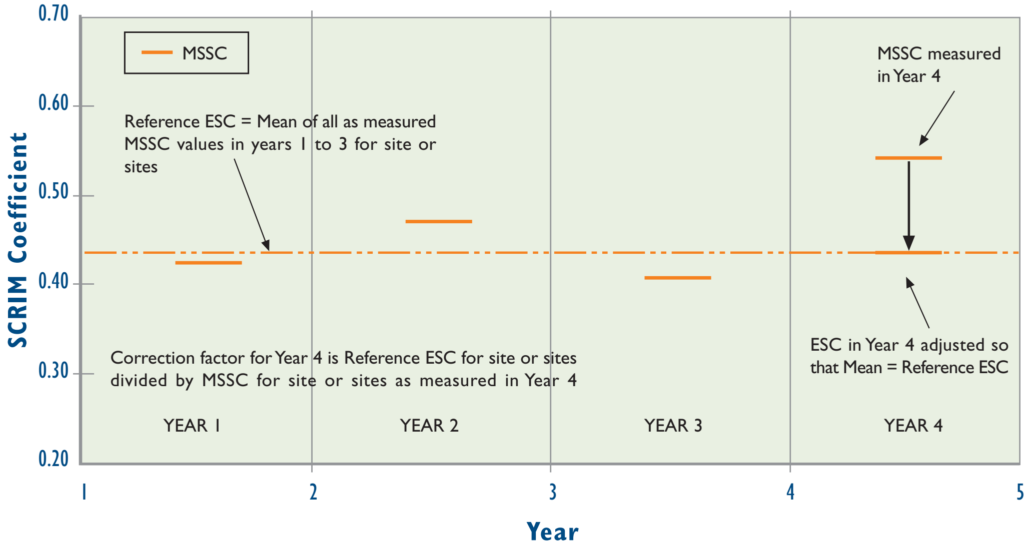

Figure 4-29 Strategy for obtaining Equilibrium SCRIM Coefficient (ESC), which is the NZ MSSC value multiplied by an Equilibrium Correction Factor. The equilibrium correction factor is calculated for each seasonal site and is applied to individual 10 m sections.

4.9.3.6 Chip Properties

For bituminous surfacings, the polishing resistance of the chip particles exposed at the surface of the road is the most important factor influencing the microtexture and hence the skid resistance. Resistance to abrasion is also important since macrotexture will be lost if a chip wears away too rapidly under the grinding action of vehicle tyres.

Polished Stone Value

Various stone polishing tests are available to assess the propensity of a stone to polish. The most frequently used test and the one used in New Zealand is called the Accelerated Polishing Test which produces Polished Stone Values (PSV). More information is in Section 8.5.8.1.

The PSV test is related to the required skid resistance and the commercial traffic by the equation established by Szatkowski & Hosking (1972):

$$PSV = 100 \times SFC + Q \times 0.00663 + 2.6 \qquad \text{Equation 4-2}$$

where: SFC = required skid resistance

Q = commercial vehicles/lane/day (>3.5 tonnes)

4.9.3.7 Traffic Volume and Type

The extent to which a road surface becomes polished is directly related to the traffic volumes of commercial vehicles and heavy commercial vehicles using the road. Consequently, a transverse profile of skid resistance will reveal lower levels of skid resistance in the wheelpaths and, on an otherwise uniform surface, a longitudinal profile will show that skid resistance levels are lower where additional stresses to the pavement are caused by braking or turning vehicles. On bituminous surfacings a highly significant correlation has been shown to exist between commercial vehicle traffic flow and equilibrium skid resistance. Figure 4-30 shows the increase in skid resistance of a road surface once a by-pass had been opened and the numbers of commercial vehicles per day (CVD) had reduced.

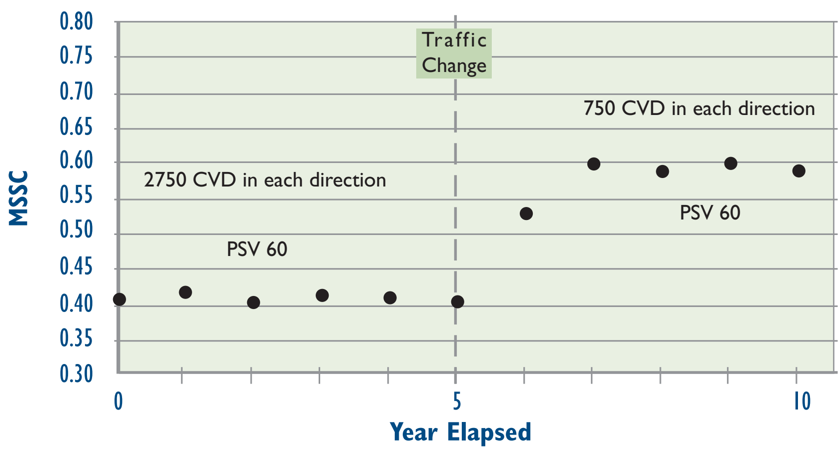

Figure 4-30 Improved skid resistance with decreased traffic volume (CVD).

4.9.3.8 Other Road Factors Affecting Skid Resistance

Other factors influencing skid resistance are chip size, chip shape, and detritus on the road.

Reducing chip size (using a finer chip size) can lead to improved skid resistance but may give a lower macrotexture.

Chip shape can also influence skid resistance, because angular particles present sharp edges and peaks which penetrate the water film. The tyre can thus grip the road surface as mentioned in Section 4.9.3.1. Table 4-6 shows the PSV results for chip with different sizes and crushed faces.

Before this research was undertaken it was believed that the PSV test wore sharp edges and peaks off the chip. Theoretically therefore a rounded river-worn aggregate would have the same PSV as the crushed version of the same aggregate. However, as can be seen from the results in Table 4-6, crushed aggregates give better PSVs than rounded aggregates. Although the PSV test is normally carried out only on Grade 4 chips (as explained in Section 8.5.8.1), other grades were tested for the purposes of this research.

Chip on roads near quarries or construction sites, where dust and detritus are tracked onto the road by construction vehicles, can polish quicker than similar chip on otherwise similar roads. A similar effect occurs when slip material or other detritus covers a road.

Table 4-6 PSV results for different sizes and angularities of chip.

Chip Condition	PSV Result
Grade 6 Uncrushed	42
Grade 6 Crushed	56
Grade 5 Uncrushed	42
Grade 5 Crushed	53
Grade 4 Uncrushed	46.5
Grade 4 50% Crushed	49.6
Grade 4 Crushed	52.8

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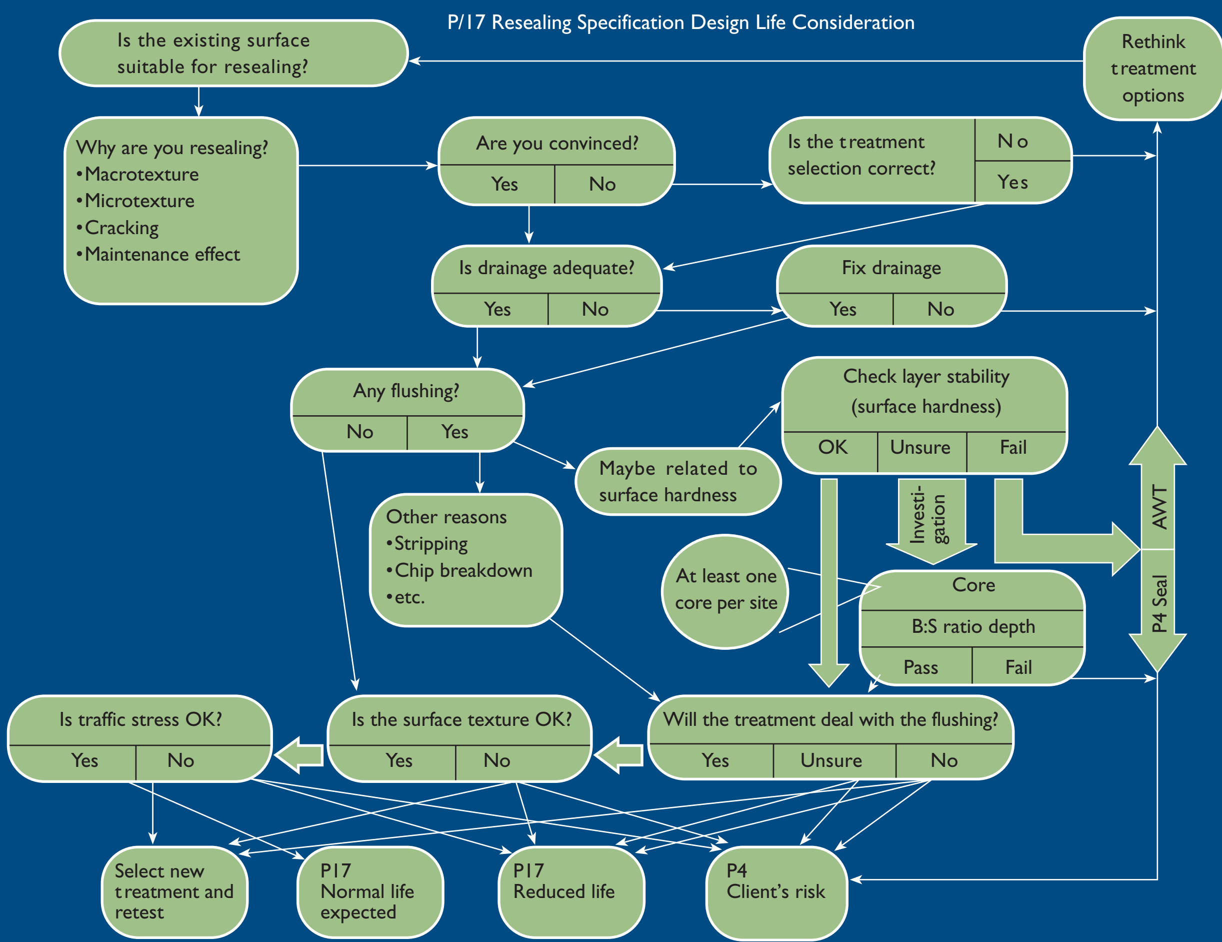
CHAPTER FIVE

Road Asset Management



Chapter 5 Road Asset Management

Previous page: This flow chart is used to identify sections of pavement that are to be resurfaced in accordance with TNZ P/17:2002 *Performance-based specification for bituminous chipseals.*

Chapter 5 Road Asset Management

5.1 Road Asset Management Principles

5.1.1 Introduction

Management of the road asset involves the application of engineering, financial and management practices to optimise the level-of-service outcome in return for the most cost-effective financial input. The function of the asset manager is to optimise investment and outcomes within the constraints of finance, service level, resources, etc. Taking only the pavement and surfacing assets into consideration, the optimisation is applied using a life-cycle management approach.

5

The objective is simply to apply the right treatment at the right time to achieve the desired level of service.

In practice the asset manager is operating in a financially restricted environment, and the constraints require the minimisation of whole-of-life costs while maintaining service levels above well-established minimum technical standards and customer values.

The key asset management principles evolving from this asset management function that are relevant to chipsealing operations are discussed in this section. The intent is to highlight the factors that should be understood at an overview level. Developing the full knowledge necessary to apply asset management principles will require reference to other documentation (e.g. NAMS 1996). An understanding of these principles affects all players involved in the delivery of the end result and, for chipsealing treatments, the different expectations and levels of involvement are as follows:

- The *asset manager* must be fully aware of the purpose, life expectancies and outcomes of all sealing options in resolving which will be applied in the Forward Works Programme (discussed in Section 5.1.2.5) to achieve the financial and service level objectives.
- The *seal designer* must be aware of the objectives and intent of the scheduled chipseal treatments in order to produce the most appropriate design. To meet the objectives, both the designer and the asset manager must target the same life expectations, service level outcomes and costs.

- The *construction team* must understand the importance of the construction standards and deliver the work at those expected required standards. The construction standards are to be specified because they are an implicit component of the service level.

The general concepts relating to road asset management, of inputs, process, outputs and implementation, are shown in Figure 5-1. The components are discussed in sequence below.

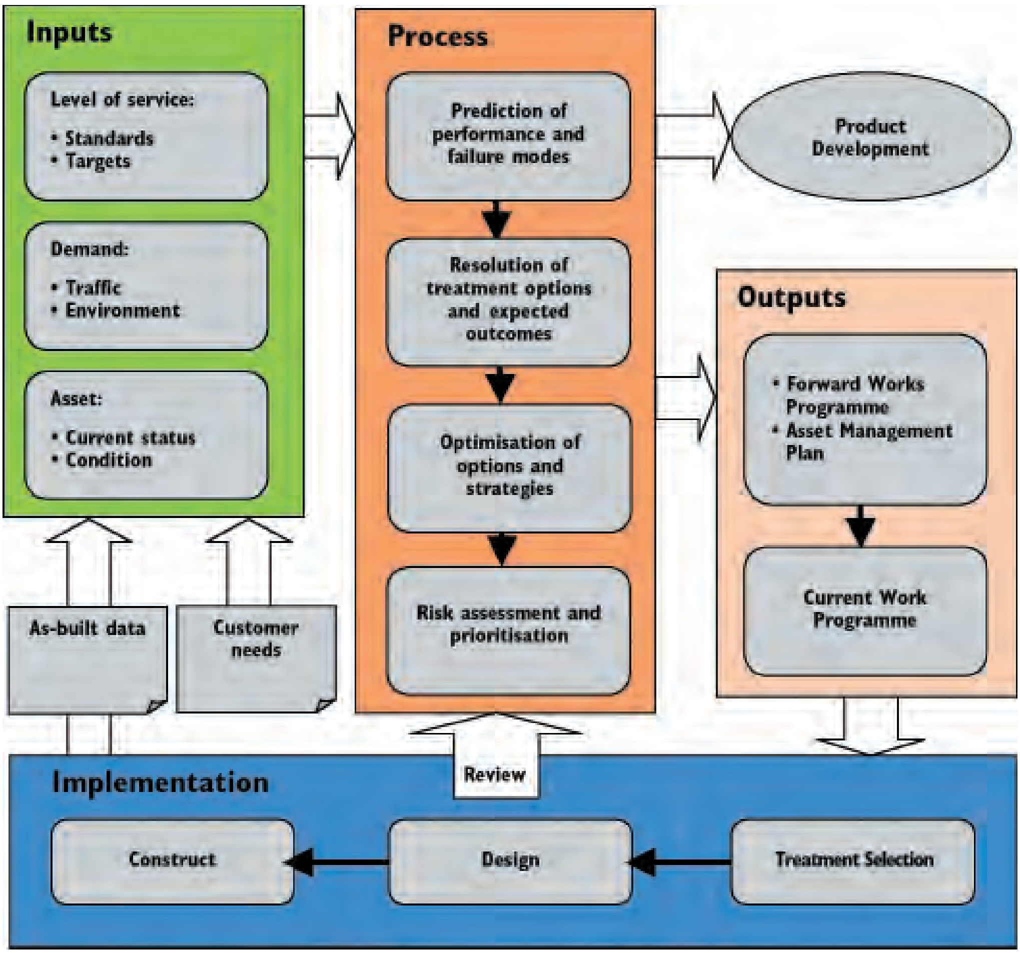


Figure 5-1 Applying the asset management process.

5.1.2 Applying the Asset Management Process

5.1.2.1 Treatment Lengths

Current best practice is for programmes to be developed based on needs, assessed at a treatment length level. A treatment length is defined as a uniformly performing section of pavement that is performing differently to the sections on either side of it. In many cases treatment lengths are synonymous with the lengths that will be scheduled for resealing.

There are exceptions to this:

- When a treatment has to be applied in a reactive manner to deal with a specific failure, such treatments may well be applied only to part of a treatment length.
- When sealing to improve skid resistance in reaction to results of the annual SCRIM survey. The original treatment length may then be split into two separate treatment lengths.

5.1.2.2 Life Cycle Asset Management

Life Cycle asset management is the concept of planning and analysis of all needs, requirements and activities that will be necessary to achieve the full life of the asset, from the current status to replacement, and is commonly referred to as a 'cradle to grave' analysis. There is much debate surrounding when the life cycle of a pavement ends. One idea is that indefinite extension of life can be achieved through the application of maintenance treatments. For this discussion the key issues are:

- A resealing treatment does not start a new life cycle.
- Typically the treatment that initiates a new life cycle will be one that renews the structural capacity of the asset.

The selection of treatments is based on consideration of all treatment options or strategies that are possible over the full life of the asset.

5.1.2.3 Inputs

The following details the inputs for asset management (see box for 'Inputs' on Figure 5-1).

Level of Service

Service levels should be regarded as the outcome that the asset provides for the end user (e.g. the asset of the pavement and the service level of its desired roughness). Service levels can be applied as fixed standards (not to be exceeded) or desirable targets. If established as desirable targets, the term 'investigatory' is frequently used which means a level at which the justification for treatment or correction should be considered.

Examples of service levels that are common in considering chipsealing requirements include:

Level of Service Outcome	Action	Example
Fixed Standards	Not to be exceeded	Texture depth
Desirable Targets	Investigatory level	Skid resistance

Construction agencies should also regard construction standards in terms of levels of service. For example, where a resurfacing is necessary to correct a texture deficiency, the level of service achieved from the treatment (the output) is calculated from (or is a function of) the texture achieved through the construction and the construction standard.

The construction standards establish the expected new service level. For example, one key service level expectation that is rated very highly by the public, and is implemented through construction standards, relates to the presence of loose sealing chip. This is a construction outcome, and the service level is achieved through the seal design and the road-sweeping requirements in the construction specification.

Demand on Asset
Once the level of service is set and the construction has achieved it, the next thing to consider is the demands that are placed on the asset causing it to deteriorate over time. As outlined in Chapters 3 and 4, the two great influences on chipseals over their life time are traffic and the environment.

Asset Condition
Next we consider the current condition of the asset. Obviously not all assets (e.g. roads) in a road network will have the same ability to meet the required level of service. The current status of some will be close to the 'as-built' condition, meeting or exceeding the required level of service. The condition of other assets will be at various stages of deterioration and at or below the required level of service.

5.1.2.4 Process

The following details the process for asset management (see box for 'Process' on Figure 5-1).

Prediction of Performance and Failure Modes
After the condition of each treatment length is known, this information can be fed into models that are assigned to predict the performance and failure modes of the asset, under the influences of the demands of traffic and environment and in terms of the levels of service.

Resolution of Treatment Options and Expected Outcomes

Part of the outcome of the model is resolution of treatment options and expected outcomes. These are combined in terms of life cycle costs.

Optimisation of Options and Strategies

The next step is optimisation of options and strategies, including the complicated decision of choosing a factor on which to base the optimisation process. Common options include optimisation based on:

- Asset condition or performance (service level).
- Total transportation costs (takes into account the costs to the agency, i.e. the RCA, to retain service level and user benefits).
- Agency costs against fixed service level (net present value analysis).

The key issue for the seal designer is that the optimisation process will provide recommended treatments (i.e. outputs), the timing of which is based on life expectancies and service level requirements. These expectations should be carried into the design stage and the designer must discuss options with the asset manager should the following matters arise:

- If the detailed design is not expected to achieve the life expectations or service levels because of constraints that possibly have not been fully understood at the planning stage (e.g. unexpected widespread pavement faults).
- If more economic options become apparent at the detailed design stage. Discussion is necessary to ensure alignment with the longer term planning considerations and assumptions (e.g. a longer chipseal life could be achieved with a different chipseal type).
- If the scheduled treatment and objectives are unrealistic (e.g. demands from high-stress areas within longer treatment lengths that had not been noticed at time of initial inspection).

The asset manager may resolve to apply a non-chipsealing treatment, e.g. asphaltic concrete, if the sealing objectives cannot be met.

Risk Assessment and Prioritisation

Risk assessment and prioritisation are important considerations in the asset management process.

As a pavement approaches the end of its life, seal designers and asset managers must be very conscious of the marginal benefit of applying "just one last reseal" rather than an area-wide pavement treatment. This applies especially for pavements that are nearing the ends of their lives because either thick and unstable seal layers have accumulated or excessive pavement deterioration has occurred.

- Where unstable surfacings exist and where one further reseal is applied, it often proves to be a catalyst for rapid flushing and bleeding (and a significant increase in surfacing repair costs) that dramatically shortens the life the reseal.
- Where the pavement itself is deteriorating, the life of the reseal is not achieved as the surface is compromised through excessive pavement repairs.
- The extent of these repairs will result in either an area-wide pavement treatment, or a full pavement rehabilitation treatment becoming necessary well before the economic life of the seal has been achieved.

Seal designers must be aware of the expected life of the new reseal, taking all these considerations into account. They must avoid the temptation of designing high cost-low risk treatments (for example two-coat seals, or the use of expensive polymer modified binders) based on the assumption that the increased cost of the treatment will be recovered through an increased seal life. In the two situations outlined above, this assumption often proves to be unrealistic, resulting in a need for rehabilitation to be brought forward before the end of life of the seal is reached.

5.1.2.5 Outputs

Forward Works Programme

The principal output of the asset management function which affects sealing operations is the Forward Works Programme. The Forward Works Programme details the specific maintenance treatments that are required for each treatment length on the network, which were obtained as outputs from the whole-of-life optimisation. It should be sufficiently detailed to convey to the seal designer the objectives of the current reseal programme covering issues such as:

- The reason for scheduling the reseal. What is the objective or specific service level output that it is designed to correct? Is it triggered by cracking, skid resistance, texture improvement, etc.?
- The service level that is expected following treatment. If the objective of the seal is to improve skid resistance, the design will possibly be different to that selected if the intent is to control maintenance costs for a short period before reconstruction (e.g. if a holding seal is applied, it will need to be recorded and depreciated over a shorter life).

- The expected design life.
- The next treatment proposed.

The development of a Forward Works Programme is a requirement of current best practice applying to infrastructure asset management and now is a legislative requirement (see Section 5.2.4). Typically the minimum programme covers the forward ten years but twenty-year programmes are becoming common.

The Asset Management Plan is another output, which is not covered here.

Current Work Programme

The Current Work Programme is extracted from the Forward Works Programme. In selecting a particular type of surfacing for a road, the five main factors to be considered are: initial cost, maintenance cost, vehicle operating cost, safety, and attractiveness to the community at large.

5.1.2.6 Implementation

As shown in the box for 'Implementation' in Figure 5-1, the next steps in the cycle of applying the asset management process are to:

- complete the treatment selection process (i.e. choosing which type of chipseal to use), and to finalise the Current Work Programme;
- carry out seal design; and
- undertake the construction.

5.1.2.7 Product Development

The item 'Product Development' on Figure 5-1 indicates that the industry is developing new products to more efficiently meet the asset management objectives. These products are based on analysis of the performance of seals currently specified, and how well they meet the objectives of the asset management process.

5.2 Pavement Management Principles

5.2.1 Systems for Treatment Selection

The principal objective of any Pavement Management System (PMS) is to enable the asset manager to optimise the level of maintenance expenditure required to achieve the level of service specified by the Road Controlling Authority (RCA). This objective can be achieved through an understanding of how the pavement and surfacing of any given roading asset is performing at a particular point in time. Through this understanding, the asset manager is able to maximise the level of service being provided to the road user while minimising the whole-of-life cost to the RCA.

With the significant advancement that has occurred with the application of computerised database technology, quick and efficient analysis of the immense amount of data collected about the condition of roads is now possible. These analytical techniques enable the asset manager to produce Exception Reports.

Exception Reports, as the name suggests, report the assets which are performing below the required level of service and are therefore 'exceptions' to an otherwise compliant network. Exception Reports greatly assist in identifying pavement sections that are performing poorly but have not yet fallen below the required level of service. These sections can then be programmed for treatment just before the level of service falls below the prescribed level. Their usefulness in relation to layer instability is discussed in Section 6.5.6, and layer instability analysis is covered in Section 6.5.5.

The principal repository of this information for most roading networks in New Zealand is the RAMM (Road Assessment and Maintenance Management) database, which can summarise all the inventory and condition information useful to the asset manager.

5.2.2 Inventory of Assets and Condition Data

The inventory of physical assets and the condition of these (both current and historical) is a key feature of any asset management system. Such inventories not only form the basis for inputs that will drive the optimisation process, but also provide data to the seal designer who uses it to select the most appropriate design and identify any risks associated with alternatives. It is imperative that, soon after chipsealing operations, the accurate as-built data of the newly sealed roads or pavement sections are fed back into the inventory.

Through relatively simple manipulation of the condition data, Exception Reports can be provided which indicate how sections of pavement are performing in terms of accumulated maintenance costs, roughness, rutting, texture, skid resistance (from high speed data capture surveys), cracking (from RAMM rating surveys), and accident data. By analysing data from previous surveys a trend analysis can predict when a pre-defined threshold level of service may be passed, enabling treatment to be programmed in a timely manner.

Although the information drawn from RAMM is exceedingly useful for the development of a robust and stable Forward Works Programme, the programme is always historical and limited to describing the current, or at best probable, condition of the pavement and surfacing within the next one to two years. RAMM outputs cannot predict the condition of the asset in five, ten or twenty years from now, and this is the information that is required by RCAs for the robust financial management of their networks and the development of long-term Asset Management Plans.

5.2.3 Intelligent Treatment Identification Systems

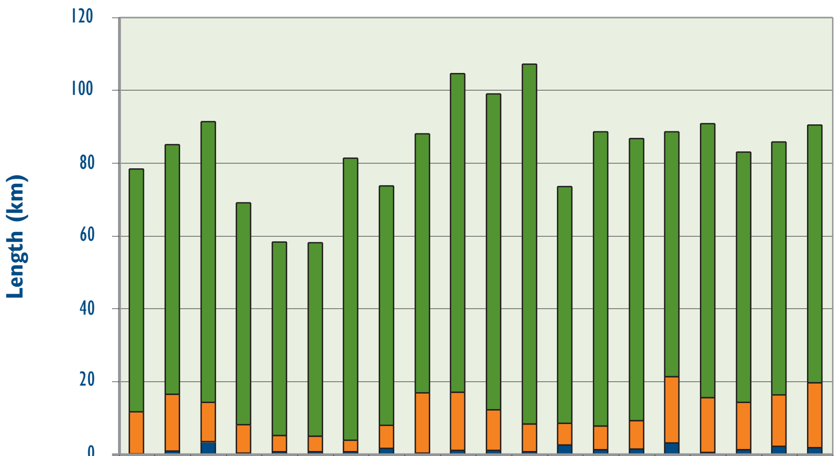
Significant advances have been made in the field of pavement deterioration modelling which has the capability of selecting future treatments based upon deterioration models. The first of these is the Treatment Selection Algorithm, a computer program within RAMM, developed to directly utilise the condition information maintained within the RAMM database. This program is capable of selecting the next pavement treatment, subject to prescribed economic constraints but is currently limited in its ability to be easily calibrated to match the actual performance of pavements over the range of climatic, geographic and traffic loading conditions that exist across New Zealand. The Treatment Selection Algorithm does not have any medium- or long-term predictive capability. Its principal function is to assist with identifying short-term needs based on current surface condition.

More recently, significant effort has gone into the development of predictive pavement deterioration models using sophisticated stand-alone software (e.g. dTIMS[1]), which is able to produce treatment selections that are well aligned with the treatments selected by experienced asset managers. These predictive modelling tools use historical performance data to predict the decline of current condition to produce medium- to long-term forecasts of intervention needs and, by analysing an extensive array of options, to make firm recommendations on optimal strategies. With access to accurate inventory and condition data held in the RAMM database, along with a programme of on-going calibration, these

1 dTIMS – Deighton's Total Infrastructure Management System software program, used for predictive modelling.

models are now capable of accurately selecting economically optimised treatments for Forward Works Programmes extending out to twenty years from the present. Figure 5-2 shows an example of predicted network requirements for the next 20 years.

However all the systems described above are only tools developed to assist the asset manager. They serve to complement but are never likely to entirely replace the engineering judgement that is required at the end to facilitate the most appropriate treatment selection for a length of pavement.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Resurfacing	67	68	77	61	53	53	78	66	71	87	87	99	65	81	77	67	75	69	70	71
Smoothing	11	16	11	8	4	4	3	6	17	16	11	8	6	6	8	18	15	13	14	18
Strengthening	0	1	3	0	1	1	1	2	0	1	1	1	2	1	2	3	1	1	2	2

Year

Figure 5-2 Model prediction of network work requirements for the next 20 years (i.e. 2003-2022) for one Transit NZ region (Hawke's Bay).

Definitions:

Resurfacing: Reseals and thin asphaltic surfacings (km)

Smoothing: Pavement treatments to reduce roughness (usually asphaltic concrete) (km)

Strengthening: Pavement treatments to increase strength (usually rehabilitation by overlays, stabilisation, or reconstruction) (km)

5.2.4 The Forward Works Programme

The outputs from the pavement deterioration model must be captured in a proposed programme, as mentioned in Section 5.1.2.5. Most asset management systems require the management of a ten-year Forward Works Programme for maintenance activities and indeed this is a requirement of the Local Government Act and for documentation required by Transfund New Zealand[2] that will be used to support funding requests.

[2] Transfund New Zealand is now Land Transport New Zealand, from 2004.

The software application known as NOMAD[3], and available as part of the RAMM software, provides an electronic method of storing and maintaining the Forward Works Programme.

The intent is that the programme should be reviewed on an ongoing basis and at least annually, using the tools provided by the pavement deterioration model as an input to assist the practitioner to find the most optimal programme. Following the review process, a commitment should be made to adopting the programme.

5.2.5 Reactive and Proactive Maintenance

The asset management principles will typically result in most treatments being applied in a proactive manner, as a 'stitch in time'. An experienced practitioner will be needed to carry out some form of needs-assessment or review against expected pre-treatment service level, and make adjustments (advancement or deferral of works) based on actual performance. The objective is to minimise the extent of reactive (unplanned) maintenance resulting from unpredicted performance.

Pavement deterioration models generally cannot be told about upcoming major capital works, e.g. a road realignment. They may predict work needed on a treatment length that is soon to go out of service, so such items need to be identified and data fed in so the programme can be adjusted.

5.2.6 Risk Assessment and Management

Risk assessment and risk management are essential road asset management considerations. The outcomes of the Forward Works Programme need to be reviewed in terms of risk, and equally, risk should be considered at the individual treatment level. It may be entirely appropriate to review individual treatments or indeed the entire whole-of-life strategy for a treatment length, based on risk disclosed at the design or construction stage that was not appreciated at the planning stage.

Therefore maintaining open dialogue is essential between design, construction and asset management teams if unforeseen or underestimated risk potential becomes apparent. For example, unexpected soft pavements or other factors may be found that can affect long-term pavement and surfacing performance.

[3] NOMAD – National Optimisation of Maintenance Allocation by Decade

5.2.7 Impact of the Committed Programme

Once future treatments have been selected for a given section of road, these will then define what strategies should be applied by the contractors responsible for the routine maintenance of the pavement and surfacing.

These maintenance intervention strategies prescribe in detail how the maintenance contractor should be scheduling the reactive repairs in response to either the next programmed treatment or, in some cases, in response to the most recently completed treatment. These strategies are developed by the asset manager to ensure that the most cost-effective reactive treatment is applied and that the routine maintenance work does not conflict with the obligations of other contractors working on that part of the roading network.

As an example of such a strategy, treatment lengths of road programmed for resealing in the coming financial year are identified with a code that defines that they are within one year of a reseal. The maintenance contractor is thus alerted to pay specific attention to the pre-reseal and drainage needs of this section of pavement for at least a year (and in some cases longer) in advance of constructing the reseal.

This approach ensures that the section of pavement to be resealed will be presented to the resealing contractor in the best possible condition, and should either eliminate, or at least significantly reduce, the extent of pre-reseal repairs that might otherwise be required immediately in advance of the reseal. This in turn will maximise the efficiency of the resealing programme by minimising unscheduled delays, and a better surface will result as the pre-seal repairs will have had time to 'settle down' before the reseal.

The flow chart on the Chapter 5 frontispiece was developed to identify sections of pavement that are to be resurfaced in accordance with TNZ P/17:2002, *Performance-based specification for bituminous reseals*. This is an 'end result' specification that requires the new reseal to meet or exceed a prescribed level of texture 12 months after construction. According to this specification the resealing contractor also carries the responsibility for maintaining the new seal for a 12-month period after construction. With this contractual obligation in place, a pavement maintenance contractor would not intervene for either premature flushing or chip loss during this 12-month maintenance period, as the liability

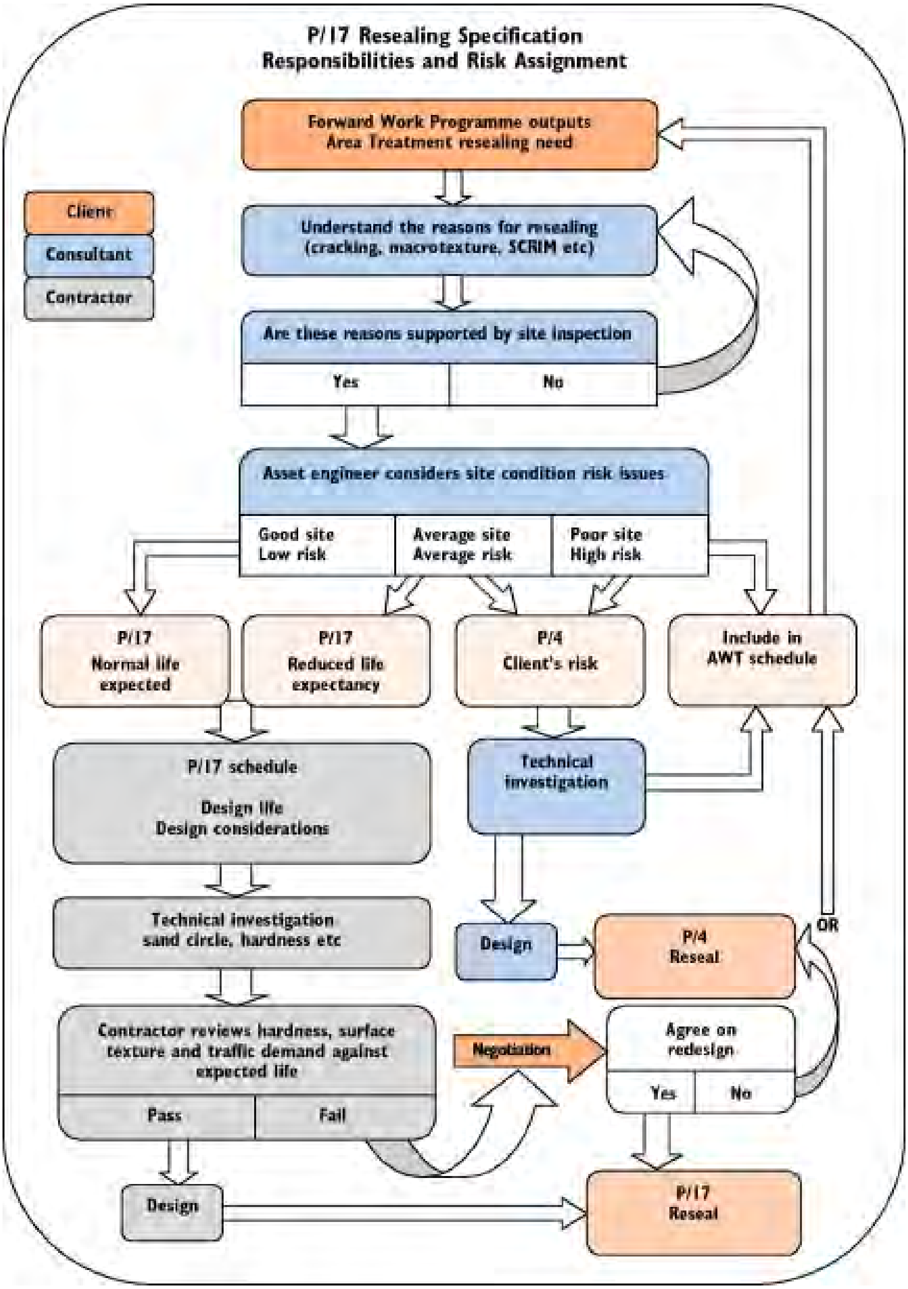


Figure 5-3 Flow chart showing resealing specification responsibilities and risk assignment, based on TNZ P/17 specification.

5

for such remedial work lies with the resealing contractor. Any such intervention could compromise planned maintenance by the resealing contractor as well as the assessment of texture achieved at the end of the 12-month maintenance period.

Other strategies may involve deferring routine maintenance work on lengths programmed for short-term pavement treatment works. The level of service on such lengths may be allowed to deteriorate in the time leading up to the planned treatments, providing of course that traffic safety is not compromised.

The primary objective that needs to be achieved through the development of these strategies, and the maintenance contractors' alignment with them, is an assurance that the lowest whole-of-life maintenance options are always being applied. Achieving this objective ensures that an economic balance between the reactive and proactive approaches to the management of the pavement is being maintained at the network level.

5.3 Life Cycle Impacts on Seal Design

5.3.1 Selection of Economic Seal Design

To select an appropriate surface for a site, a balance is required between not only the engineering needs for extending the life of seals and appropriate treatments and the associated costs, but also for safety reasons, skid resistance requirements, vehicle operating costs, community, environmental and aesthetic requirements (Section 6.10). Skid resistance considerations are discussed in Section 4.9 where the need for higher macrotexture levels in high speed environments is discussed. Other safety considerations include spray suppression and roadmarking contrast in wet weather. Many of these factors are discussed in the Austroads *Guide to the selection of road surfacings* (2000).

A range of other considerations also needs to be taken into account before the final surfacing is selected.

If the decision is to be based solely on the cost to the RCA, then the ratio of expected life from an alternative treatment to the expected life of a chipseal, as shown in Figure 5-4, can be used. In this figure the net present value (NPV) of the increased costs of a number of alternative surfacings have been discounted at 10%. Comparing a chipseal with an expected life of 6 years to an alternative treatment with an expected life of 20 years, it shows that the ratio of the cost of the alternative must not be more than twice that of the seal, or the treatment will not be economic.

In New Zealand, a dense asphaltic concrete surfacing will typically be 4 to 5 times the cost of a chipseal and will last 10 to 15 years. Figure 5-4 shows that this alternative surfacing would be economic only if the chipseal life was less than 2 years, a situation which can occur on high stress areas where a chipseal can fail rapidly.

From an RCA perspective, the extra cost of an alternative surfacing needs to be balanced against the benefits that will be given to the road users. The RCA needs to determine the conditions under which the road users will be prepared to pay extra for a more expensive treatment.

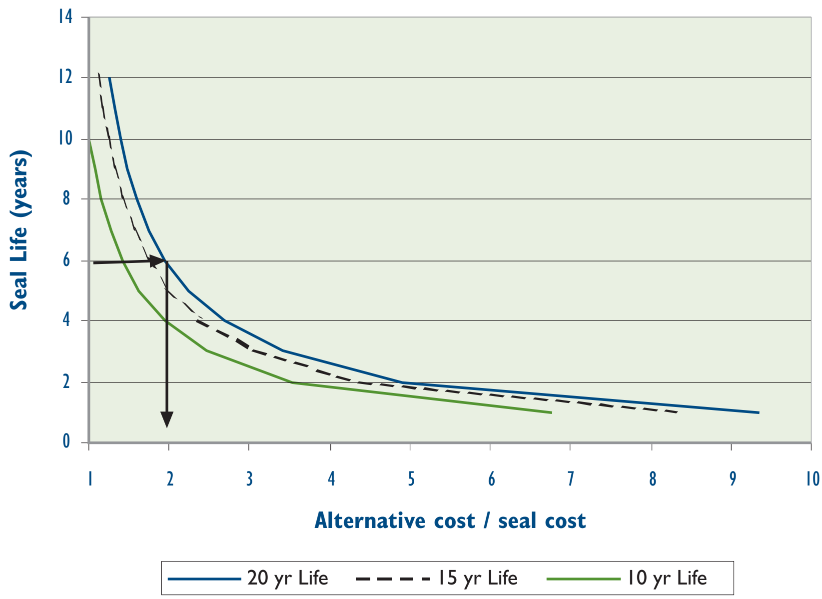


Figure 5-4 Ratio of the cost of the alternative treatment to that of a chipseal (based on a net discounted value of 10%).

The seal designer must apply engineering judgement and consider all these factors when selecting the next treatment, while also considering the economics of the treatment options. The designer must also be aware of the potential impact the next treatment will have on the overall pavement life cycle, and should always aim to maximise the time before the next major investment in the pavement becomes necessary.

5.3.2 Pavement Lives

The expected lives of the proposed resurfacing treatment need to be understood by the seal designer. While tables of default lifetimes exist, more recent studies undertaken on the performance of a wide range of seal types have enabled the design life of a reseal to be calculated as follows.

For single coat seals:

$$\mathbf{Yd = 4.916 + 1.68\,ALD - (1.03 + 0.219\,ALD)\log_{10} elv} \quad \text{Equation 5-1}$$

For multicoat seals:

$$\mathbf{Yd = 14.87 + ALD - 3.719\log_{10} elv} \quad \text{Equation 5-2}$$

where: Yd = Design Life (years)

elv = equivalent light vehicles/lane/day (v/l/d)

ALD = average least dimension (mm) of the sealing chip used

For multicoat seals the larger chip ALD is to be used. To calculate elv, the following equation can be used.

5

$$\mathbf{elv = \frac{AADT}{No.\ of\ lanes} \times \frac{(1 + 9\,(HCV))}{100}} \quad \text{Equation 5-3}$$

where: AADT = annual average daily traffic on the section of road

HCV = percentage of heavy commercial vehicles

The above equations are useful for predicting the life of the seal based on the parameters of chip ALD and traffic loading. Where traffic loading is very low (less than 50 v/l/d) the design values may indicate an unrealistically long seal life. Other factors will influence the actual life that will be achieved. In particular they are the stresses applied to the seal on tight bends, steep gradients and intersections; the condition of the existing surface and pavement to be sealed over; the loss of skid resistance; and the stability of the existing surface layers.

Taking all these other factors into account along with an understanding of how long the existing surface has lasted (compared to its design life 'Yd') will enable the seal designer to determine the expected life of the new reseal.

By evaluating the expected life and construction cost for each of the applicable resurfacing options, the designer can then compare and select the lowest cost option by calculating the present value costs for each one. Where the actual or predicted growth in maintenance costs is also known over time for the treatment length under consideration, these costs should be discounted and included in the total present value sum.

A worked example is given opposite.

Worked Example:

Site Conditions:

AADT (annual average daily traffic):	2500
HCV (heavy commercial vehicles):	8%
Number of lanes:	2
elv (equivalent light vehicles):	2150
Site length:	1000 m
Age of existing surface at the time of resealing:	6 years
Design life of existing surface (Yd):	8 years
Declining seal cycle life:	evident
Reason for sealing:	existing surface flush
Drainage:	no problems evident

Technically Feasible Resealing Option	ALD (mm)	Cost per km NZ$	Design Life Yd (yr)	Reduced Design Life (yr)
Grade 3 single coat seal	8.75	35,000	9.8	7
Grade 2/4 two coat	10.75	60,000	13.2	10

The reduced design life for each option is assessed as 0.75 × Yd to reflect that the last surface lasted only 75% of its design life.

Further reductions may be appropriate if the stability of the existing surface is doubtful or if the stresses from traffic loading are likely to lead to chip polishing and the loss of skid resistance.

Using the Reduced Design Life, a Present Value factor (for a 10% per annum discount rate) can be chosen.

Resealing Option	Resealing Present Value Factor	Present Value of Future Reseal Costs NZ$/km
Grade 3 single coat seal	0.5131	NZ$35,000 x 0.5131 = $17,960
Grade 2/4 two coat	0.3855	NZ$60,000 x 0.3855 = $23,130

The Grade 3 single coat seal is therefore the lowest cost option, assuming that the future cost of the next treatment will be equivalent to the current cost for each option.

Figure 5-5 shows a typical pavement life cycle, beginning with a new pavement construction. Over time the condition of the new pavement and surfacing declines as a result of traffic and environmental factors.

As the condition of the pavement declines and cost of routine reactive maintenance increases, a point is reached where the lowest whole-of-life cost (typically in terms of a 25-year economic view) is achieved by undertaking a full-width (of road) Area-Wide Pavement Treatment (AWPT) in preference to continuing with reactive patch repairs. The timing of these area-wide treatments is tested using a Present Value analysis to compare the Present Value costs of continuing with the reactive repairs with the Present Value costs of the area-wide treatment. Where the investment in the pavement through the AWPT shows a Net Present Value (NPV) saving compared to continued reactive maintenance, then this will result in the lowest whole-of-life pavement cost being achieved.

One or more AWPT may be undertaken before the pavement condition and accumulated maintenance costs reach a point where a complete rebuild or replacement of the pavement becomes necessary. This full rebuild is usually justified through a Benefit/Cost analysis which considers the savings achieved by avoiding the high cost of the on-going maintenance necessary to maintain an acceptable level of service, as well as the costs to the road user arising from increasing pavement roughness.

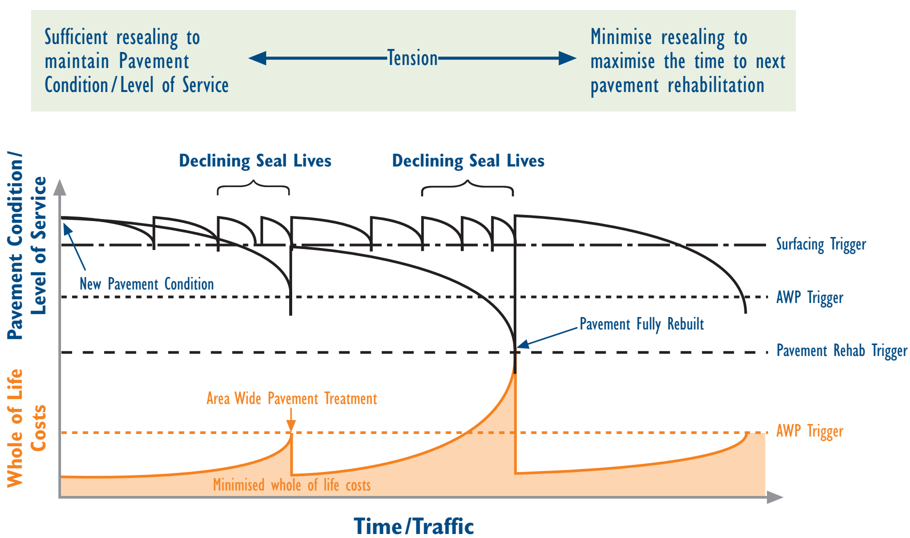


Figure 5-5 The pavement surfacing life cycle.

Typically the AWPT or full pavement rebuild destroys all the existing seal layers, and a new surfacing life cycle thus begins at this point.

Resealing should be programmed when the condition of the pavement surface falls below prescribed limits for texture, skid resistance or a lack of adequate pavement waterproofing (e.g. when surface cracking becomes evident).

5.3.3 End of Pavement-Life Cycle Considerations

Testing the resealing economics becomes increasingly important as the life of each subsequent reseal becomes shorter, and the instability of the existing surface increases. See discussion on shortening seal lives and layer instability in Section 4.7.4.2.

The last reseal in advance of an expected AWPT or pavement rehabilitation will only be economic if the seal designer is confident that, by applying this reseal, the next pavement treatment will be deferred long enough to ensure the Present Value savings of this deferral will exceed the Present Value costs of the reseal.

Example: Reseal versus Area-wide Pavement Treatment

If the average cost of a reseal is *$38,000 per km, and the cost of the next AWPT is estimated to be $150,000 per km, then for this example, pavement treatment would have to be deferred by at least 4 years for this reseal to be economic.

Using the Present Worth factor (Transfund NZ 1997) at a 10% Discount Rate at year 4 of 0.6830, then ($150,000 – (0.6830 × $150,000)) = $47,550 per km.
This means that, by deferring this pavement investment for 4 years, a Present Value saving is made that exceeds the Present Value cost of the reseal.

The 4-year life of the reseal is not likely to be achieved because of a history of shortened seal lives on the site caused by rapid flushing, the development of shallow shears through surface instability, or accelerated deterioration of the underlying pavement. Therefore the lowest whole-of-life option is to bring forward the AWPT in place of the reseal treatment.

* $ are NZ$.

5.3.4 Unscheduled Resurfacing Needs

In certain conditions, a road may need urgent action to improve safety. For example, a road that is severely flushed will have insufficient macrotexture in the wheelpaths for an open road speed (>70km/h) environment. In warm weather, the binder bleeds and both the macrotexture and the microtexture of the surfacing chip are masked by bitumen. This can result in a very slippery surface in damp conditions, and in hot weather the excess bitumen can adhere to tyres, allowing 'chunks' of the surface to be plucked out and carried or tracked on.

In such situations consideration of life cycle efficiencies is obviously overridden by the need to restore safety. However, asset managers must avoid adopting a quick fix solution which may turn out to be totally inadequate in the medium to long term. For example, covering the surface with a reseal to restore the skid resistance may provide short-term restoration of texture and skid resistance, but this has been proven in many cases to cause premature flushing and so make the long-term skid resistance worse.

Repair of unexpected chip loss from new seals which may occur after the first frost of winter, as well as other unscheduled repairs, are covered in Chapters 7 and 12.

5.3.5 Timing of Resurfacing

Programming of reseals is subject to many variables, e.g. time of year and seasonal constraints, completion of preparation works, economic constraints and environmental constraints. Resealing too frequently can waste large amounts of money but also can result in unstable and unsafe road surfaces. On the other hand, delaying too long may result in serious skid-resistance deficiencies and extensive pavement damage, both of which are even more expensive to rectify.

5.4 References

Austroads. 2000. Guide to the selection of road surfacings. *Austroads Publication No. AP-63/00*. 82pp. Austroads, Sydney, NSW.

National Asset Management Steering (NAMS) Group. 1996. *New Zealand Infrastructure Asset Management Manual*. Ingenium (Association of Local Government Engineering NZ Inc.), Thames, New Zealand.

Transfund New Zealand. 1997. Programme and funding manual. Edition 1. *Transfund New Zealand Manual Number: PF/1.*

Transit New Zealand. 2002. Performance-based specification for bituminous reseals. *TNZ P/17:2002.*

easons for resealing

NZ TRANSPORT AGENCY
WAKA KOTAHI

ntroduction

he purpose of this note is to rationalise the current *Reasons for resealing* to ensure accurate reporting and nalysis. Currently there is duplication within *Reasons for resealing* recorded in RAMM, and many codes are nclear, ambiguous or do not apply to chipsealing.

ategories

ase use only the following *Reasons for resealing* for annual planning spreadsheets, RAMM records and NOMA e the following pages for further details on each category.

ategory	RAMM Code	Comment	Chip-sealing	Thin AC
econd oat	SE	A second coat is a reseal over the top of a first coat seal.	Yes	No
ushing	FL	Includes all resealing required due to loss of macrotexture.	Yes	Yes
racking	CR	Includes all cracks that may allow water ingress to the underlying pavement.	Yes	Yes
olished	PS	Failure of the surfacing material where traffic stress polishes the surfacing aggregate below acceptable levels of skid resistance (not just low SC or ESC. See Further details on following pages).	Yes	Yes
cabbing	**SC**	Scabbing as a failure mechanism in an old chipseal where the binder fails and chip is lost due to the increased hardness and brittleness of the bitumen.	Yes	No
avelling	RA	Loss of chip from an asphaltic concrete or a slurry surface. It occurs where the binder has oxidised and is losing its grip on the surfacing aggregate.	No	Yes
olding eal	HS	A chipseal constructed in an attempt to extend the life of a failed pavement for a short period.	Yes	No
pecial urfacings	SS	All surfacings where the reason clearly does not fit into any other category. Full reasons are required.	Yes	Yes

ategory and RAMM code	Comment	Notes
econd coat, SE  	A second coat is a reseal over the top of a first coat seal. It is designed to ensure the surface is waterproof and durable.	Includes: • second coats over a first coat • second coats over a pavement repair or permanent surface to complete a repair. Note: There is already a function callec first coat. Note: Not to be used with thin AC. Use special surfacings, SS.
ushing, FL 	Flushing includes all resealing required due to loss of macrotexture.	Flushing is the natural end of life condition for most chipseals. Any bleeding shows the chipseal is flushed. Includes: • all causes of loss of macrotexture • flushing due to unstable surface. The reason flushing should be used where the chipseal addresses flushing on any portion of the pavement width, eg a combination chipseal which uses sandwich seal in the wheel paths and a voidfill seal outside the wheel paths in the un-trafficked areas.
racking, CR 	Includes all cracks that may allow water ingress to the underlying pavement.	Includes: • cracking of surfacing • cracks around pavement repairs • potholes. Chipseals will crack if: • pavement deflections are excessiv • bitumen is very old, oxidised, hard and brittle. Chipseals may be designed to accommodate large pavement deflections and surfacing strains. The reason for resealing fits into the category cracking where the chipseal expected to have a reasonable life. The category holding seal should be used when a chipseal is applied as a short term holding strategy before major works.

	the surfacing material where traffic stress polishes the surfacing aggregate below acceptable levels of skid resistance. All causes of polishing are included.	surfacing must have low skid resistanc and meet the following criteria: 1. For chipseals macrotexture > 1.0 m MPD. Note: If texture is < 1.0 mm, use flushing, FL. 2. The proposed resurfacing must us an aggregate with a higher polishi resistance and be expected to provide skid resistance above the investigatory level for the design li of the surfacing.
cabbing, SC 	Scabbing as a failure mechanism in an old chipseal (typically aged > 10 years old) where the binder fails and chip is lost due to the increased hardness and brittleness of the bitumen.	Scabbing relates to all chip loss not attributable to a construction failure. I. when initial scabbing occurs > 12 mont after chipseal construction. Note: Where initial chip loss occurs < months after chipseal construction, us special surfacings. Note: Not to be used with thin AC. Use ravelling, RA.
avelling 	Loss of chip from an asphaltic concrete or a slurry surface. It occurs where the binder has oxidised and is losing its grip on the surfacing aggregate.	Note: Not to be used with chipsealing. Use scabbing, SC.
olding seal, HS 	A chipseal constructed in an attempt to extend the life of a failed pavement for a short period.	The chipseal will not be included in chipseal life statistics. Note: A reseal will not fix a pavement failure. The reason for resealing fits into the category cracking where the chipseal expected to have a reasonable life. The category holding seal should be used when a chipseal is applied as a short term holding strategy before ma works. Note: Not to be used with thin AC.

	the reason clearly does not fit any other category. Full reasons are required.	• traffic threshold (approaches to urban areas) • urban issues (noise etc) • damage (eg spillage on the road, f on road, gouging) • high skid resistance and location specific treatments (eg bolidt, calcined bauxite) • rumble strips (as part of a traffic threshold) • where specialist chipsealing techniques are used to rut fill whe paths but the remainder of the surfacing width is not resealed.

ategories not allowed

e following categories, currently in use, are not allowed in the future:

- aged
- birthday seal
- brittle binder (use cracking or scabbing)
- condition
- skid resistance (must use either flushed or polished)
- stress
- traffic volumes (use special surfacing)
- urban issues (use special surfacing).

ultiple reasons

there are multiple reasons, record only the dominant *Reason for resealing.* Generally this would be expected either flushing or scabbing.

CHAPTER SIX

Chipseal Selection

Previous page: A chipseal in use on State Highway 1 just north of Kaikoura. Mt Manakau (2610 m), high point of the Seaward Kaikoura Range in the background.

Photo courtesy of Terry Hann, Wreford Hann Photography Ltd

Chapter 6 Chipseal Selection

Chapter 6 Chipseal Selection

6.1 Principles of Chipseal Selection

The success of a chipseal does not depend solely on the design of the seal. As important is the selection of the appropriate seal type for the pavement in the context of the sealing history of that pavement. Figure 6-1 shows the sequence that, in general, should be followed for selecting a typical New Zealand pavement, i.e. a flexible granular pavement constructed of layers of unbound granular aggregate, with a thin surfacing that is either a chipseal or a thin asphaltic concrete.

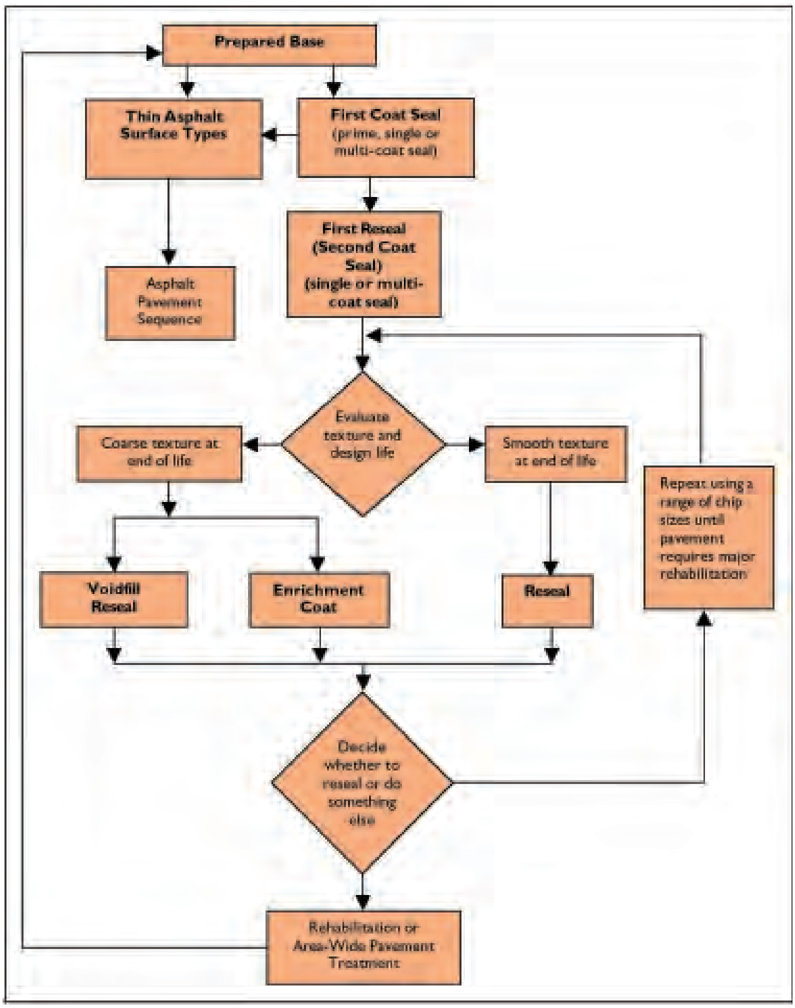


Figure 6-1 Standard sealing sequence for a typical flexible granular pavement used in New Zealand.

The seal types introduced in Chapter 3 are presented in summary form in Table 6-1, which was developed by a representative group from Transit, Local Authorities, Consultants and Contractors. The issues considered are those arising on a straight road with low traffic volumes (e.g. 1000 AADT).

Table 6-1 Summary of seal types used in New Zealand to compensate for engineering issues arising on straight roads with low traffic volumes (e.g. 1000 AADT).

Seal Type	First Coat	Reseal	Urban/ Rural/ Residential	Risk Index High/Med/ Low	Cost Index	Life Cycle Expectations Short/Med /Long	Notes
Single coats *	Y	Y	Y – caution in Urban	H – Urban L – Rural M to H – Residential	Low	Medium	
Two coats *	Y	Y	Y	L – Rural M – Residential H – Urban	High	Long	
Racked-in seals *	Y (warning for high rainfall areas)	Y	Y	Ditto	Medium	Long	
Sandwich seals *	N	Y	Y	M	Medium	Medium	
Voidfill seals *	N	Y	Y	L	Low	Short	
Wet lock seals*	N	Y	Y	H	High	Short	Short life, as high binder to stone ratio
Dry lock seals *	Y*	Y*	Y	L	Medium	Medium	
Fog Coats / Rejuvenating / Enrichment seals *	N	Y	Y – caution for skid resistance, trafficking	M	Low	Short	
Slurry seals *	N	Y	Y	M	High	Medium	
SAM seals *	N	Y	Y	H	High	Medium	
Cape seals *	N	Y	Y	M	High	Long	Cutters and embedment issues 1st coat
Geotextile seals *	Y (over soft bases)	Y	Y	H	High	Medium	
Special skid-resistant seals *	N	N	Y	M	High	Unknown	
Asphaltic concrete *	N	N	N	N	N	N	Not used on low volume roads

* See Chapter 3 for details of seal types H – high; M – medium; L – low; N – no; Y – yes

As defined in Section 3.3, thin asphaltic mix or thin chipseal surfacings are less than 45 mm thick over a flexible granular base, while thick rigid pavements constructed of structural asphalt are generally 110 mm or greater in thickness.

Structural asphalt and concrete pavements may require a chipseal, thin asphaltic surfacing, or some other surfacing on top to improve skid resistance and waterproofing, or to resist surface deterioration. The same general principles apply to seals on rigid pavements as to seals in flexible granular pavements, with some modifications to the seal designs as noted in Chapter 9.

6.2 First Coat Treatments

As discussed in Chapter 3, the first treatment for a granular pavement or overlay serves principally to prepare the base for the main treatment. It will normally be a first coat seal but occasionally a prime coat. The main function is to ensure a good bond between the larger aggregate in the base and the surfacing. To achieve this it is essential that any surface dust layer is penetrated or 'wet through' by a low-viscosity bitumen-based binder that can adhere firmly to the underlying stone.

> A prime coat has very low viscosity and is used to wet the aggregate, whereas a first coat seal must be considerably more viscous as it also must hold a layer of chip in place.

In many cases, a thin layer of asphaltic mix on its own is not waterproof enough to seal the pavement, especially where full compaction cannot be achieved because of a soft base or difficult laying conditions. Modification of the mix design can compensate for these difficulties and improve waterproofness. A waterproofing treatment such as a first coat seal or prime coat under the hot mix should be used with caution. The bitumen in a first coat seal will heat up when hot mix is applied to it, and then may migrate up into the thin layers of asphalt. This bitumen can saturate the mix (decreasing the % of air voids) leading to shoving and rutting (defects which are explained in Section 3.11).

Single seal coat applications on granular bases are not thick or waterproof enough to provide a durable surfacing under medium and high traffic volumes. They can fail very quickly once the first symptoms of distress appear, and if failure occurs over winter they can be extremely expensive to repair. Also such repairs will rarely be satisfactory.

Some practitioners consider two single coats will be more waterproof than applying the same amount of binder in one single coat.

After the first treatment to the base has been made, a second coat seal is applied to enhance the waterproofness of the surface. This surface will typically be durable and last for 8 to 15 years depending on the chip size and traffic volumes. At the end of this life, the next step in the surfacing life cycle will typically be a voidfill or reseal, although occasionally under very low traffic levels an enrichment coat is applied.

The cycle will continue (as discussed in Chapter 5) until the pavement requires rehabilitation because either:

- the build-up of seals has resulted in an unstable surface so that an economic life is not obtained, or
- the pavement has failed structurally.

The maintenance of even texture and prevention of flushing caused by later layer instability can be best achieved by alternating reseals of the standard with the voidfill or texturising type.

6.2.1 First Coat Seals

6

The first coat and second coat reseal treatments are essentially a part of the pavement construction or major rehabilitation process, and their programming is linked to the programming of the pavement works. However seals constructed in winter conditions have a much higher risk of early failure than those constructed in warmer drier periods.

Figure 6-2 A first coat seal is laid on the highway around Tauranga Harbour, Bay of Plenty. The distributor (right) is laying the binder, followed by the chip spreader (reversing over the chips newly laid on the binder). Rolling to compact the chips into the binder will follow. Photo courtesy of Philip Muir, Works Infrastructure

This risk can be mitigated to some extent by using processes and materials (such as bitumen-bound basecourse and precoated chip, etc.) specifically designed to counter the risk of early failure. Further discussion on how to prepare for a first coat seal and minimise early failures is covered in Chapter 7.

For most higher traffic volume highways, first coat seals (Figure 6-2) can be expected to survive only a single winter. In parts of New Zealand where climates are extreme, the preference may be to lay a first coat in spring as early as the basecourse can be prepared and dried out, and then to reseal it with a second coat towards the end of the construction season. Alternatively in these areas, a 'two-coat as a first-coat' seal may be a better choice.

On low volume roads, the first coat (whether a single or two coat seal) may be expected to last much longer. Construction of a second coat should be programmed based on observations of the seal surface.

6.2.2 Options for First Coat Seals

The four most commonly used treatments, in decreasing order of cost, are:

1. Seal with Grade 4 chip, followed the next year by a Grade 3 reseal.
2. Seal with Grade 3, followed the next year by a Grade 5 or 6 voidfill.
3. Seal with a two-coat Grade 3/5.
4. Seal with Grade 3.

1. ***Seal with Grade 4, followed the next year by a Grade 3 reseal***

This option has been the traditional system used on highways with high traffic levels in New Zealand. However, if the existing texture is expected to be too coarse at reseal time to meet the criteria set out in Section 9.8.5, option 2 is preferred. Where significant traffic stress levels are a problem, a two-coat seal (option 3) is better.

2. ***Seal with Grade 3, followed the next year by a Grade 5 or 6 voidfill***

For roads with medium to heavy traffic, this option is preferable to option 1 especially where experience has shown that a Grade 4 would generally give too coarse a texture after one or two years.

3. ***Seal with a two-coat Grade 3/5***

This option is considered as having an equivalent life to option 2, but provides better traffic stress resistance in the period soon after construction.

4. ***Seal with Grade 3***

This option is often used on lightly trafficked roads where failure caused by water ingress is not considered to be a high risk and where traffic stresses are few.

Options 2, 3 and 4 are not given any further seal coats until macrotexture loss or other distress indicates that they are warranted.

6.2.3 Prime Coats

A prime coat, in the road pavement context, is the application of a low viscosity cut-back bituminous material (primer) to a prepared granular base to promote a good adhesive bond between the surfacing and the base. Good adhesion of a conventional first coat seal to a granular base is normally obtained by reducing the viscosity of the binder to replicate some of a primer's characteristics. However this reduction in viscosity compromises binder cohesive strength and lengthens curing time. This is normally a problem that can be managed with careful traffic control and by timing with respect to weather and temperature conditions.

The option of a prime coat and then second coat seal is not encouraged in New Zealand or recommended for normal use because of the following three main disadvantages:

- *Safety.* Cutback primers contain a high proportion of volatile cutter which increases flammability risk during transport and application. Such a safety hazard is one of the many reasons that primers are not recommended for use in New Zealand.
- *Weather Limitations.* Damp, cold conditions inhibit the penetrating action of a primer and can dramatically increase curing times. Strong winds can cause spray drift.
- *Pollution risks.* Rain can wash uncured primer off a surface.

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However, some distinct advantages are gained through the use of prime coats in certain circumstances, especially on 'greenfield' sites where the above risks are more easily controlled. A prime coat does not have to hold chip in place so it can be tailor-made to achieve the best possible bond to the basecourse surface. Its application rate is low, so some practitioners consider that a prime coat can give a superior surface for a second coat seal[1] or thin asphalt surfacing to adhere to, at a lower cost than a first coat seal.

Safety and temperature limitations, to some extent, may be overcome with the use of special proprietary emulsified primers.

6.3 Pretreatment Seals

Many pretreatments can be used to prepare a surface before resealing, as it is important to reduce any texture variation that has arisen during its life. This is called texturising and many methods of texturising are available, e.g. texturising seals, but some options do not include sealing (e.g. water blasting or other high pressure water treatments to reinstate texture: see Section 7.3.4.2).

[1] The first chipseal on top of a prime coat is called a 'second coat seal' because the prime coat itself acts as the 'first coat'.

6.4 Reseals

6.4.1 Second Coat Seals

Applying a second coat seal (reseal) over the first coat provides a thick durable layer. It is essential to give a first coat seal enough trafficking before a reseal is applied. If this is not done, the first coat may continue to compact after the second coat is laid and the result will be serious flushing. Usually second coat reseals are applied after at least six months of warm weather trafficking, in order to give the new pavement time to 'settle down' and for the seal to compact.

If a prime coat has been used, the second coat reseal should be applied as soon as practical after the prime coat has cured.

The selection of the type of second coat seal should be determined at the time of pavement design.

6.4.2 Enrichment Seals

These are a light application of binder, with no chip applied, and usually sprayed over an ageing coarse-textured chipseal, as referred to in Section 3.10.1. The binders used are usually emulsions with low bitumen contents.

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They are used to:

- Rejuvenate or enrich an existing seal coat;
- Rejuvenate old very coarse seals, often in low traffic environments where the texture is still coarse, the chip is still in good condition, but the binder is becoming brittle and chip loss is beginning to occur;
- Prevent chip loss in new seals where binder has been significantly under-applied.

These rejuvenating seals are a cost-effective solution to maintaining sound coarse-textured surfacings in need of waterproofing, or more binder, or where surfacings are showing signs of failure caused by brittle binder. In the past they have been applied to chipsealed airport runways or lightly trafficked roads, but are seldom used in New Zealand on highly trafficked pavements because they create surfaces with low skid resistance.

Where appropriate, the application of a rejuvenating seal (i.e. no chip applied) can extend the life of the surfacing by maintaining the original coarse texture. If an enrichment coat is used, the skid resistance will be temporarily reduced because a very low viscosity binder is present on the upper surfaces of the larger chips. Traffic speed restrictions must remain in place until this residue is worn off and the skid resistance rises to acceptable levels.

6.4.3 Investigations for Treatment Selection

For reasons of cost and practicality, the preliminary condition survey (Section 5.1.2.4) (an input to the Forward Works and the Current Work Programmes (Section 5.1.2.5)) is not very detailed. A much more thorough investigation is required before committing to the expensive resurfacing process, and greater detail is also required to select and then to design the treatment (Section 5.1.2.6). For this reason the asset manager will prepare a list of candidate sites for sealing from the Forward Works Programme that is longer than the expected Current Work Programme. The process of detailed investigation of the candidate sections can be expected to refine the priorities in the list, and the programme is then adjusted accordingly. The detailed investigation of the condition of the pavement must also include the basic causes of any distress before any decision is made on how to treat the surface. The detailed inspection of the surface will determine if the sample measured in the condition survey really reflects the current condition.

Obviously the causes of any unacceptable pavement performance (that are not related just to the ageing of the seal) must be properly rectified before resealing, or they will simply continue to operate and will decrease the service life of the new seal as well (e.g. defects which cause flushing).

The detailed investigation and the treatment selection process must be carried out well in advance of the seal design process so that the necessary pavement and drainage repairs can be completed in enough time to allow the necessary curing and compaction of the repairs.

The final seal design process may raise further issues such as excessive texture variation or hardness variation between repair patches and the surrounding surface which may, in turn, lead to a further adjustment to the intended programme. An example is a reduction in binder application rate to compensate for a soft underlying surface.

Any significant defects should be repaired as part of the maintenance regime. Sections which are significantly improved by repairs and candidate sections which are not of high priority may be scheduled for resealing at a later time. Timing of repairs is discussed further in Chapter 7.

6.5 Seal Selection and Engineering Issues

The selection of the seal type and chip (treatment selection) is one of the most important aspects of chipsealing. In the past the choice was associated only with the size of chip to use in a single coat seal. Now a large number of seal types are available and the choice of treatment is based not solely on engineering decisions but also on cost, safety, environmental and user preferences (see Sections 6.6 to 6.10).

Figure 6-3 gives a flow chart of the basic engineering decisions that need to be made. The sealing sequence given in Figure 6-1 and the flow chart in Figure 6-3 are designed to guard against using a succession of seals having the same or similar chip size which would increase the chance of layer instability.

The flow chart is designed to be used in the following way.

1. Review the available condition data for the surface which requires resealing.

The four main conditions of the existing seal that affect the choice of treatment are:

- flushing or unstable seal, smooth-textured surfaces;
- loss of skid resistance, low macrotexture;
- cracked surfaces;
- highly stressed surfaces.

2. Start at the top left box of the flow chart (Figure 6-3), follow the arrows down and to the right.
3. Answer the questions (green boxes) which expand on the nature of the condition of the seal.
4. The flow chart will lead to the suggested treatment for the situation at hand (orange boxes).

6.5.1 Flushing or Smooth Textured Pavement Surfaces

Flushing can be the expected end-of-life condition of a seal especially under heavier traffic. If flushing as an end-of-seal-life condition has occurred, then the answer to the first question in the flow chart (Figure 6-3) would be “No”. However, if premature flushing has occurred, the answer is “Yes”.

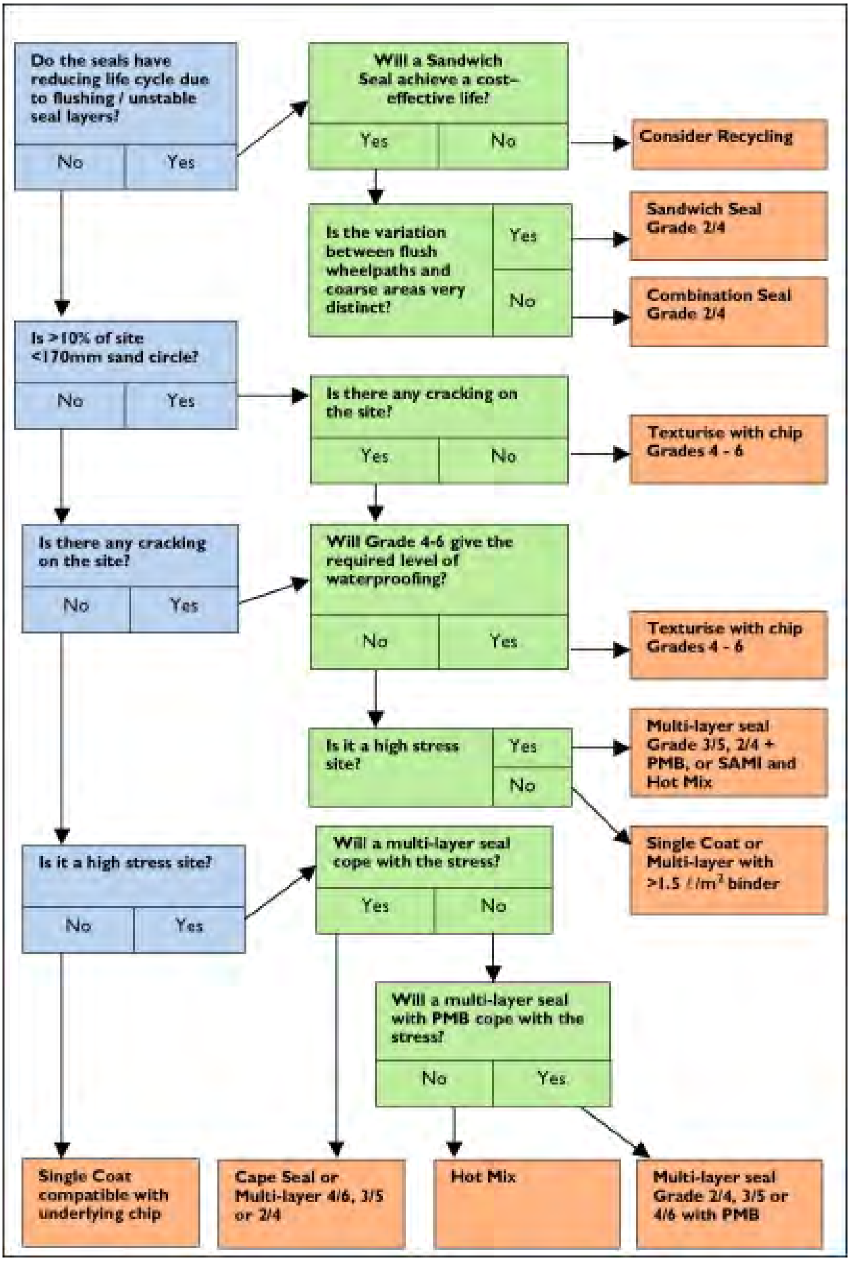

Figure 6-3 Flow chart and decision tree for deciding on a reseal.

6.5.2 Coarse Textured Pavement Surfaces

The standard New Zealand practice has been to apply a voidfill seal where the texture measured by the sand circle diameter (explained in Chapter 9) is less than 170 mm. This is to guard against obtaining a high binder:stone ratio and also to add a smaller chip to increase the chip interlock in the seal layer and shear strength of the surface.

Small chip can fit into the surface voids of a coarse-textured existing sealed surface, rather than bridging them as would a larger chip. The result is called a voidfill seal (described in Section 3.7.9). The chip chosen is usually Grade 6, although Grade 5 can be used provided that, after rolling, it does not project above the tops of the chip of the existing seal. As the binder requirement for a voidfill seal is less affected by variations in underlying texture, this seal can be applied over a variable coarse surface to reduce the variation in macrotexture. The texture of this new surface is quite independent of the original surface. If used appropriately, voidfill seals can prevent cumulative development of uneven texture.

Since the surface voids of the underlying existing chipseal are largely filled with chip instead of binder, the 'mix' of layered seals will have a lower binder content and be far more stable. Thus the chance of embedment of subsequent seals is greatly reduced. However voidfill seals must not be applied to flushed or bleeding wheelpaths as this will tend to exacerbate the problem.

Where the binder has become brittle and the risk of chip loss is likely, the existing chip usually stands well proud of the binder. A voidfill is an ideal treatment in this situation. Frequently voidfills need to be applied in adverse winter weather conditions under considerable traffic. In such conditions, a Grade 6 chip with an emulsion binder is usually the most suitable combination. (Bituminous emulsion can have superior adhesion qualities in damp and cold conditions, but it must be tailor-made to provide a fast enough break-time.)

A Grade 6 voidfill coat is often resealed within 2 years if the traffic density is high, because the macrotexture of the reseal has reduced to the extent that flushing is imminent.

Much better service life can be achieved if the voidfill is applied to coarse areas one to two years before the condition of the old seal demands a reseal. Used in that way the voidfill chip can interlock well with the remaining texture, and the voidfill seal is not required to bridge extensive cracking. Such early intervention can enable a larger chip to be used, such as Grade 5 or even 4. In this case a good waterproof surface can be maintained for 4 to 5 years, giving a much more economical result. For best results, the size of voidfill chip should be determined to find the largest chip size that will properly interlock with the original texture and yet not increase the texture depth.

6.5.3 Cracked Pavement Surfaces

As discussed in Chapter 4, cracking is one of the main end-of-life conditions for a chipseal. Once a chipseal is cracked, water can enter the lower layers of a pavement and cause damage. Cracking is generally repaired by resealing, though chipseals using polymer modified binders (PMBs) called SAMs (Stress Absorbing Membranes) are also used, and crack filling is another option. More information is given in Chapter 7 and Section 8.4.

(a) Crack Filling

Where pavement cracking is not extensive, crack filling or bandaging can be used to repair it, as described in Section 7.3.3.1.

(b) SAM or SAMI (Stress Absorbing Membrane Interlayer) Seals

Where pavement cracking has become so extensive that crack filling is not an economic option, or the cracks are narrow but extensive and cannot be filled with a normal chipseal with a higher bitumen application rate, the use of a PMB (e.g. in a SAM, or SAMI) or a geotextile seal can be an economic alternative to reconstruction. Filling the wider cracks before the membrane is applied is recommended.

(c) Chipsealing

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Where cracking is hairline (<1 mm wide) and affects less than 5% of the pavement, the repair is simply a normal reseal using chipseal with a chip size that gives a binder application rate of greater than 1.5 ℓ/m^2.

6.5.4 Stressed Pavement Surfaces

Pavement surfaces fail on corners, intersections and steep gradients where the high stresses are caused by braking or turning traffic. If severe enough, traffic stresses can tear out chips from the chipseal surface and the surface then rapidly loses its integrity.

These high stress sites can be divided into those that are associated with:

- Cornering;
- Braking and slow-speed turning.

In practice the seal designer would inspect the site in order to assess the stress levels (always assuming a sound substrate), and could increase or decrease the classifications for cornering, braking and turning based on site-specific conditions.

6.5.4.1 *Cornering*

High stress corners can be rated 1 to 6 according to the advisory speed, supplemented by the gradient, as proposed in the following classification (Table 6-2).

Table 6-2 Classification for stress rating on corners.

Gradient (%)	Advisory Speed (km/h)			
	<30	30-50	50-70	>70
<5	4	3	2	1
5-10	5	4	3	2
>10	6	5	4	3

In this classification, the lower the number, the lower the stress on the site, so that a classification of 1 implies that the stress is very low and the section is flat and relatively straight.

The number of heavy commercial vehicles (HCVs) would affect the ranking because HCVs with multiple axle groupings or spaced axle trailers can cause additional shear forces (often called 'tyre scrub') by the non-steering wheels being partially dragged around turns. This effect is exacerbated where speeds are low.

6.5.4.2 *Braking and Turning*

Braking and turning areas which may require specialised treatment include:

- Roundabouts;
- Intersections;
- Commercial driveways (in industrial areas);
- Railway crossings;
- Pedestrian crossings.

Using the same rating system of 1 to 6 as for cornering, but based on traffic volume per lane per day (HCV/l/day), the following classification (Table 6-3) is proposed.

Table 6-3 Classification for stress rating for braking and turning areas.

Number HCV/l/day	Roundabout	Intersection	Commercial Driveway	Railway Crossing	Pedestrian Crossing
<20	5	3	5	2	2
20-50	6	5	6	3	4
>50	6	6	6	4	4

Again the comments regarding tyre scrub generated by HCVs apply here, and in all cases, the rating should be adjusted accordingly to account for this.

6.5.4.3 Ranking of Seal Strength for Stressed Sites

Table 6-4 shows an approximate ranking of the resistance of the different seal types against the shear stresses of turning and braking traffic.

The use of polymers in the binder will usually not affect the stability of the chipseal as much as a change in seal type, and will usually cost a little more than the next most expensive option in the list in Table 6-4. Other options to improve the stability of the chipseal, such as the use of less cutter or more stiff binders, along with precoated or heated chips, and active traffic control, are effective and may be more economical.

Table 6-4 Approximate ranking of seal types according to their surfacing strengths.

Strength		Seal Type			Price
	↓	Single Chipseal		↓	
	↓	Dry Lock		↓	
Increasing Shear	↓	Racked-in Seal		↓	
Strength	↓	Two Coat Seal	Slurry Seal	↓	Increasing Price
	↓	Cape Seal	Polymer Slurry Seal	↓	
	↓	Dense Asphalt	Open Graded Porous Asphalt	↓	

The ranking shown in Table 6-4 is not hard and fast because performance depends critically on design, construction, and the weather during and after construction. For example, a single coat chipseal that has been well designed and constructed, and laid in the most favourable season, may outperform a poorly constructed dense graded asphalt. This makes it difficult to set absolute rules about when to use the different types of seal.

When considering the sealing of high stress parts of a road, the relative economy of changing seal types versus carrying out the operation in the most favourable part of the sealing season should be carefully considered. This simpler remedy may be all that is needed. Additional traffic control to direct slowly moving vehicles over the fresh seal, and to move the traffic stream gradually across the entire width of the seal to aid compaction, is usually very cost-effective. However the costs of traffic delays must be considered.

Within each seal type, smaller chip tends to be less adversely affected by traffic shear forces than larger chip. This is more pronounced for single than for multicoat seals.

In addition, the nature of traffic stresses has a very strong influence, so that single coat chipseals may perform very well on very steep grades and tight curves if traffic is low to moderate. However under heavier traffic and higher stresses, a single coat chipseal generally cannot be expected to perform.

6.5.5 Layer Instability

6.5.5.1 Introduction

Analysis of the failure mode of a surfacing for which layer instability (described in Section 4.7.4.2) is suspected, is best described by introducing the concept of binder:stone ratio (Gray & Hart 2003).

However, awareness is currently limited to a pragmatic understanding of the limits of the binder:stone ratio in the layer which is most susceptible to layer instability.

Current best practice suggests that, when the cumulative chipseal layer depth exceeds 40 mm and the binder:stone ratio approaches 12% by weight of binder, sealing practitioners should be alerted to the possible presence of layer instability.

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They should approach the seal design process for that particular pavement section with caution. For incremental steps above the 12% trigger, different treatment options should be used, each of which are focused on lowering the binder:stone ratio.

The suggested 12% trigger value does not equate precisely to the point at which concern over the stability of an asphaltic mix would arise. However, the chip properties (e.g. grading) that are present in multiple chipseal layers differ somewhat to those that would be present in an asphaltic concrete mix design (Asphalt Institute 1997).

The 12% trigger has been derived through analysis of pavements where flushing is present and layer instability was found to be a contributing factor. This empirical trigger was based on extensive analysis of flushed pavements in the Hawke's Bay area between 1995 and 2003 (Gray & Hart 2003). These factors and triggers may however be different in different climatic conditions.

6.5.5.2 Identification of Failure Mode

A generic model has been developed to assist with the identification of candidate treatment lengths for technical analysis with regard to possible layer instability, against the above criteria (see box in Section 6.5.5.1). This model poses the following questions for a candidate length:

- Is flushing a failure mode?
- Is loss of texture rapid and/or premature?
- Was flushing evident before the previous resurfacing?
- Was the life of previously applied reseals getting shorter, and reducing after each successive treatment (referred to as a 'pinching reseal cycle': as in Figure 5-5)?

If affirmative answers to the above questions predominate, consideration should be given to taking a core sample of the layer for technical analysis. This core is analysed against the layer depth and binder:stone ratio criteria. A core will also allow the underlying layer material types and thicknesses to be established.

6.5.5.3 Treatment Options

Options suggested for the treatment of surfacings where layer instability is identified as a failure mechanism are focused on modifying the binder:stone ratio of the layer. Unless this is effectively corrected, normal performance cannot be expected from any conventional reseal applied to the flushed surface.

Obviously different treatment options will influence the binder:stone ratio to different extents. Although not proposed as the definitive and complete list of treatment options, the following typical treatments give an indication of the degree of correction that can be expected and the suggested application of these.

Where the layer depth is greater than 40 mm, and the measured binder:stone ratio is:

- *Around 12% or less by weight*

  The risk of layer instability becoming a problem is low. If flushing is present, conventional treatments designed to remove surplus bitumen should be considered in favour of covering the excess binder with further reseals. Otherwise, if buried by a new chipseal, the excess binder will contribute to future layer instability. Water blasting or other high pressure water treatment is a common suitable treatment.

- *Between 12% and 15% by weight*

  The risk of layer instability resulting in premature failure of a subsequent reseal is a possibility. At this level, treatments designed to reduce the binder:stone ratio become necessary, e.g. water blasting or other high pressure water treatment (to reduce the binder content), or hot chip (to increase the chip content). Generally, applying cutters to enhance the take of fresh chip is not desirable because the diluents may permanently affect the viscosity of the binder near the surface and accelerate deterioration of the layer.

- *Between 15% and 20% by weight*

The risk of failure is high, and any treatments must target a significant correction. The sandwich seal treatment was designed for application in such areas. A layer of Grade 2 chip is applied dry to the existing surface, followed by a low application of bitumen to retain a Grade 4 wet lock seal. Applications of bitumen between the Grades 2 and 4 layers at rates as low as 0.8–1.0 ℓ/m² are being achieved.

This surfacing treatment is proving very durable, is being applied in high demand locations with good success, and obviously provides a significant correction to the binder:stone ratio (i.e. much new chip, very little bitumen). Further, the layer has significant potential to absorb any fresh free bitumen rising to the surface before flushing becomes an issue again. In an urban environment a Grade 3/5 sandwich seal may be a more appropriate solution from an environmental or social perspective.

- *Above 20% by weight*

Experience is proving that an entire layer with more than 20% by weight binder:stone ratio needs treatment. Options include a granular overlay, pavement rehabilitation or recycling.

Recycling was developed as a technique designed to mix the existing surfacing layers with the underlying basecourse plus additional material, e.g. extra aggregate and a small amount of cement (between 2% to 3%) before applying a fresh first coat surfacing. This is essentially converting the existing pavement, including unstable multiple chipseal layers, into a bitumen-stabilised basecourse.

If undertaking conventional reconstruction or overlay however, care should be taken when burying the existing layer with only a thin depth of overlay material, as the structurally unstable layer may continue to deform and shear under the shallow overlay depth. Further information on the recycling process is found in the paper by Gray & Hart (2003).

6.5.5.4 Analytical Representation

These site identification techniques and treatment options are summarised in the decision-making flow chart of Figure 6-4.

6.5.6 Exception Reporting

Exception Reports, as the name suggests and introduced in Section 5.2.1, report the assets which are performing below the required level of service and are therefore 'exceptions' to an otherwise compliant network. Exception reports greatly assist in identifying pavement sections that are performing poorly but have not yet fallen below the required level of service. These sections can then be programmed for treatment just before the level of service falls below the prescribed level. Their usefulness in relation to layer instability is discussed here.

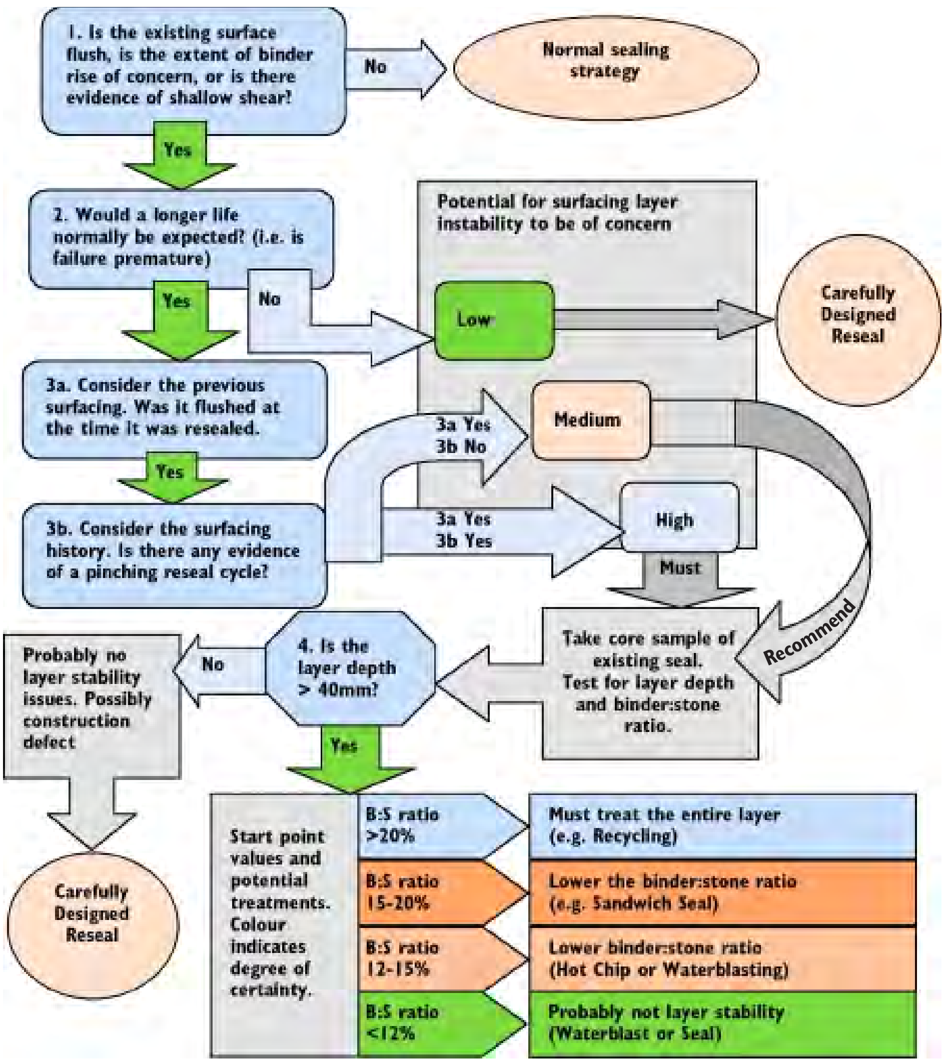

Figure 6-4 Decision-making flow chart for treatment selection analysis.

Reasonable success with the identification of potential layer instability sites has been achieved using exception reporting from the RAMM database. For example, the RAMM database contains the following information at a treatment length level:

- Presence of flushing: easily interpreted from condition data.
- Premature failure: RAMM can report on the expected seal life at a generic level (Table 4-4 lists the default seal lives). RAMM also contains data for each reseal where the 'expected life' field has been updated.
- Reduction in texture depth: when texture depth reduces by 0.3 mm per year or more between annual high speed data surveys.
- Shortening (pinching) reseal cycle: treatment lengths are flagged by RAMM where the life of each successive reseal is reducing.
- Flushing before the last reseal: interpreted from historical surfacing and condition data.

6.6 Seal Selection and Road User Safety

The safety of the road user is an important consideration when selecting the appropriate chipseal or treatment. Skid resistance and the complementary topic of texture depth is crucial to a safe surface and is dealt with in some detail below and in Section 4.9. How skid resistance is affected by frost and ice is considered in Section 6.8. Other road user safety factors are touched on in this Section 6.6, particularly water spray and roadmarking contrast.

6.6.1 Skid Resistance

6.6.1.1 Relationship Between Skid Resistance and Crashes

As discussed in Section 4.9, raising the skid resistance of the road surface decreases the rate of wet skidding crashes. Also different sites present different risks (as explained in Section 4.9.2).

> If skid resistance is below the Investigatory Level (Table 4-5) as defined in TNZ T/10, or any other safety-related defect is observed, some type of remedial treatment must be applied promptly.

Road surfaces requiring high levels of skid resistance are normally associated with high levels of traffic stress. The PSV of the chip and the minimum texture depths need to be considered, and that means some surfaces cannot be used for the open road, e.g. Type 3 slurries (as they are not coarse textured enough for high traffic volume roads).

In deciding on the treatment that should be used, available sources of chip having high PSV need to be considered. Under high traffic loading, normal sealing chip may polish very quickly, and then special treatments using artificial chip (e.g. calcined bauxite) need to be used. These treatments are at least ten times more expensive than a normal chipseal but are becoming more common in New Zealand to achieve the safety benefits of adequate skid resistance.

Where failed surfacings or high stress situations occur, a chip with a proven on-road performance in similarly stressed situations should be used.

6.6.1.2 Treatment Selection for Skid Resistance

Site Assessment

For the state highway network an Exception Report (see Sections 5.2.1 and 6.5.6) is compiled to record all sites that have a skid resistance of >0.1 SFC (Sideway Friction Coefficient) below the Investigatory Level (IL). These sites are assessed to programme them for treatment and, as is always important in treatment selection, the assessment includes a site investigation as well as an inspection of the survey results to make a treatment selection decision.

If the investigation shows no reason to doubt the survey results and the site is below the Investigatory Level, then a treatment to improve the skid resistance should be considered. If the maintenance treatment cannot be applied because of weather restrictions (e.g. too late in the sealing season), then temporary signs (e.g. 'slippery when wet') to warn the motorist may be appropriate.

If, after investigating the site and reviewing all the site data, some uncertainty exists with the result of the survey data, the results need to be confirmed (by re-testing). Often a SCRIM machine is not available for this type of work, and in this situation other available skid testers could be considered, e.g. British Pendulum Tester (BPT), GripTester, Norsemeter RoAR (see Figure 4-22).

Although the correlation between these machines and the SCRIM is not ideal, testing may be undertaken in the area under investigation and in an adjacent area that complies with the Investigatory Levels, as a comparative test (Figure 6-5).

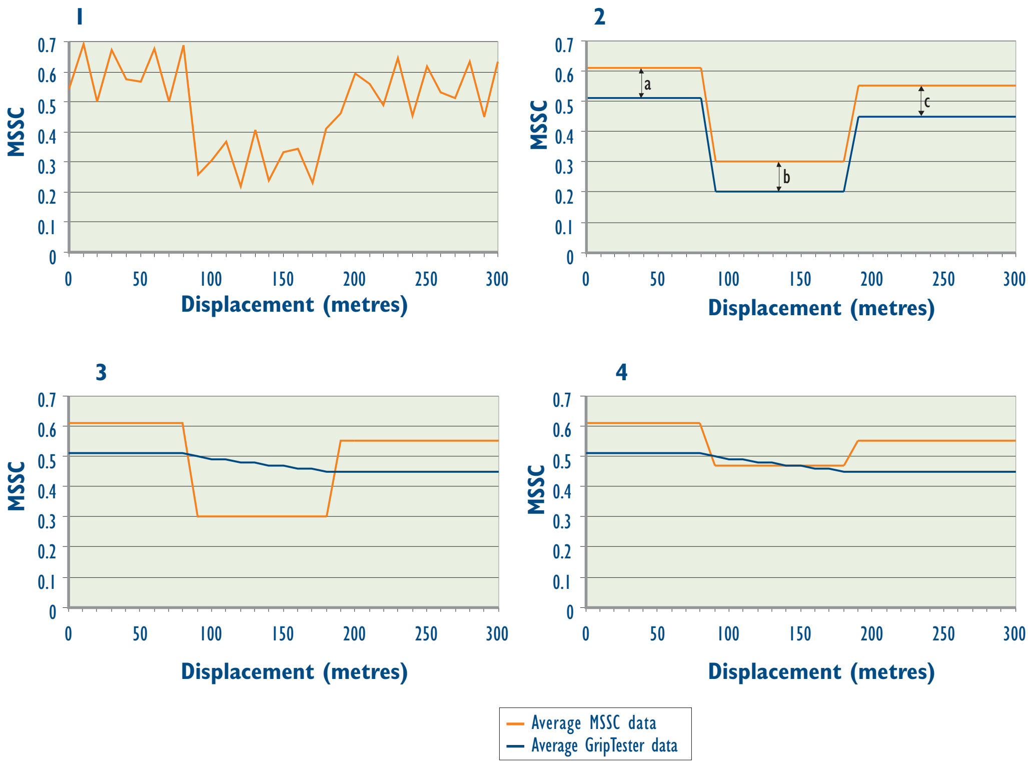

Figure 6-5 Comparative tests using a different skid tester where some uncertainty exists in the SCRIM data.

1. A non-complying section of SCRIM data between 100 to 180 m displacement of chipseal along the road.
2. A test run with the GripTester. If a ≈ b ≈ c, then non-complying section is a permanent condition and SCRIM is correct. Take action to fix defect.
3. This test run shows that the non-complying section is a temporary situation, and no action is needed.
4. If only the non-complying section had been tested, it would have been impossible to tell if the condition was temporary or permanent.

If the results from the additional skid tests indicate that the skid resistance of the surface is likely to be below the Investigatory Level, the data should be included with other factors in producing the Current Work Programme for resealing. This produces a proactive skid policy and not simply a reaction to skid-related crashes. This proactive strategy, and the alternative, a reactive skid resistance strategy, are outlined in the Austroads *Guidelines for the management of road surface skid resistance* (2005).

If the investigation confirms that the site is below the Investigatory Level and there is sufficient texture depth, the surfacing aggregate on the existing pavement should be evaluated to determine if the low SCRIM value is to be expected or not.

To assess if the aggregate's skid resistance properties are performing on the road as they should, use the PSV equation from TNZ T/10:

$$\mathbf{PSV = 100 \times SFC + Q \times 0.00663 + 2.6} \qquad \text{Equation 6-1}$$

where:

SFC is the ESC (Equilibrium SCRIM Coefficient, as per TNZ T/10) (see Table 4-5) required;

Q is the commercial vehicles per lane per day (> 3.5 tonne).

This equation can be re-arranged to:

$$\mathbf{SFC = \frac{(PSV - (Q \times 0.00663 + 2.6))}{100}} \qquad \text{Equation 6-2}$$

Thus by putting the PSV of the chip that is in service on the road and the commercial vehicles in the equation, the calculated SFC can be obtained and compared with the measured SFC.

If there is no significant difference between the calculated value for SFC from Equation 6-2 and the survey results, the results can be considered 'expected'.

If the difference is significant between the calculated and measured SFC value, then the result would be considered 'unexpected'.

It is important that, when selecting a chip for the resurfacing, it has the required PSV. Although the PSV test is probably the best method available to illustrate how a chip will polish in service, a number of variables such as weathering, size of chip, angularity, traffic stress, etc., are not taken into account in the PSV Equation 6-1. Thus the relationship between PSV and SFC in Equation 6-1 should be regarded as merely indicative.

Where skid resistance problems have been experienced, and this necessitates a new surfacing, the materials chosen should have a proven on-road skid performance in similarly stressed situations.

In cases where the PSV equation indicated that the chip should have given the appropriate SFC, yet has fallen short, there could be additional stresses acting on the site.

Using the constant in the PSV equation as a stress factor can compensate for these additional stresses.

Hence the PSV equation can be displayed as:

$$\mathbf{PSV = 100 \times SFC + Q \times 0.00663 + stress\ factor} \qquad \text{Equation 6-3}$$

Stress factors not accounted for in the equation include:

- gradient,
- curvature relative to travel speed, e.g. 80 km/h design curves on open roads,
- braking zones, e.g. approaches to intersections,
- on and off ramps,
- acceleration zones,
- intersections, turning areas, roundabouts.

Some research has indicated that the PSV equation is not as accurate as was once believed. However, it is still the best estimate available but should be used with caution.

6

6.6.1.3 Example Calculation Using the Stress Factor

Site Details:

Commercial vehicles:	=	200 per lane per day
PSV from test:	=	50
SCRIM survey result:	=	0.42
Site Category:	=	2 (from Table 4-5)

Steps:

1. Using the re-arranged equation, calculate if survey result is expected:

$$\mathbf{SFC} = \frac{(\mathbf{PSV} - (\mathbf{Q} \times 0.00663 + 2.6))}{100}$$

$$\mathbf{SFC} = \frac{(50 - (200 \times 0.00663 + 2.6))}{100}$$

$$\mathbf{SFC} = \mathbf{0.46}$$

Thus the survey result is unexpected since the survey result is 0.42 and the calculated result is 0.46.

Even if the chip performed as the PSV dictated, the SFC value is still too low since the SFC requirement for a category 2 site is 0.5.

2. Determine the in-situ PSV for the chip by using the SCRIM survey result as the SFC in the equation:

$$\mathbf{PSV = 100 \times SFC + Q \times 0.00663 + 2.6}$$

$$\mathbf{PSV = 100 \times 0.42 + Q \times 0.00663 + 2.6}$$

$$\mathbf{PSV = 46}$$

Even though the chip has a measured PSV of 50, it is only providing skid resistance equivalent to that of a chip with PSV = 46 due to the stress at the location.

3. Determine the stress factor by calculating the difference between **actual PSV** and **in-situ PSV**:

Stress factor = (50 – 46) + 2.6
Stress factor = 6.6

4. Use the stress factor in the PSV equation to determine the required PSV at this particular site:

For Site Category 2, the required ESC is 0.5 (Table 4-5).

Therefore the PSV required is:

$$\mathbf{PSV = 100 \times 0.5 + 200 \times 0.00663 + 6.6}$$

$$\mathbf{= 58}$$

Therefore the PSV required:

- to take into account the additional stress at the location and
- to provide an SFC of 0.5

  is **58**

6.6.2 Water Spray

Another aspect to consider in addition to skid resistance, when selecting seals to improve road safety, is water spray. Water spray needs to be minimised so that drivers can see where they are going when following taller heavy vehicles (trucks) which can generate heavy sprays of water in wet weather.

The amount of water spray is directly related to road camber and the quantity of water, and inversely related to texture depth and porosity of the surface, i.e. greater texture depth will reduce water spray, as will greater porosity.

Although the minimum texture depths required for skid resistance also assist in minimising spray from heavy vehicles, a higher degree of spray suppression can be required on some lengths of road. These may be areas where heavy vehicles are passed and clear visibility is required, as for example on passing lanes and divided carriageways (Figure 6-6). An increase in the texture depth (more than the minimum required) through the use of a large chip or alternatively the use of OGPA (open-graded porous asphalt) should be considered.

Figure 6-6 A chipseal on climbing lanes where high speed traffic passes heavy vehicles.

Photo courtesy of Allen Browne, Opus

6.6.3 Roadmarking Contrast

Another aspect of road safety is delineation. Delineation is achieved through roadmarking, edgemarker posts, reflectorised raised pavement markers (RRPMs), and other visual cues, e.g. chevron boards, guardrails, and sight rails.

Visibility of road markings on wet nights can be a problem on pavements with low texture depth, especially on dense graded asphaltic concrete. In deciding on a surfacing treatment this problem needs to be considered, especially in urban areas.

Although a Road Controlling Authority (RCA) may have a policy that allows a lower texture depth than specified in TNZ T/10, the safety aspects of wet-night visibility need to be considered. Safety aspects can weight the decision towards high-texture surfacing treatments in urban areas and in other areas where high traffic volume means delineation in wet-night conditions is important.

Alternatively, specialised delineation treatments can be applied to areas of dense graded asphaltic concrete to ensure wet-night visibility. Options include specially textured thermoplastic markings, or thicker applications of roadmarking paint that incorporate larger sized glass beads. Information is available from the NZ Roadmarkers Federation on the selection of roadmarkings (NZRF 2004) and from their website: www.nzrf.co.nz/docs/MaterialsGuide0404.pdf

6.7 Seal Selection for Bridge Decks

A bridge is a structure specially designed to cross a gap in the road network, usually over drainage systems. The bridge decks have to withstand high stresses, and are generally constructed of rigid materials which means they require special consideration when selecting the appropriate treatment for sealing them. For more information see Bridge Inspection and Maintenance Manual (Transit NZ 2001).

> Because of their special design requirements the regional bridge engineer should always be consulted for advice and input by the surfacings engineer in charge of maintaining and re-sealing the roads in that region.

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The construction and materials of the bridge deck determine the kinds of surfacings and treatments that can be applied to it. For example, some culverts for drainage systems (Figure 6-7) form part of the roadway, and the pavement runs straight across them, e.g.

Figure 6-7 An example of a culvert with a high fill. In this case, design of the pavement and surfacing are as for a conventional subgrade (see Section 3.3).

Photo courtesy of Frank McGuire, Transit NZ over corrugated steel culverts and concrete box culverts. In these cases the surface treatment and its design and construction are the same as for the conventional pavement over the rest of the road. In cases where the fill over the culvert is shallow (e.g. < 1.5m) specific design is required for the pavement.

The structural capacity of the bridge is designed to sustain specific loads including the weight of the surfacing to be used. So although a thin surfacing applied to the constructed bridge deck is allowed for in the bridge design, there is a limit to the thickness and number of layers that can be added during successive maintenance treatments. Therefore before changing the surfacing of a bridge, and possibly adversely altering the loading on the bridge structure, the road surfacing engineer should consult the bridge engineer for advice.

6.7.1 Functions of Bridge Deck Surfacings

The functions of the bridge deck surfacing are to:

- accommodate and smooth out deck surface irregularities arising from construction;
- produce a trafficable surface;
- facilitate a smooth ride;
- provide a safe skid-resistant texture;
- maintain colour continuity and texture that are consistent with the approach road;
- facilitate efficient drainage of rainwater from the carriageway by co-ordinating the surfacing with kerb-side drainage channels, drain holes and scuppers;
- waterproof the deck structure;
- promote durability of the deck structure by providing additional protection to reinforcement steel for concrete decks and to steel-plated decking (this is particularly desirable if de-icing salts are likely to be used during the life of the bridge);
- provide a safe, uniform texture and aesthetic consistency with the approach road (Figure 6-8).

6.7.2 Maintenance of Bridge Decks

While the rationale for maintenance for many of the various surface treatments which apply to road pavements can also apply to bridge deck surfacings, special conditions do arise. Several types of surfacing defects are typically only associated with bridge decks, and include:

- delamination of the wearing surface from the deck substrate;
- erosion at deck joints;
- differential settlement and surface discontinuities at abutments (see Figure 6-10).

Figure 6-8 An approach road that is consistent with the bridge deck surfacing.

Photo courtesy of Frank McGuire, Transit NZ

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Rectification of these defects requires specific treatments that are not usually provided in routine surfacing operations for roads. As a consequence the bridge engineer must be consulted for their design input before specifying and undertaking a maintenance treatment for a bridge deck.

Another example is a bridge surface that requires scarifying before resurfacing, when care is required to:

- ensure that scarification does not go deeper than the surfacing;
- avoid eroding the permanent part of the deck;
- avoid interfering with the steel reinforcement; and
- avoid reducing both the concrete cover and the structural load-bearing capacity of the bridge.

6.7.3 Selection of Surfacings

The service life of a bridge surfacing is likely to be longer as the substrate is uniform and stiff compared to the flexible surfacing for the approaches. The end-of-life for the bridge surfacing is usually dictated by either embrittlement of binder or cracking.

Normally the approaches can be chipsealed and matched to the surfacing used on the bridge, but a reseal of the adjacent road does not necessarily mean the bridge should also be resealed at the same time.

Multiple seals can result in excessive surfacing thickness at transverse features, e.g. joints, and must be applied carefully so they are kept at fixed elevations.

Other deck types, such as orthotropic steel plate deck, give rise to problems in developing adequate adhesion between the steel substrate and the surfacing interface, to the extent that chipseals are not an appropriate surfacing. These deck surfaces (e.g. steel deck in an orthotropic plate span) do not have enough surface texture for chipseals to lock on to and they may delaminate. For these surfaces special bridge overlays are employed.

Selecting chip size and bitumen application rates are as for a conventional chipseal and other relevant guidance appropriate for a bridge deck surfacing is covered in Section 9.8.6.

6.7.4 Surfacing Types for Bridge Decks

The focus of this book is primarily on thin bituminous chipseal surfacings, although these are only one of many types of surfaces and materials that may be employed on bridge decks.

The application of a chipseal over a bridge deck can be an effective and warranted treatment, provided that the function of the deck joints is not impaired by the intrusion of bitumen and chip, that the new surface does not compromise the structural capacity of the bridge deck to sustain traffic loads, and the bridge engineer is in agreement.

In New Zealand, bridge decks whether of concrete, steel, wood, or other materials, are usually surfaced with a range of generic surfacing materials for bridges including:

- Thin bituminous surfacing (as in a chipseal);
- Asphalt mix of thickness capable of restoring a smooth ride and a safe trafficable surface;
- Special materials, e.g. epoxy, polyurethane, bitumens modified by additives to promote adhesion at the deck–surface interface, materials resistant to solvents and chemical spills;
- Surfacings of special details, e.g. asphalt plug joints;
- Materials that promote skid resistance of the wearing surface, e.g. calcined bauxite chip;
- Geotextile seals (Figures 6-9 and 3-26) to restrict water from entering bridge joints.

The use of special treatments and materials is dictated by serviceability requirements of deck joints, differential movements at joints between original and widened parts of bridges, and by the need to provide adequate confinement at the edges of surfacings. Bruce et al. (1999) identified deck joints as the most common maintenance problem on concrete bridges. Such defects should be treated before applying a conventional surface treatment.

In special cases the surfacing is required to act integrally with the bridge deck to provide composite action and to enhance the load-bearing capacity of the bridge (e.g. the Auckland Harbour Bridge extension spans with asphaltic concrete surfacing). In these cases the addition of a simple overlay may not be appropriate.

Figure 6-9 A geotextile two coat seal being applied to a single-lane timber bridge (on State Highway 6, West Coast of South Island) to protect joints and metal parts from the effects of water.
Clockwise from top left: Laying the geotextile over hand-sprayed tack coat. Top right: Smoothing down the geotextile. Middle right: Spraying the geotextile with the binder. Bottom right: Spreading the chip over the geotextile. Bottom left: Rolling the chip onto the geotextile. Middle left: Spraying the second application of binder over the geotextile and first chip layer. The next step is to apply a second layer of chip.

Photos courtesy of Les McKenzie, Opus

6.7.5 Approach Abutment Pavement Surfacings

A key consideration at many bridge approaches is the maintenance of a smooth ride at the transition between the abutment pavement and the bridge deck surface.

Figure 6-10 Differential settlement of the earthfill at the abutment (from Transit NZ 2001).

Differential settlement of the earthfill at the abutment (e.g. settlement of slabs) relative to the deck surface is difficult to avoid even with careful design, construction and compaction of the earthworks (Figure 6-10). Therefore the bridge engineer should be consulted as the settlement may be an indicator of other structural issues requiring specific treatment.

Correcting uneven approach surfaces with basecourse hard fill and/or an asphaltic mix can best be done at the time of a surface treatment. Care is required to produce a smooth transition from the approach road across the bridge deck that is of sufficient length to ensure a smooth ride and reduce vehicle bounce.

Road users benefit from a smooth ride and there is benefit to the bridge as well, as a smooth approach reduces the dynamic loads imposed by bouncing vehicles.

6.7.6 Some Helpful Pointers to Preparing a Bridge Deck for Surfacing

- Check the deck surface for signs of structural deterioration.
- Discuss maintenance treatment options with the bridge engineer to ensure that the chosen maintenance treatment for the surfacing is appropriate.
- Check if:
  - (a) Smoothing treatment on the approaches is likely in the near future. If so, it may be appropriate to defer the deck and adjacent road reseal until approaches have been prepared.
  - (b) Maintenance and repairs to deck joints are required before chipsealing.
  - (c) Intended chip size (and any associated pretreatment) will result in unacceptable superimposed deck loads.
- Cover or mask bridge deck joints to exclude bitumen and chip from the joint before applying the chipseal or other bituminous surfacing, and clear them after the sealing has been done.
- Locate deck drains and scuppers before applying the chipseal or other bituminous surfacing, and ensure they are not blocked after the treatment.
- Check the deck surface for signs of any deterioration of the structural capacity of the deck. Cracking of a concrete bridge deck may require treatment and/or special membrane treatment to prevent water penetration or corrosion of reinforcing steel.
- Complete any necessary structural repairs to the deck surface and joints before applying bituminous surfacing.
- Timber decks can impose special requirements for a suitable flexible surfacing. They usually need a primer treatment to promote and ensure adhesion of the chipseal surfacing to the timber substrate.
- If the detail of the job is not simple, check with a bridge specialist.

6.8 Seal Selection for Frost, Ice and Snow Conditions

6.8.1 Introduction

Frost, ice and snow present a particular hazard to road users (Figure 6-11) because they dramatically reduce the skid resistance of the road surface. Of the three, frost and ice are the most hazardous as they are unexpected, because their presence is not obvious. Frost and ice can occur on short sections of New Zealand roads in winter conditions, except on roads in Northland and on most coastal highways.

Figure 6-11 Keeping traffic flowing along snow-bound and icy roads requires special chipsealing applications.
Photo courtesy of Les McKenzie, Opus

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Many influences affect the formation of ice on roads. Some are regional such as:

- location and
- climate.

However, many of these influences are highly location-specific such as:

- shading which influences radiation gain or loss;
- road surface type;
- nature of the basecourse and subgrades;
- depth to water table and moisture content of pavement layers;
- road gradient.

6.8.2 Formation of Frost and Thin Ice on Roads

Frost and ice formation occur on road surfaces that are about 0°C or less, but the reasons that the road cools down to this temperature are much more complex. The thermal properties of the road surface and base layers influence its heat-storage and heat-flow capacity (VTI 1981), while the terrain and adjacent trees influence how much sun reaches the road in the daytime. Usually the sun heats the road more than the adjacent land during daytime and, as the road has better heat-storage and heat-flow properties than the adjacent land, it cools more slowly at night (for most situations).

Frost or ice is less likely to form on a road exposed to sun compared to the adjacent land. Conversely, areas shaded from the sun all day will have no reservoir of heat and will be prone to frost or ice formation.

The important role of the base layers as a heat reservoir means the road surface has a lesser effect in reducing frost and ice formation. Dense dark-coloured asphalt surfaces are much hotter than chipseal in direct sunlight, but this difference is of little relevance in New Zealand outside the alpine regions.

The main categories of winter condition on the road identified in the Swedish research (VTI 1981) are:

- Hoar Frost (white frost);
- Ice: thick ice (several layers of ice crystals thick); thin ice or ice glaze (one layer of ice crystals); ground icing;
- Snow: loose snow, compacted snow, slush, sleet.

Hoar frost (white frost) forms when the temperature of the road is both less than 0°C and less than the dew point of the air immediately above. (The dew point is the temperature where the water-holding capacity of the air is at its limit, i.e. its relative humidity is 100%.)

Frost can form in three main types of weather, all of which are relevant to New Zealand but the first two are the most common.

- clear calm nights when radiative cooling rapidly cools the road but the air temperature is close to 0°C;
- after a cold clear night when the rising sun causes air circulation, and moist air moves above the already cold road;
- after a cold but cloudy night, the sky clears and the road rapidly cools but the air is still moist.

Thin ice or 'ice glaze' is one-crystal layer-thick ice that moulds over the macrotexture of the road. This condition is considered to result from:

- super-cooled rain landing on a road surface that is close to 0°C, where it instantly freezes;
- light rain on a road surface which is already less than 0°C, where it quickly freezes;
- moisture on a cooling road from earlier dew or light rain, which then freezes when the road cools to below 0°C;
- frost or light snow compacted by trafficking.

For the non-alpine areas of New Zealand, the last two factors will be the more common causes of ice on the roads.

Snow is visible to road users and its impacts can generally be anticipated by RCAs and drivers (e.g. notices advising that tyre chains should be used). If snow falls unexpectedly, it may block the road to traffic until snow-clearing machines clear it. If snow has been forecast, the local RCA's winter maintenance procedures should allow for some preparation in readiness for the snow event, e.g. signs, snow-clearing crews on stand-by (Figures 6-11 and 6-16). Snow-clearing by snow plough or grader can damage coarse textured surfaces, and their drivers need to take care not to damage the chipseal and other road-related assets. Where snow is common, snow blowers which are less damaging to road surfaces may have been bought as part of an RCA's plant.

6.8.3 Hoar Frost on New Zealand Road Surfaces

A study by Dravitzki et al. (2003) examined hoar frost build-up on different road surfacings (both chipseal and AC) in New Zealand. On chipseal, frost was noted to form first on the tips of the chips because, with radiative cooling of the road, the chips are cooler than the deeper bituminous layer of the seal. The frost consists of small granular crystals forming a single layer over the chips. The crystals adhere only loosely to the chips and are easily dislodged.

As the frost becomes more intense, it forms a continuous layer over the chip and bituminous binder. As it becomes even more intense, several layers of frost crystals form. All these crystals are only loosely bound and are easily removed. For example trafficking can dislodge most frost crystals off the tips of the chips so that vehicle paths along the road become apparent.

Frost on smooth pavement surfaces, such as asphaltic concrete, tends to form quite uniformly over the surface. The initial stage of frost forming on the tips of the finer chips is soon superseded by formation of a more continuous layer.

6.8.4 Sites of Frost Formation

A New Zealand study (Dravitzki et al. 2003) found that the single most important factor for most roads outside alpine areas is shading the road by terrain or by trees. Frost appeared to form exclusively at sites where the road was not exposed to the sun for any part of the day, or where exposure, if it did occur, was very brief, e.g. 5–30 minutes.

At these sites, a heavy dew could form in the early evening even if nearby areas were reasonably dry. Frost would then form overnight or in the early morning. Further, because these locations were not exposed to the sun, frost once formed could remain throughout the day on the untrafficked sections and the frost layer could be further thickened by an additional freezing cycle during the following night.

6.8.5 Impact of Frost and Ice on Skid Resistance

The impacts of frost and ice on skid resistance are shown in Figures 6-12 and 6-13. They show the skid resistance in the natural frost and ice conditions measured with the British Pendulum Tester (BPT) expressed as a percentage of the skid resistance in the wet condition, all plotted against texture depth. Although concerns are that the BPT may not show the full effect of the macrotexture in frost conditions, Dravitzki considers it shows the effect of ice conditions adequately. Data points are shown for both wheelpath and non-wheelpath samples which have marked differences in microtexture.

Outliers aside, Figure 6-12 shows that frost conditions reduce skid resistance to 40-60% of the wet skid resistance for pavements with texture depths less than 1 mm, and to 50-70% of the wet skid resistance for texture depths about 2-3 mm.

Figure 6-13 shows that ice conditions reduce skid resistance much more, to only 20-40% of the wet skid resistance for textures less than 1 mm, and to 40-60% of the wet skid resistance for textures about 2-3 mm in depth. This means that pavements with finer texture have lower skid resistance in frosty and icy conditions.

6.8.6 Identifying Locations of Frost Formation

Identifying areas where frost and ice formation are likely to occur is an important task because most of these locations are scattered and occur over only short stretches of road.

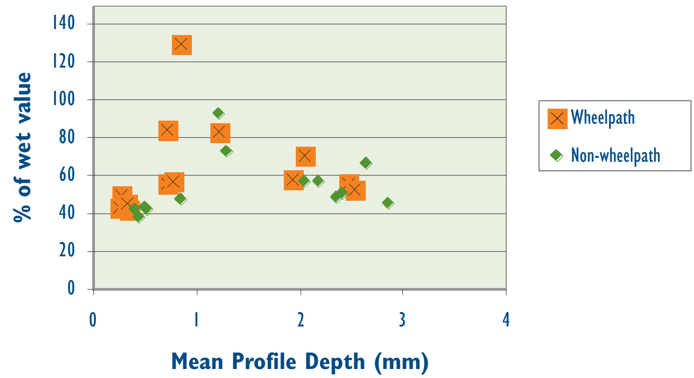


Figure 6-12 Skid Resistance (in BPN) of road samples in natural frost conditions, expressed as percentage of wet value of skid resistance versus texture depth (as MPD mm).

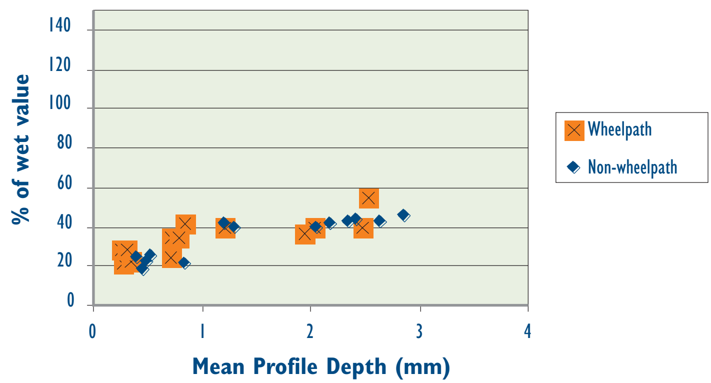


Figure 6-13 Skid Resistance (in BPN) of road samples in ice conditions, expressed as percentage of wet value of skid resistance versus texture depth (as MPD mm).

The most rigorous way to locate these spots, in order to apply appropriate long- or short-term treatments, is a technique known as thermal mapping. Thermal mapping data is developed into a computer model to predict when and where frost and ice are likely to occur. Large numbers of sophisticated warning systems e.g. Road Weather Information System (RWIS) or other systems are required to feed daily temperature and humidity data into the computer containing the model developed from the thermal mapping data. The model then predicts where and when frost and ice are likely to occur in real time.

Thermal mapping along with the RWIS stations and associated software to support it are in use in some places in New Zealand. However, an effective and cheaper option is to identify sites where frost and ice are likely to occur by careful visual inspection and manual recording during winter when the sun is low in the sky. This inspection could also be made in other months if allowance is made for the angle of the winter sun. These areas can then be treated by increasing texture or by cutting back vegetation to expose the road to the sun.

6.8.7 Implications for Road Management

The effect of frost or thin ice is significant in road management because it lowers skid resistance so much. The current skid resistance strategy is to provide increased skid resistance for wet roads, but for icy roads strategies focus more on rapid response for snow clearing and 'just in time' application of grit and chemical de-icers.

6.8.7.1 Minimum Texture Depth

Based on studies using the BPT:

- Low texture surfaces (those about 0.8 mm or less) appear very vulnerable to the effects of frost and ice;
- Deep texture surfaces (those about 2-3 mm) may retain a higher skid resistance than smooth surfaces in frost and thin ice conditions, but the improvement is not large.

Therefore in locations where frost or ice occur intermittently and the extent of this condition is not severe, maintain the macrotexture with a minimum of about 1.5 mm texture depth (measured as MPD) (Figure 6-14).

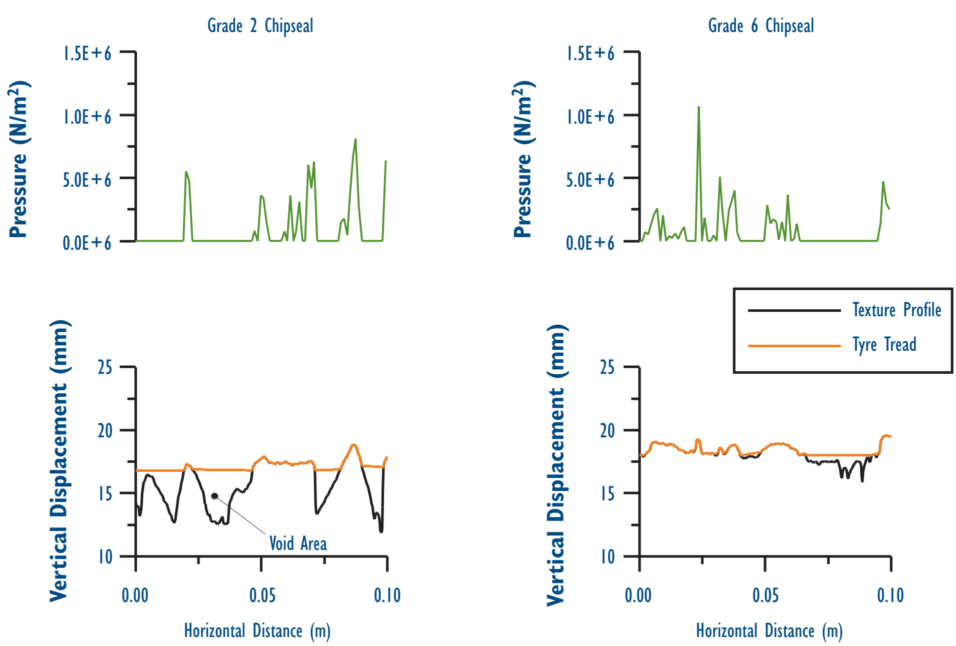
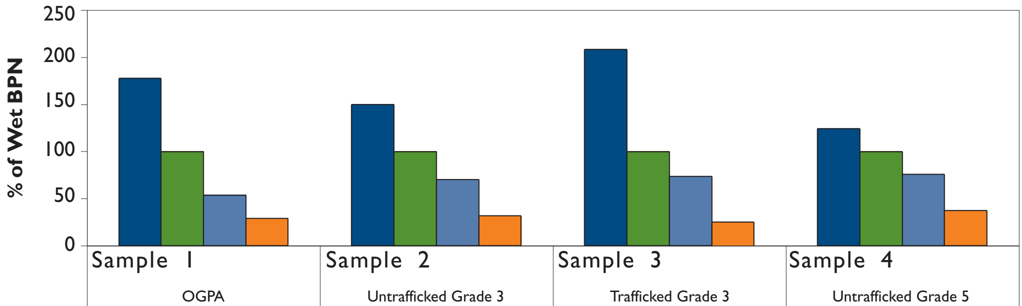


Figure 6-14 Comparing the contact made by the tyre footprint with chip of Grade 2 (coarse) and Grade 6 (fine), and the high point pressures (N/m^2) generated at the high points of the chips.

6.8.7.2 Effects of CMA (Calcium Magnesium Acetate)

In locations where frost and ice occur often, an additional management strategy is to apply CMA as a prevention treatment when the weather conditions and the forecast indicate likely formation of frost and ice. Comparisons of skid resistance under dry, wet, with and without CMA are illustrated in Figure 6-15.



	OGPA	Untrafficked Grade 3	Trafficked Grade 3	Untrafficked Grade 5
Dry	178	150	209	124
Wet	100	100	100	100
CMA	54	70	74	76
Ice	29	32	25	37

Figure 6-15 Comparison of skid resistance measured in dry conditions, in wet conditions without CMA, with CMA, and with ice (without CMA).

Using CMA to provide a higher skid resistance than that of an iced surface offers a paradox as CMA becomes very slippery if wetted, e.g. during a dewy night. In fact the skid resistance of a surface wetted with CMA is lower than of a wet road. For this reason CMA needs to be applied 'just in time', i.e. early morning (4am) before the frost forms. In addition, warning signs, e.g. SLIPPERY WHEN WET or SLIPPERY WHEN ICY, need to be issued because of the increased slipperiness caused by CMA.

6.8.8 Resurfacing Snow- and Ice-Prone Roads

Both chipseal and asphalt surfacings for roads likely to be affected by frost, ice and snow need to provide adequate skid resistance under these conditions. Their design should take into account the following matters for reducing the formation of ice or frost on a road, and for maintaining adequate skid resistance in cold conditions.

6.8.8.1 Road Geometry

If the alignment of the road is straight, the risk of loss of control caused by frost or ice may be less. However tight corners and steep gradients offer greater risks if ice forms on them, and the likelihood of skid-related crashes in icy conditions is therefore high. The high stresses caused by turning and scuffing means chip loss has often occurred on those sections as well, offering less skid resistance in cold conditions.

In such locations, asphaltic mixes (Stone Mastic Asphalt (SMA), Open Graded Porous Asphalt (OGPA), asphaltic concrete (AC)) may achieve better value for money in terms of whole-of-life cycle costs, but a minimum texture depth needs to be specified to achieve adequate skid resistance in cold conditions.

6.8.8.2 Chip Selection for Snow-prone Roads

Snow-plough action damages single coat chipseals with high macrotexture, and conversely, uneven rough pavement shape will damage the snow plough (Figure 6-16).

Figure 6-16 Snow clearing with graders and loaders (with wheel chains) can cause damage to the chipseal.
Photo courtesy of Les McKenzie, Opus

Two coat, racked-in, or locked-in type reseals will have less macrotexture but will be more resistant to snow-plough damage, and have their place in snow-prone areas. Seals with lower macrotexture aid thawing of snow and ice, and conversely those which have less chip and more macrotexture will take longer to thaw.

The normal procedure of applying voidfilling to coarse chipseals followed by a coarse reseal at a later date is appropriate for these conditions (see Section 6.5.2).

6.8.8.3 Binder Selection for Snow-prone Roads

When designing seals for cold conditions, the normal process for selecting the binder should be followed, keeping kerosene contents between 4% to 6%, so that binder curing is hastened before the onset of the next cold season.

However because the daily and seasonal temperature ranges are large, the binder needs to have greater adhesion, especially if the seal coat has to be constructed either late or very early in the summer. Use of adhesion agents are therefore recommended.

PMBs may better enable a binder to withstand the high temperature variations of day and night, i.e. to make the binder less temperature susceptible.

6.8.8.4 Timing of Resurfacing

Planning the timing of the resealing operation is important, in order to make use of the warmest part of the year. Early sealing (before the Christmas holidays[2]) gives the advantage of better chip embedment through trafficking by the higher volumes of holiday traffic.

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As stated in previous sections, the earlier in summer that resurfacing is completed, the longer is the time available for embedment and curing to take place, and thus the better the chance for a successful seal in the cold conditions likely to occur during the following winter.

Because the variations in temperatures and weather are high in these extreme environments, the resealing operation should begin when a fine and warm weather window of several days is forecast.

The chipsealing operation should be carried out during the months when the variation between night and day temperatures is least (early summer) as this will help curing. Resurfacing completed after the end of February (late summer), when the daily temperature variation is increasing, may be prone to failure because the wide variation in temperatures slows down binder curing, adhesion and embedment.

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2 The summer sealing season in New Zealand (Southern Hemisphere) spans the Christmas holiday period. Summer holidays (vacation) are generally taken over Christmas and into January.

6.9 Seal Selection for Mitigating Road Traffic Noise

Road traffic noise is generated by traffic travelling along the road, and it is determined by a number of factors, one of which is the type of road surface used.

6.9.1 Sound and Noise

The terms 'sound' and 'noise' are often used interchangeably. However 'sound' is the physical phenomenon of vibrations in the air that we hear with our ears, and 'noise' has a qualitative connotation that is usually applied to unwanted sound.

> Sound from traffic using roads, though measured with a sound level meter, is almost always termed 'road traffic noise' irrespective of the sound level. In practice the levels of road traffic noise which are readily accepted by the community could be called 'road traffic sound', and higher levels that are unacceptable to the community should be called 'road traffic noise'.

6.9.2 Sources of Road Traffic Noise

The road surface affects traffic noise by the interaction of the road surface with the vehicle tyre. This complex set of both mechanical and aerodynamic interactions that occur between the vehicle tyre, its tread pattern and the road surface, are illustrated by Figures 6-17 and 6-18 (used with permission from Sandberg & Ejsmont 2002).

Road surface texture and porosity are but two of the factors influencing these mechanical and aerodynamic interactions. The nature of the tyres is also important and, as a consequence, the road surface effects on noise differ for light and heavy vehicles.

The types of vehicles also affect road traffic noise from the sources related to the vehicle engine and body. For example, noise is generated from the mechanical moving parts from the engine and the engine exhaust, from the gearbox and drive shaft, and from the vibration from the engine and underlying road to the vehicle structure, which then radiates out from the metal body.

With modern cars, tyre–road noise is the major contributor to traffic noise at all speeds (Table 6-5). For older cars at low speeds, vehicle motor noise is the main contributor of noise and tyre–road noise has been found to be the major contributor to traffic noise only after vehicle speeds exceeded 70 km/h. The low frequency tyre–road noise is particularly annoying in residential areas. It is largely caused by the coarse (or larger sized) chips, which may be required to achieve adequate water drainage, and be more durable for high-speed situations. Chips of larger size are also desirable to reduce the 'tyre hiss' on wet pavements.

Table 6-5 Relationship of vehicle age and speed as sources of traffic noise.

Vehicle age	Vehicle / Motor Noise	Tyre-Road Noise
Older cars		
<70 km/h	Major contributor	Minor contributor
>70 km/h	Minor contributor	Major contributor
Modern cars (all speeds)	Minor contributor	Major contributor

Finer sized top surface aggregates will reduce the noise generation, but they are less durable and may suffer early failure through chip embedment and flushing, especially under heavy traffic loads.

6.9.3 Noise Impacts and their Measurement

The level of sound is measured by the pressure that the air vibration exerts on a flexible diaphragm (microphone). Sound level is quantified as decibels, symbol dB, which are $^1/_{10}$th of a Bel. Decibels and Bels are not physical quantities but are ratios that compare the pressure of the sound to the pressure of the quietest sound just detectable by the human ear. Sound levels of 50dB, 60dB and 70dB are 10^5, 10^6 and 10^7 times greater than this just-detectable sound.

6

Sound from most sources is composed of a number of individual frequencies. The human ear is not equally sensitive to these frequencies and the sound level may be adjusted to allow for this difference in frequency, a process called 'weighting'. This processed level is shown as dBA.

Noise levels are expressed in several ways. One way is the average noise level measured over the day. Common average measures are L_{eq} or the equivalent noise level, or L_{10} which is the noise exceeded 10% of the time. A second way to express noise is to measure the highest instantaneous noise of a passing vehicle, or the maximum noise level (L_{max}). The measure L_{10} can be changed to L_{max} by taking a 1 second average of the high noise levels of passing vehicles, i.e. L_{eq} (1 second).

6.9.4 Community Impacts

The level of road traffic noise is a physical quantity, the significance of which can be assessed in connection with its impact on the community. The impact of traffic noise can be determined by surveying the community, and numerous surveys have now established reasonable relationships between road traffic noise level and community impact.

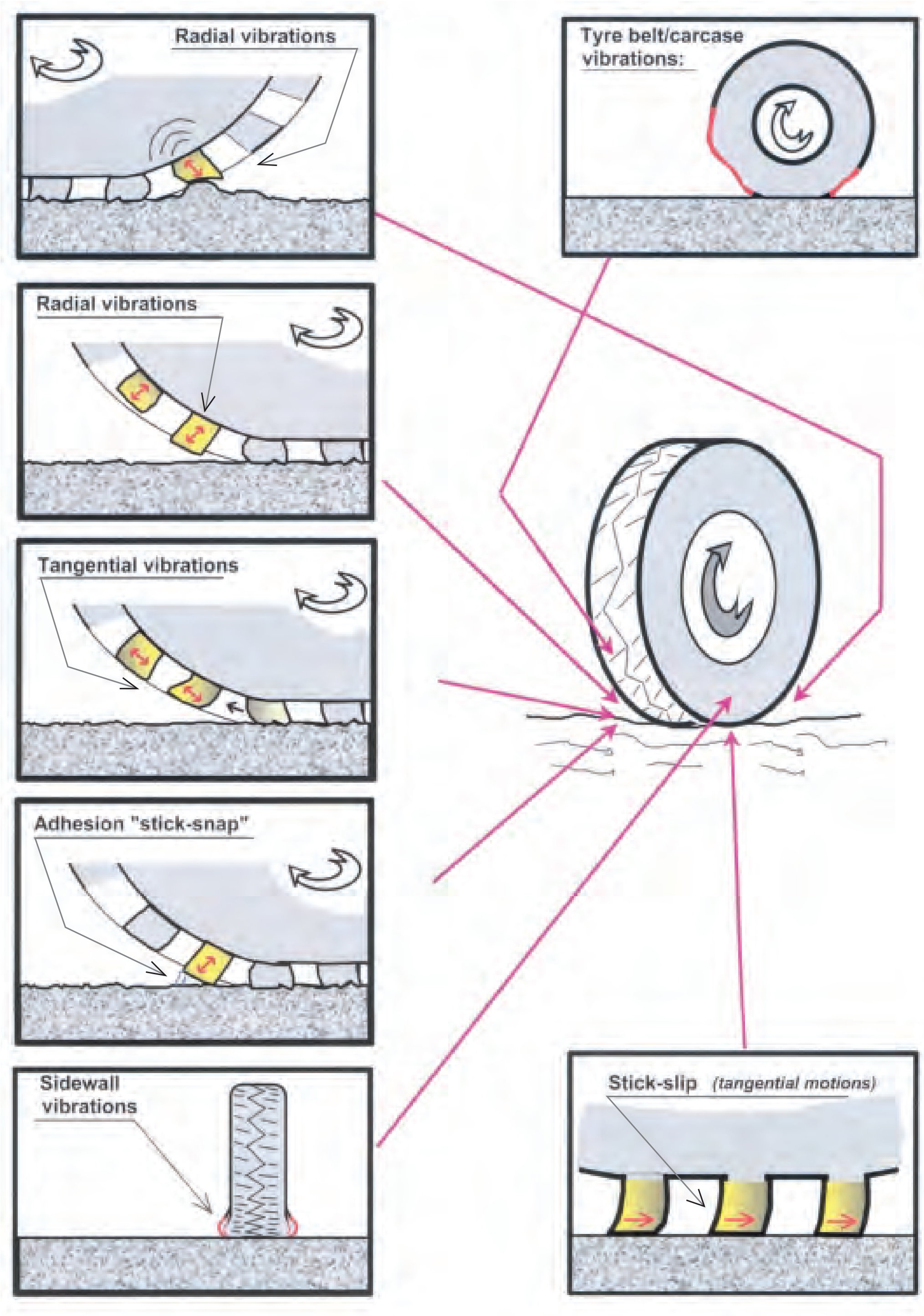

Figure 6-17 The vibration-related mechanisms of tyre–road noise generation (by tread impact and adhesion) (reproduced with permission from Sandberg & Ejsmont 2002).

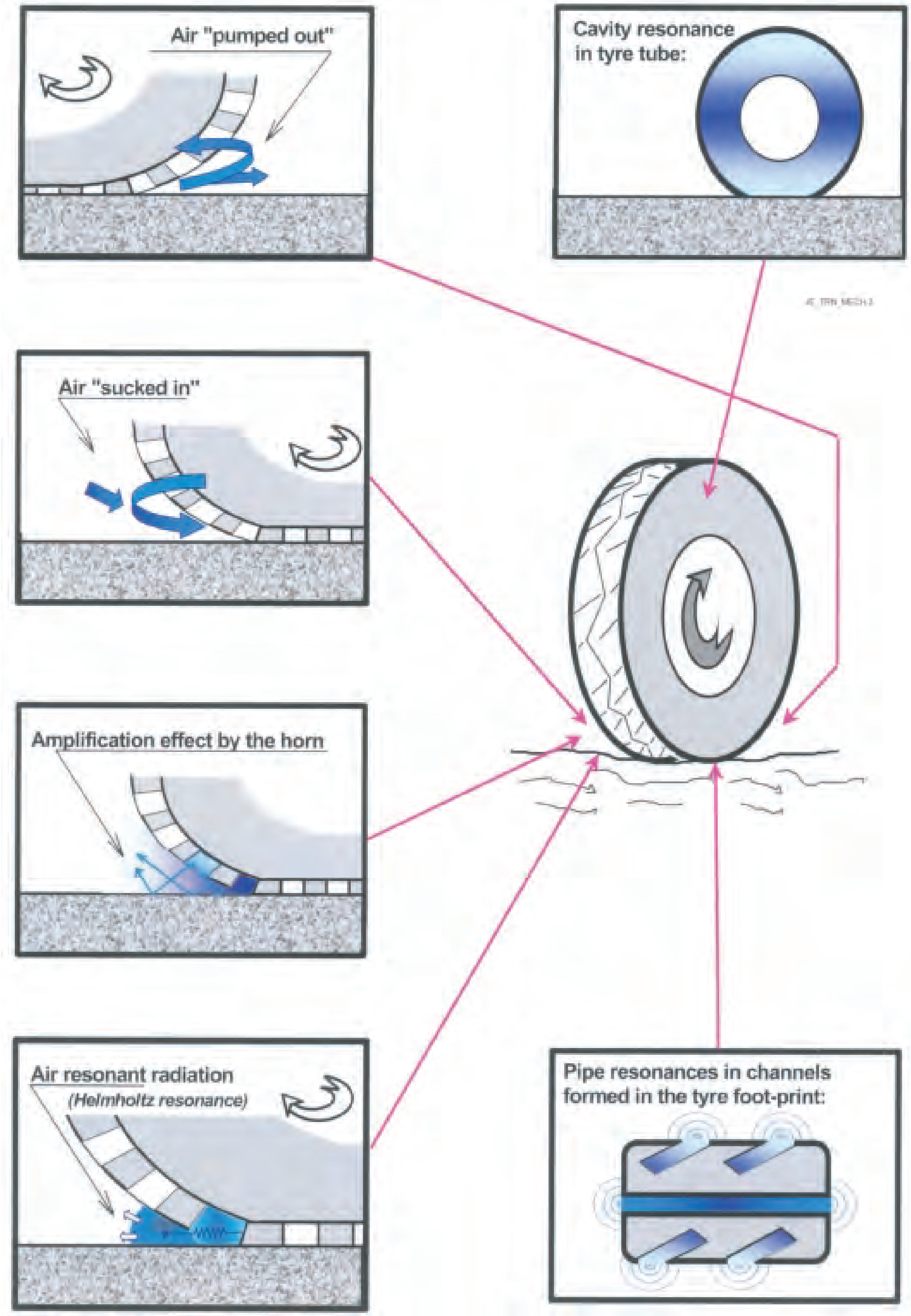

Figure 6-18 Aerodynamic-related mechanisms of tyre–road noise generation (by air displacement) (reproduced with permission from Sandberg & Ejsmont 2002).

Research also shows that, where traffic noise is not loud enough to have direct health effects, it can still have a significant influence on how people feel about their neighbourhood and how they live their lives. People highly annoyed by noise can experience stress and indirect health effects. Noise may also affect how people use their property, and may range from smaller changes, such as turning up radios, to other changes such as discouraging outdoor activities, or having to close windows and doors, or to extremes such as avoiding rooms exposed to peak hours traffic until it has decreased, or even having to re-locate.

The range in noise level between acceptable and unacceptable impacts is only about 25 dBA. Quiet suburban streets have daily average noise levels of about 45-50 dBA, whereas roads such as motorways and busy urban arterials, which are often at the limits of acceptability to the community, have daily average noise levels of about 70-75 dBA. Within this 25 dBA range, up to 10 dBA but more typically 4-5 dBA can be influenced by choice of road surface type.

Surface selection is therefore an effective method of controlling road traffic noise and is one of the few options available to RCAs.

The road surface effect on total noise may seem to be small, i.e. only a few dBA. However this is not the case. Because the road–tyre interaction is the dominant source, most of the daily average level, e.g. 50 dBA or 75 dBA, is from the road–tyre effect. Therefore, altering the surface has the potential to change these levels by 5-10 dBA.

6.9.5 Modelling for Community Impacts of Noise

Modelling for the road surface type indicates expected change only in the physical quantity of the noise. The noise benefits provided by a particular surface need to be balanced against the benefits to the affected community. Research shows that the community impact caused by a change in noise level is dependent also on the existing noise level. A decrease in noise where levels are already high has a greater impact than the same decrease in noise where existing levels are low to moderate.

Annoyance and behaviour are closely related. When a more noisy seal is used with an associated increase in traffic noise, then changes in social behaviour may result.

However, the community response to noise levels differs widely. Surveys show that, as well as the 15% of residents in a busy street who may be highly annoyed by the traffic, and another 25% annoyed, some 15% and 25% will consider the noise level to be very satisfactory or satisfactory respectively. Change in impact therefore has to be assessed against a quite high level of impact, such as the change in the population who are "highly annoyed", or the change in the population who have to significantly change their use of their house, e.g. "changed rooms", or "come home late" to avoid noise.

Table 6-6 shows the effect on the community noise environment of the change in noise that comes with choosing different road surface types. Columns 1 and 2 show the change in noise levels (dBA), and columns 3, 4, and 5 show the extent of improvement for three typical noise environments (of <60 dBA, 60-69 dBA, >70 dBA).

The level of impact chosen is arbitrary. The scale below shows a classification (used in Table 6-6) for the extent of improvement against the baseline percentage of the population that is **acutely affected**:

- a **big improvement** to the noise environment means that the % acutely affected has been reduced by 15% of the total population;
- an **improvement** to the noise environment means that the % acutely affected has been reduced by 10% of the total population;
- a **small improvement** to the noise environment means that the % acutely affected has been reduced by 5% of the total population;
- a **little worse** is a 5% increase in the % population acutely affected;
- **worse** is a 10% increase in the % population acutely affected;
- **much worse** is a 15% increase in the % population acutely affected.

Table 6-6 Guideline (indicative only) for selecting surface types in reseals, showing the change in noise level (dBA) from the baseline % of acutely affected population, against the expected improvement in the living environment.

Change in Noise Level (dBA) related to Road Surface Change		Less than 60 dBA Leq_{24hr}	Between 60-69 dBA Leq_{24hr}	Above 70 dBA Leq_{24hr}
Reduction	More than –3.6	Small Improvement	Improvement	Big Improvement
	–1.1 to –3.5		Small Improvement	Improvement
	0 to –1	Little Change	Little Change	Small Improvement
No Change	0	N/A	N/A	N/A
Increase	0 to 1	Little Change	Little Change	A Little Worse
	1.1 to 3.5	A Little Worse	A Little Worse	Worse
	3.6 and greater		Worse	Much Worse

6.9.6 Road Surface Effects

Effects of road surface on noise are measured by standard techniques (e.g. BSI 1995, 2001a, b) in which the noise levels of vehicles being driven at a steady speed are measured by a roadside sound-level meter. The meter records the sound (noise) level generated at the 1 second in which the vehicle is directly opposite it.

The standards are taken as follows: on a dense asphaltic concrete surface these noise levels are about 68 dBA and 79 dBA for cars and trucks respectively, at 50 km/h, 76 dBA for cars at 100 km/h, and 84 dBA for trucks at 90 km/h. Table 6-7 shows the noise effects of different road surfaces over different speeds for both cars and trucks. This data was obtained in an experimental investigation of the effects of the road surface on noise, undertaken in the Wellington region in 2002 (Dravitzki in prep.).

Table 6-7 Effects of different road surfaces on cruise-by noise levels (dBA) for light and heavy vehicles (cars and trucks), at different speeds.

Speed km/h	Noise (dBA) from Light vehicle (car)						Noise (dBA) from Heavy vehicle (truck)				
	AC	OGPA	Grade 3/5	Grade 3	Grade 2/4	Grade 2	OGPA	Grade 3/5	Grade 3	Grade 2/4	Grade 2
50	68	69	74	74	74	75	77	80	80	-	-
70	72	73	78	78	79	81	80	82	82	81	83
90	-	-	-	-	-	-	82	85	84	84	85
100	-	77	83	83	85	84	-	-	-	-	-

The effect of other surface types on noise is expressed as relative to that on dense asphaltic concrete for each vehicle type. For example on chipseal surfacing, cars are +4 dBA more noisy than on dense AC, and trucks are +1 dBA more noisy. When vehicle speed increases total noise increases, so it is important that surface types are changed to suit changes in the traffic using the road. If a traditional low-speed surfacing is retained for a road on which the traffic travels at higher speeds, the traffic noise increases.

Slurry seals (e.g. Type 3 described in Section 3.8.1) offer a suitable alternative to a conventional chipseal when low traffic noise and a lack of loose chips are important considerations, because reductions of up to 3 dBA (compared with chipseals) are possible. They also offer a coarser texture than dense AC for use on these roads that are more highly trafficked, and on state highways. These are often key reasons for their use in urban or semi-urban situations in shopping, urban or residential areas where road and traffic noise is an important consideration.

Table 6-8 shows differences in noise level for common road surfaces used in New Zealand, using data obtained from Dravitzki (in prep.). The noise effects of different kinds of

Table 6-8 Effects of road surface types on noise, relative to dense AC, for light and heavy vehicles (cars and trucks) travelling at speeds of 50-100 km/h.

Vehicle Type	Dense AC[1]	Standard OGPA[2]	High Voids OGPA[3]	Fine Chip Grades 4,5,6	Med. Chip Grade 3	Coarse Chip Grade 2; Two coat seals
Car/light	0	0	-2	3	4	6
Truck/heavy	0	-2	–	-2	1	1

Notes
1 Mix 10 dense asphalt concrete (AC).
2 OGPA complying with TNZ P/11. 20% voids laid at approx. 30 mm thickness.
3 30% voids (at 40 mm thick). Special materials laid to 70-100 mm may be -4 relative to AC.

surfaces were first measured, then compared to that obtained on asphaltic concrete which is taken as the baseline. Several replicates were made of each surface type, and the surface types with similar effects are grouped.

The values in Table 6-8 have been determined as the composite for new and aged surfaces that are near replacement. Experiments have shown that, over a typical surface life of 7-10 years, the noise effect varies usually by 1 dBA. For chipseals the noise level is highest for the new surface, then decreases with age from a loss of texture. For dense AC the noise level is lowest for the new surface and then increases with ageing, as ageing usually results in a roughening of the road surface.

The values in Table 6-8 therefore are the differences in noise effects of the road surfaces for the main portion of the service life. Different values may be reported from different studies. One local authority reports that their measurements do not support two coat seals being 6 dBA above that for AC at any speed.

6.9.7 Seal Selection for Noise Reduction

Although the effects of the road surface are dependent on the vehicle type, these interrelated effects need to be combined to show the effects for typical streams of traffic. One way to calculate the combined effects is to use a noise calculation model, such as the Nordic model for road traffic noise prediction which calculates the noise produced by the traffic streams separately. (The Nordic model was first introduced in the 1970s as a common road surface noise prediction model used by the five Nordic countries (Sweden, Denmark, Norway, Finland, Iceland). The latest version is given in TemaNord, 1966.)

Table 6-9 has been produced from a series of calculations using the Nordic model to produce the net surface effect for any volume of traffic, with the ratio of light to heavy vehicles identified. Table 6-8 showed that the noise effect of different surfaces at 50 km/h was the same as at 100 km/h, and Table 6-9 can be used for calculating the most appropriate road surfacing for different speed zones, and the roading engineer can use it to assess the effect (or benefit) of choosing one surface type over another.

For example, if a street was already surfaced with Grade 3 chip, and the volume of heavy traffic is low, e.g. 3%, then a significant noise reduction (about 3.7 dBA) could be achieved by using an AC.

However if this street had a high proportion of heavy vehicles, e.g. 20%, then the benefit of using AC represents only a 0.8 dBA reduction in noise, and OGPA would give a greater noise reduction.

Table 6-9 Combined effects of different road surfaces and of light and heavy vehicles on tyre–road noise (dBA) (AC taken as baseline).

% Heavy vehicles	Noise (dBA) generated by light and heavy vehicles on different road surfaces				
	Dense AC	OGPA	Fine chip Grades 4,5,6	Medium chip Grade 3	Coarse chip Grade 2; Two coat seals
0	0	0	3.0	4.0	6.0
3	0	–0.3	3.0	3.7	5.5
10	0	–0.8	1.5	1.5	4.5
20	0	–1.0	0.8	0.8	3.5

6.10 Seal Selection for Environmental and Community Reasons

Sealing activities have the potential to create a range of positive and negative effects on the natural environment and neighbouring communities. However, costly remedial work and unwanted negative publicity can be avoided by considering environmental and community effects early when planning sealing works.

The objectives of RCAs increasingly reflect a commitment and duty to responsibly manage effects on the environment and community. When operating under the RMA 1991, an RCA has a duty to “avoid, remedy or mitigate any adverse effect on the environment”. Under the Land Transport Management Act 2003 (LTMA), Transit New Zealand must “exhibit a sense of social and environmental responsibility” in operating the State Highway network.

Good practice techniques that protect the environment are often cost-effective and easy to put into practice if included at the early stages of a job. They include minimising waste, reducing energy consumption and taking care of run-off and water use. Control of noise, stormwater run-off, and dust also become important issues in urban areas.

6.10.1 Waste Minimisation

Waste minimisation includes consideration of the way waste is disposed of, reducing the amount of waste to dispose of, say at the landfill, and reducing the demand on primary sources of materials, e.g. of aggregates. As planning for waste minimisation is part of construction, ways of achieving it are given in Section 11.7.1.

6.10.2 Energy Efficiency

Taking simple steps to reduce energy consumption can result in cost savings and make a positive contribution to national energy reduction targets. Consider these steps at the planning and selection stage, so that they can be carried out in the construction stage of a chipseal (Section 11.7.2).

For example, greater efficiency and better prices may be obtained if local sealing contractors and aggregate producers are kept well informed of the intended reseal programme as it is developed.

6.10.3 Water Management

The effects of sealing activities on the volumes of water used and impacts of water run-off on stormwater can be reduced through careful water use and sensible management practices (Section 11.7.3).

Key water management objectives include:

- Reducing the volume of potable (drinking quality) water used in sealing and maintenance activities, e.g. for washing down, by turning off hoses when not required.
- Ensuring pollutants from sealing activities do not enter waterways.
- Control stormwater run-off by including catch pits, sumps.
- Filtering and re-using water collected from high pressure water treatments.

Good management practices to minimise contamination include:

- Avoiding spillage of binders, and being prepared for such events.
- Ensuring containment devices are in place and spillage kits (of fine aggregate to cover oily spills, portable textile dams to block run-off) are available.
- Ensuring that fire extinguishers are accessible. RNZ's BCA 9904 recommends that the local Fire Brigade be alerted that the job is under way.

6.10.4 Complaints about Chipseal Standards

Recent research (Cleland et al. 2004) analysing the complaints database of a number of RCAs found that 30% of road surface complaints are about construction. Figure 6-19 displays the breakdown of the seven types of these construction complaints.

The primary construction complaint is about *poor finish* (38.6%), and refers to a work site not being restored to its former condition. This includes construction materials left behind, materials removed but not reinstated after work was completed (such as road markings or signage), and general damage or mess left post-road construction or maintenance.

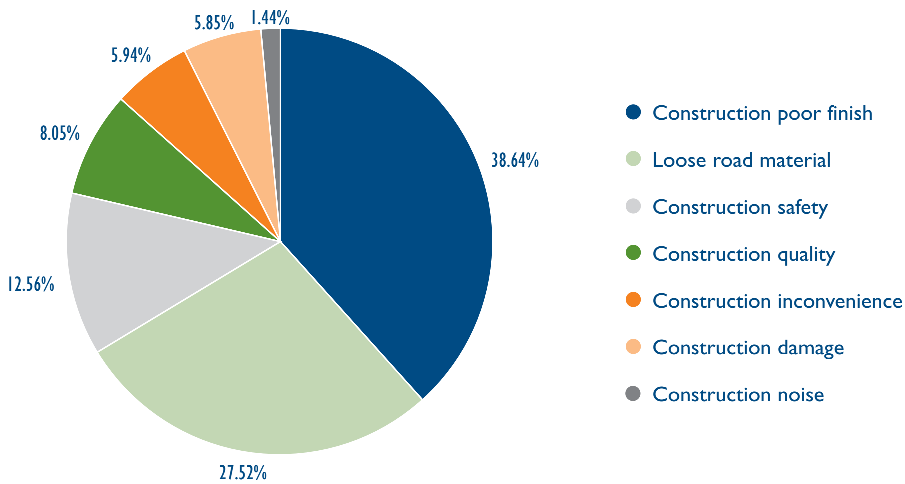

Figure 6-19 Analysis of road construction complaints lodged with RCAs.

Loose road material (27.5%) accounts for the chip or aggregate that comes away from the road surface, and these complaints are mostly made immediately after the construction of a new road seal.

The *safety* of the sites is often questioned (12.6%), particularly with regard to members of the public altering the layout or removing some of the temporary traffic control devices. Within this category were also some complaints made from a pedestrian perspective of work sites.

Although *noise* has strong links to community annoyance (Dravitzki et al., in prep.), noise is the construction feature that is least complained about (1.4%). From the commentary provided in each complaint, those about construction noise were made only when the public felt that the construction was undertaken at inappropriate times, such as late at night or early morning. At reasonable times the public were generally accepting of construction noise.

6.10.5 Community Liaison

> Keeping the community informed about proposed sealing activities can reduce the impact on the community of major interruptions or delays.

Close consultation with the contractor, RCA, road user groups, directly affected neighbours and the wider community should aim to minimise and manage any impacts or disruption of chipsealing on the community. Consultation is important to avoid conflict. The effects of chipsealing on other events needs to be considered, which is elaborated further in Section 11.2 on programming and preparation for sealing day.

6.10.6 Tracking

> Tracking loose chip and binder along roads by vehicles, or into houses and shops and onto other surrounding surfaces by pedestrians, is not desirable, especially in commercial and residential areas.

Tracking is sometimes a serious problem during chipseal construction, but can also happen to the surface later in its life. In principle this type of defect should be possible to avoid by allowing for it in design, construction and maintenance. Economics will dictate the choice of using a standard chipseal or an alternative more expensive treatment that will minimise tracking.

Table 6-10 gives a comparison ranking of the different seal types in terms of binder pick-up and loose chip. A racked-in seal is regarded as the lowest risk option other than a slurry. The racked-in seal has only one application of binder on to the original surface, and the racking in of the smaller chip locks the seal together. Any excess chip can be swept up and removed quickly before it becomes a problem.

On a two coat seal the second application of binder sits on top of the first chip, which creates the risk that the binder can stick to tyres. To minimise this risk of binder pick-up, the second chip is often applied in excess but this creates a situation where excess chip can continue to be dislodged by traffic for months. As will be seen in Chapter 9 the application rates of binder for single coat, two coat and racked-in seals are very similar. Therefore, unless the site stress demands the use of a standard two coat seal in urban areas, either a single coat or a racked-in seal should be considered as the default options.

6.10.7 Appearance and Aesthetics

An even appearance to the road surface not only looks good, but is also safer and gives a smoother ride. An even appearance can be achieved with coarse textured surfaces, with less construction effort, than with very fine smooth surfaces.

For example, on a slurry treatment the longitudinal joints are often prominent, whereas at the other end of the scale, on a well-constructed Grade 2 seal the longitudinal joints are often difficult to identify.

Even though the texture depth of a multicoat seal may be similar to that of a single coat seal, the appearance and development of the texture is different (see Figure 11-2).

6.10.8 Pedestrian and Cyclist Preferences

Pedestrians and cyclists dislike using very coarse surfaces. However, with care and consultation, a surface can be designed to provide an adequately smooth surface that retains all the required safety features, e.g. adequate drainage and skid resistance. In pedestrian areas a seal can be constructed using Grade 5 chip. Although this surface may not be regarded as suitable for areas of high traffic volumes, it is a viable option on footpaths. Alternatively a slurry treatment is often used as a re-surfacing treatment for footpaths and other pedestrian areas, especially as a maintenance treatment over asphaltic concrete.

6.10.9 Fuel Consumption and Tyre Wear

The friction from surfaces with good skid resistance causes increased fuel consumption and tyre wear. On heavily trafficked roads, the additional fuel and tyre wear costs are considerable if very coarse chip is used, whereas a less coarse chip will achieve the maximum safety benefits from improved skid resistance, yet with lower fuel and wear costs.

A comparison of the surface treatments for these community expectations is given in Table 6-10, in which the seal types are ranked from 1 best to 4 worst.

Table 6-10 Comparison by rank of four seal types for their effects on environmental and community issues.

Environmental or Community Issue	Single Coat	Racked-in	Two Coat	Cape Seal Slurry
Noise	2	2	2	1
Loose Chip	3	2	4	1
Bitumen Pick-up / Tracking	3	2	4	2
Pedestrians	3	2	2	1
Cyclists	3	2	2	1
Aesthetics / Appearance	3	2	3	1
Fuel Consumption / Tyre Wear	2	2	2	1

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CHAPTER SEVEN

Preseal Preparation

Chapter 7 Preseal Preparation

Previous page: Preparing the basecourse of a road for sealing by compacting it with a steam roller, c1910.
Photo from Alexander Turnbull Library, Steffano Francis Webb Collection (ATL G-4032-1/1)

Chapter 7 Preseal Preparation

7.1 Introduction

This chapter explores the why, what, when, where and how of preseal preparation for both first coat seals and reseals, because the life and performance of any chipseal or other surfacing treatment is very much dependent on how well the preliminary preparation work of the existing surface is carried out. Preseal preparation is also known as 'preseal repairs' and 'prep'.

The goals for such preparation work can be summarised as follows:

- To maximise effective life for the new seal and ensure adequate seal performance throughout its life;
- To ensure adhesion of the new seal to the existing surface over all the seal area;
- To improve the riding quality by levelling uneven surfaces, including adjustment of service covers.

To achieve these goals, preliminary preparation works are carried out on any pavement area being readied for chipsealing or other resurfacing. The preparation works can be separated into two distinct categories, each with its own requirements and methodologies. They are:

- Basecourse preparation for first coat chipsealing of a new pavement (frontispiece);
- Surface repair, digout repair, and other preparation for the resealing of an existing pavement.

7.1.1 New or Unsealed Pavements

For new or unsealed pavements being readied for first coat chipsealing, preseal preparation includes the final sweeping of the unsealed surface to remove any soft layer of aggregate fines that have collected on top of the compacted basecourse (Figure 7-1). Removal of this fine layer is important to ensure adhesion of the sealing binder to the aggregate surface of the basecourse. If the fines are not removed, the new chip will 'punch' into this layer and the seal will flush.

First coat seal preparation will also include repairing surface defects such as variable or open-textured areas, loose aggregate or water-saturated areas, all of which are detrimental to the performance of a first coat seal.

Figure 7-1 The basecourse for State Highway 2 in Cook County, Gisborne, was swept clear of loose aggregate and other detritus by this rotary broom mounted in front of a tractor (with solid wheels and tyres), in the 1920s. Photo courtesy of John Matthews, Technix Group Ltd

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7.1.2 Existing Sealed Pavements

For existing sealed surfaces, preseal preparation is most likely to involve surface and structural (base) repair works in some form.

As discussed in Chapters 3, 4 and 5, the decision to reseal a road or street section and the likely preparation required for it will have been made by identifying and measuring surface and other defects (using RAMM[1] Road Condition Rating Surveys, Treatment Selection and Validation inspections).

In addition to repair of obvious surface failures, e.g. potholes, minor cracking, edge-break repairs and other defects, preseal preparation can include pavement repairs and subsoil drainage works, minor shape correction and smoothing of uneven surfaces, adjustment of service covers, joint sealing, or isolated pavement rehabilitation works.

The inspection and renewal of catchpit and other road surface drainage structures (including kerb and channel (K&C)) before resealing is also important to avoid digging up the road a few years after a reseal has been laid. Needless to say, co-ordination with providers of

1 RAMM – Road Assessment and Maintenance Management system.

underground utilities (communications, power, drainage, etc.) is important to ensure that planned maintenance of their services is carried out before the road is resealed.

The defect types and common repair methods used in preseal preparation works outlined briefly in Section 3.11 are covered in detail in this Chapter 7. For repair of seal failures that occur soon after construction of new reseals, see Chapter 12.

7.1.3 Pretreatment Seals

Chipseals must be applied to a uniform sound base layer, and treatments that can be used to achieve this, e.g. pretreatment seals such as texturising seals, are discussed in Section 7.3.4. Many methods of texturising are available for reinstating surface texture or for reducing the variation in texture of a surface before chipsealing, some of which do not include sealing (e.g. high pressure water treatments).

7.1.4 Timing of Preparation

When to carry out preseal preparation works is very much dependent on the type of preparation. Before first coat sealing, most preparation works for the basecourse are carried out in the days immediately preceding the day of sealing, and right up to the day of sealing.

Before resealing existing sealed surfaces however, preseal repair works should be carried out well in advance of the resealing date. Any minor surface repair, patching, or shape-correction works using asphaltic mix should be carried out at least 3 months in advance to allow time for the asphalt to cure and harden. Otherwise the new chipseal will be subject to faults caused when sealing over a soft substrate (see Section 4.7.4.1). Any minor repair, e.g. pavement rehabilitation, rip and remake, or stabilising, and first coat sealing areas, should be completed at least 9 months before resealing. A timetable for the various preseal repairs is presented in Table 7-1.

7.2 Preparation for First Coat Seals

7.2.1 Granular Aggregate Basecourses

For roads with medium to heavy traffic, granular aggregate basecourse material should comply with TNZ M/4:2003 specification, and should be constructed in accordance with TNZ B/2:1997 specification (Figure 7-2).

Table 7-1 Timing of preseal repairs.

Maintenance Treatment	Desirable Time of Completion Before Resealing
Repair of edge breaks, patching, or smoothing using:	
Cold mix with fluxed bitumen	>9 months
Cold mix with cutback bitumen binder	>9 months
Cold mix with bitumen emulsion binder	>9 months
Asphalt	>9 months
Slurry surfacing	>9 months
Crack filling using:	
Bitumen emulsion	2 months
Cutback bitumen products	6 months
Hot application bitumen products including PMBs	2 months
Corrective treatment of flushed chipseal surfacings and patches using:	
Chips only	2 weeks
Solvent chip treatments	2 to 6 months
Maintenance of shoulders and longitudinal drains:	
Before resealing	2 weeks
After resealing	2 weeks
Line marking before resealing:	6 months
Miscellaneous	
Weed and lichen removal (chemical means)	1 week (or as recommended by manufacturer)
Lichen removal (mechanical)	Pre-seal sweeping
Water cutting/blasting	6 weeks

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Figure 7-2 Preparation of basecourse for chipsealing has changed a great deal in the last 80 years. Left: A steam roller compacts a new basecourse on State Highway 2 near Manutuke, Cook County, Gisborne, in the 1920s. Photo courtesy of John Matthews, Technix Group Ltd
Right: A basecourse to comply with the TNZ B/2:1997 specification is prepared on the Alpurt A2 section of State Highway 1, Auckland in 1999. Photo courtesy of Philip Muir, Works Infrastructure Ltd

The TNZ B/2 specification requires a high standard of compaction to densify the base (98% Maximum Dry Density (MDD) for basecourse and 95% MDD for sub-base material), and to obtain a situation in which the material is dried back to a saturation level of less than 80% before sealing. Saturation is calculated from the moisture content and solid density of the aggregate in the following formula detailed in TNZ B/2.

$$\text{\% saturation} = \frac{\text{dry density} \times \text{\% water}}{1 - \dfrac{\text{dry density}}{\text{solid density of the particles}}}$$

Failure to meet these two criteria is likely to result in an unstable base that will rut or shove, and lead to flushing. Immediately before sealing, density and water content can be checked by a Nuclear Density Meter (NDM) or other appropriate test method to ensure compliance.

Of equal importance for the success of the first coat seal is the final basecourse finish for which TNZ B/2 has the following requirement:

> *The basecourse surface finish, as distinct from the surface shape, shall be such that when swept, it presents a tightly compacted, non-glazed, clean stone mosaic surface that will not ravel as a result of sweeping. The standard of sweeping shall be sufficient to remove all loose aggregate, dirt, dust, silt and other detritus matter.*

This latter requirement is frequently not met, perhaps because no clear test method is available to measure it, but what is intended is quite clear however. Essentially the surface should be almost entirely composed of clean stone particles, large enough to be visible to the naked eye and with fine lines of a 'mortar' of the finer sand and silt-sized particles between each chip (Figure 7-3).

The term 'stone mosaic' is a misnomer that dates from the period when most basecourse compaction was carried out by a static (not a vibratory) steel-wheeled roller (frontispiece). These rollers tended to cause the larger surface stones to be pushed into a flat surface alignment, so the surface looked like a mosaic of different sized flat tiles. Because steel-wheeled rollers tend to crush the stones to fine dust, modern practice is to do most compaction with vibrating steel rollers, finishing with a few passes with the vibration off, then tightening the surface with a mix of rubber-tyred rolling and trafficking. This leads to a surface having appreciable macrotexture once the surface has been swept to produce the desired clean stony surface.

This type of surface finish can be very difficult to achieve, especially when constructing the basecourse in a situation where it is not possible to divert the traffic. Unfortunately this is the usual situation for most rehabilitation works on two-lane roads.

The reasons for setting such a demanding requirement in TNZ B/2 are to prevent formation of layers of fines, as follows:

- *Formation of a layer of fines:* when a basecourse surface is covered by a layer of fine sand- and silt-size particles, the surface is far weaker than the body of the basecourse that has been constructed to the TNZ M/4 specification. (Paradoxically such a surface may be very hard when it is dry before sealing, but in moist conditions, the layer sucks up water like a sponge, becoming saturated and very soft.)
- *Formation of a wet layer of fines:* all sealed bases will 'sweat' very quickly under the seal in New Zealand conditions. A slippery 'carpet' of wet fines forms and the first coat seal applied over it is not satisfactorily anchored to the basecourse surface. The first coat seal can often be rolled up like a carpet.

In both cases, the seal binder eventually penetrates and binds the dust layer but this cannot be guaranteed. Long term, the adhesion of the seal coat to a basecourse with a dusty surface will always be inferior to that of a basecourse complying with TNZ B/2 (like those shown in Figure 7-3), as a permeable layer will remain under the sealed surface.

Figure 7-3 Basecourses prepared for first coat sealing from aggregates that are characteristic of different parts of New Zealand, after they have been prepared by sweeping.
Photos in clockwise order from top left are from the West Coast; Napier, Hawke's Bay; the Rotorua–Waikaremoana area; State Highway 1 near Palmerston North; by courtesy of Les McKenzie, Opus; Laurence Harrow, Opus; Norman Major; and Lindsay Roundhill, Opus, respectively.

7.2.1.1 Causes of Basecourse Failure

The consequences of having the soft layer of fines on top of the basecourse are:

- Poor adhesion of the seal to the base, putting greater stress on the seal under traffic and resulting in chip loss and loss of waterproofing.
- A permeable layer of fines that initially tends to soak up binder, and lowers the ability of binder to hold on to the sealing chip. The chips may punch down into the wetter layer of fines, resulting in binder rise and flushing.
- Excess fines forming a permeable layer under the seal. These fines can wet up over a large area with water infiltrating through tiny defects in the seal. The increased amount of water seeping into the basecourse can lead to potholes, sometimes called 'blowouts' as they appear to be caused by water pressure from beneath blowing holes in the seal.
- Frost-susceptible silt layers aggravating frost damage. Silt is easily damaged by frost, especially if directly under the seal coat. Most silt layers are thin however, and the effect of frost heave is not large scale, but over time the seal can totally delaminate from the basecourse, with more water entering each freeze-thaw cycle until the surface is totally disrupted.

7.2.1.2 Remedies for Basecourse Failure

To avoid these detrimental effects, any build-up of fines on the basecourse surface must be removed before sealing to achieve the desired stony surface. To achieve this, the following steps are taken:

- Spreading (or gritting) the final compacted surface with, ideally, clean Grades 5 or 6 sealing chip (although some surfacing engineers have used chips as coarse as Grades 4 and 3).
- Trafficking the surface for one or several days, depending on the traffic volume.
- To speed up the process, rolling for a pass or two to punch in the clean chip and break up the 'cake'.
- Grinding the loose chip by traffic to remove any caked-on fines.
- Drag-brooming to keep the grit in the wheelpaths.
- Careful traffic control to ensure that the full pavement width is trafficked.
- Final mechanical sweeping immediately before sealing to remove only the thin layer of loosened dust and loose chip.

Another option is:

- Watering and mechanical sweeping which can remove the material, but the basecourse will then have to be dried out before sealing. The gritting and trafficking procedure as described above can remove the fines with less water but may take longer.

When constructing a basecourse under traffic, wet weather can result in failures, e.g. potholing (Figure 7-4) of its actual surface. The problem will be much worse where there is a thick cohesive layer of fines on the base surface. If potholing does occur, the base must be scarified usually with a grader to below the base of the potholes, regraded and re-compacted. Any attempt to merely fill the potholes by grading AP20[2] material into them and rolling, will result in poorly compacted spots that will be revealed as depressions in the surface shortly after the new seal is opened to traffic. Hence it is better to drag broom to keep the surface intact (or 'hold the surface') in order to avoid pothole formation.

Figure 7-4 Even when chipsealing was less common, failures soon after pavement construction occurred, as they may do today. Here this road works team repairs a non-compliant section of freshly compacted pavement in the main street of a small New Zealand town in the 1920s.

Photo courtesy of John Matthews, Technix Group Ltd

[2] AP20 – all passing 20 mm sieve.

On lightly trafficked roads, softer cheaper aggregates may be used for chip instead of harder material complying with TNZ M/4. However these materials tend to break down under the rollers and produce more surface fines. As much as is possible, these fines should be removed to achieve a stone-mosaic surface. If this is not possible without breaking up the soft stone particles to fines, consider adjusting the first coat binder to enhance the penetration and binding of the fines. Some surfacing engineers advocate the use of slow break emulsions for this situation.

7.2.2 Stabilised Pavements

As an alternative to constructing pavements with granular aggregate material such as quarried M/4 basecourse, old road pavements are commonly stabilised in situ (Austroads 1998). This involves ripping or breaking up and pulverising the existing basecourse pavement (and seal layers as applicable to the site), then mixing in a stabilising agent such as lime, Portland cement or other proprietary products.

The aim of the stabiliser is to bind the finer soil particles (including silt and clay particles). The intention is not to create a rigid concrete slab pavement but simply to improve the basecourse aggregates to perform as much as possible like a well-graded basecourse.

General design and construction of stabilised pavements will vary widely depending on the existing material type and make-up, and the stabilising agent chosen. However the following information relating to preparing the surface of the stabilised pavement to ensure good adhesion of the seal coat will apply in all cases.

7.2.2.1 Causes of Stabilisation Failure

Stabilised bases can shed their seal coats, because lime- and cement-stabilised basecourse materials have relatively high fines content. If the fines have been bound and waterproofed by the stabiliser, achieving the stone-mosaic surface is not quite as important, provided that the stabilisation reactions have occurred throughout the entire depth of the basecourse and to its very surface well in advance of resealing.

> Where full depth stabilisation is not achieved, and these fines have not been well bound and waterproofed by the stabiliser, they can cause the repair or seal coat to fail prematurely through the same mechanism that regular basecourses with a layer of fines on top would fail, as described in Section 7.2.1.

Portland cement is a relatively quick-acting agent, but if its normal setting reaction with water is interrupted it will not attain full strength. Just as concrete will not achieve full strength if it dries out before curing is completed, the surface layer of fines of a cement-stabilised base will never achieve full strength if it dries out before the setting reaction is well advanced. It will subsequently break down under traffic forces, which results in the seal being bonded to only the layer of dust that has formed on the basecourse surface.

7.2.2.2 Remedies for Stabilisation Failure

For the above reasons, the basecourse must be kept at or near the optimum moisture content from the time the cement is first made wet by contact with the basecourse or by initial compaction watering, until the time it is sealed.

In addition, if optimum performance is to be achieved, over-watering must be prevented because it dilutes the cement mortar. It is therefore desirable to apply the seal as soon as possible after stabilisation.

> Lime stabilisation or other proprietary products (such as those based on steel-mill slag) react to water less quickly than Portland cement. However, as with cement, these products usually also rely on water being added to the mixture of stabilising agent and basecourse material to ensure reaction with the fine material.

If for any reason the stabilising agent does not react or is not fully cured, a build-up of unstabilised fine material on the surface is likely. This fine material or dust layer must be removed before first coat sealing.

The problem of a layer of dust on the stabilised basecourse surface can also arise if:

- the stabilising agent or cement content is too low to bind the fines;
- very soft, coarse- and medium-sized aggregates are used without enough strong cement and fines mortar around them to bind and protect them;
- the surface of the base is over-watered or unexpected rain occurs, diluting the cement mortar and lowering its strength;
- surface shaping or trimming is attempted after the stabilisation agent has cured.

Provided good stabilisation construction practices (including any recommendations from the supplier) are followed during construction, very little unstabilised or loose fine material should remain on the compacted base surface. Sweeping should be as light as possible, and only enough to remove loose material. Sealing should follow as soon as the loose material has been swept off to prevent excess drying of the surface and/or the formation of additional fines caused by traffic action.

7.3 Preparation for Reseals

The actions required to prepare existing surfaces before resealing are now discussed. The desirable timing for carrying out and completing the repairs is listed in Table 7-1 (Section 7.1.4).

7.3.1 Investigation

Preseal preparation before resealing may fall into any of the three following categories:

1. Drainage and shoulder repairs;
2. Road pavement (surface and base) repairs; and
3. Top surface texture repairs.

Determining the amount and type of repairs that are necessary requires careful and detailed inspection of the area to be resealed.

In today's road construction and maintenance environment, the person carrying out the inspection, mark-out and recording of preseal repairs may be an employee of the local council or other road controlling authority (RCA), an engineering consultancy, or a roading construction company. Whoever the person works for, they are to carry out a preseal inspection during which they will consider the following questions and then programme the relevant repair solutions accordingly:

1. Do the drainage facilities work effectively?
2. Are road shoulders and adjacent verges in need of attention?
3. Is there edge rutting or edge break?
4. Are there potholes, shallow shear failures, cracks or cracked areas in need of repair?
5. Are there service trenches showing signs of settlement or requiring joint-sealing, pre-levelling or structural repairs?
6. Are there manholes and other utility service covers that require adjustments to be level with the proposed surface?
7. Are there depressions, wheel-ruts or other pavement deformations that require pre-levelling?
8. Are there areas of uneven surface texture, chip loss or flushing?
9. Are there flushing and bleeding spots?
10. Is the cement grouting of road bases on concrete roads intact, and are tree roots likely to lift concrete bases?

11. Check vehicle crossings:
    - Do vehicle crossings cause scraping of car towbars, exhausts or other fittings?
    - Are slot crossings clear or blocked?
12. Are subsoil drains (under the channel or the pavement) needed?
13. Is the surface permeable?
14. Are there weeds or other deleterious matter (mud, dust, moss, lichen, etc.) that have to be removed?
15. Are K&C effective with no high lip at channel edge or isolated sunken lengths of channel?
16. Are there any water-ponding areas on the surface?
17. Are K&C and other related drainage structures in poor condition?

Typical solutions for preseal repairs are covered below in Sections 7.3.2 to 7.3.5.

7.3.2 Drainage and Shoulder Repairs

7.3.2.1 Off-road Drainage

> Moisture is the main enemy of road pavements and impacts significantly on the performance of both the pavement and of any surface treatment.

Drainage from the surface, and beyond and away from the pavement base, must be unobstructed to ensure optimum performance.

Because cleaning, repairing, modifying or constructing new drainage channels (whether they are open-cut earth drains, roadside water tables or formed concrete channels, or K&C) all involve heavy construction machinery, any sealed surface may be damaged. New chipseals which are very tender, and thus more prone to damage within the first few months after sealing, are most likely to be damaged in this way.

> Therefore any drainage repairs, major cleaning, or other works should be undertaken well before resealing works are carried out.

7.3.2.2 Shoulder Repairs (including Edge Rutting)

Shoulders and feather edges, as well as supporting the pavement, also need to be of the correct shape to promote rapid run-off of surface water (see Figure 3-1).

If that is not correct, water can get under the pavement layer by infiltration from the adjacent shoulder. More often than not this is also the area closest to the wheelpath that is on the outside edge of the pavement. In that position, it is subject to maximum loading.

Causes

A shoulder not flatter than 12:1 is recommended because too flat a shoulder will slow down run-off. Where shoulders are grassed, compost will accumulate as a result of repeated mowing and will form a lip which prevents rapid run-off and often causes water to run parallel to the centreline or to pond on the surface in low areas. Depending on climatic conditions, this material needs to be removed regularly (every two or three years), and definitely before a surface treatment is applied.

Edge rutting (i.e. the formation of a channel parallel to the edge of the seal) also causes water to run or pond close to the edge of the trafficable surface. It can also be a danger to traffic if allowed to become so deep that the wheels of a straying vehicle get trapped in the rut. Edge rutting also promotes the development of edge break (see Section 7.3.2.3).

Remedies

Shoulder grading, dressing and, where appropriate, build-up with extra aggregate material or removal of surplus material is often necessary before re-surfacing. Grass should be removed from the edge of the seal before resealing because long grass becomes limp from the heat of the reseal bitumen, then falls onto the new surface, contaminating and weakening the seal.

7.3.2.3 Edge Break

Edge break is the loss and/or breaking away of existing bituminous surfacing material at the outside edge of the sealed surface.

Causes

Edge break often occurs where the surfaced width is too narrow, on insides of tight curves with a lack of pavement support (caused by edge rutting or too steep a shoulder), or where moisture has weakened the outside edge.

It can also occur when a previous reseal has not been properly lapped onto an adjacent concrete K&C, or dish channel (i.e. a shallow U-shaped channel).

Remedies
To prevent a rapid increase of the edge break, which creates discomfort to the travelling public and affects the overall integrity of the pavement and to ensure a uniform width of carriageway, edge break needs to be repaired before a new surface treatment is applied.

Repair methods will differ depending on the defect size, location (in relation to the nearest supply of materials), and the maintenance contractor's plant and resources (as dictated by the relevant maintenance contract).

In urban areas, edge break is typically repaired by reinstatement with hot mix (i.e. asphaltic concrete).

In rural areas, basecourse and first coat seal using a binder of emulsion or cutback bitumen, cold mix, or hot mix may be used.

7.3.3 Pavement Repairs

Repairs, commonly called 'digouts', may be required on sections of the road pavement, either to the basecourse or to the surfacing layers.

Causes

> If the structural layers of the pavement are weak or have washed out, they need to be strengthened by digout and replacement.

Causes of these defects are outlined in Chapter 3.11, but most preseal defects are caused by loss of waterproofing and ingress of water. This may be either through cracks, potholes or wash out, and they affect the lower structural layers of the pavement, not the surfacing.

Remedies
Any of several pavement and/or surface repair methods may be suitable for any particular defect noted for repair. The particular method will relate to depth or type of basecourse failure, available resources and materials, location and traffic loading, and an RCA's current practice and contractual requirements. Detailed below are the more common or typical defects and possible repair types:

7.3.3.1 Cracking

A good understanding of the cause and type of cracking is essential for effective treatment of the defect. Read Sections 3.11.2, 4.3 and 4.7.3 which outline the typical causes of cracking including fatigue of the seal, structural damage, and environmental effects.

If the symptoms are not carefully analysed to ascertain the causes, the treatment of those causes may be inappropriate and will result in an ineffective reseal.

> Before jumping to the conclusion that crack repairs are needed, it is important to remember that some minor cracking can be a normal end-of-life condition for a seal on an otherwise sound pavement.

In such a case the reseal is applied specifically to fix and seal the cracks. Hence if an area does not need shape or drainage repairs, there is no need to repair any minor cracking before resealing.

Causes

In addition to cracks caused by fatigue, structural damage, binder ageing and oxidation, some environmental effects that cause cracks which have not been discussed in previous sections include:

- effects of moss and lichen;
- heave from plant growth, frost or chemical effects;
- surface cracking caused by tree roots, if trees were planted closer to the road than their height. If the trees are to be retained, then their roots may need to be cut between the road and trees, with a purpose-built deep cutting saw or ground knife.

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Cracks that are discoloured by fines pumping up from the basecourse indicate that water has penetrated through the surface and into the base. The pavement will have weakened, and loss of shape, localised rutting, or potholing may have occurred. These areas require repair before resealing.

Effects

> Cracked pavements are not waterproof. Ingress of water into pavements significantly reduces their strength and pavement failure will ultimately result. Premature cracks in asphalt surfaces generally mean weak base materials and high deflections.

Remedies: Treatment of structural layers

Where the pavement base or the subgrade has obviously become unstable and a surface treatment is not an appropriate repair, localised pavement or subgrade rehabilitation will be required. This could involve:

- removal and replacement of the affected pavement and/or subgrade layers (i.e. digouts);

- in-situ stabilisation of the base layer (see Austroads 1998);
- granular overlay (see Austroads 2004a) with a sufficient depth of material (though this is not practical on urban roads with K&C);
- subsoil drainage installation in association with any of the above;
- re-surfacing of the treated area with a first coat seal or asphaltic concrete layer.

Where only the basecourse or surfacing layers are likely to have been affected, the treatment may be limited to drainage improvements in conjunction with shallow repair methods such as rip and remake, in-situ stabilisation, or scarify and surface repair.

Even if the treatment does not totally fix the problem area, the person overseeing the pavement repair must be sure that it will not compromise the expected life of the proposed reseal about to follow.

Remedies: Treatment of surface layers

> Where cracking is *hairline* (<1 mm wide) and affects less than 5% of the pavement, a normal reseal using chipseal with a chip size that gives a binder application rate of greater than 1.5 ℓ/m^2 may be appropriate.

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Where crack widths are *narrow*, about 1 to 5 mm, bandaging or a SAM[3] seal is used. In the bandaging technique the hot binder is poured on to the cleaned pavement and then spread with a metal tool to make a 'bandage' 2-3 mm thick and 75-100 mm wide (Figure 7-5). If using a SAM, binder application rates in excess of 2 ℓ/m^2 will be required. Binder applications of more than 3 ℓ/m^2 using a PMB (polymer modified bitumen, see Chapter 8.4) with a two coat Grade 3/5 seal have been successful without subsequent bleeding and tyre pick-up.

However, where crack widths are 3 mm or wider, the hot PMB of the SAM can flow into the crack, resulting in only a thin film which cannot form a good membrane over the crack. Therefore wider cracks should be filled with special filling materials before the PMB membrane is applied.

On *5 to 15 mm-wide cracks,* bandaging is advisable on surfaces that are laid hot. If the surface is laid cold, or laid on a cold surface, 'crack filling' is used. In crack filling, the crack is cleaned or routed, primed and then carefully filled to the top with the crack-filling binder. This gives support to the crack edges.

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3 SAM – Stress Absorbing Membrane.

Figure 7-5 Filling a large joint crack using the bandage technique.

Courtesy of Austroads Sprayed Sealing Guide (2004b)

Wide cracks (>15 mm) are generally filled. In some applications, e.g. bridge decks, the bottom of the joint is filled with foam plastic to obtain the best width to depth ratio, and to stop the hot binder flowing down through the joint.

Large joint cracks or cemented-pavement slab cracks (of greater than 2 mm width) should be separately treated by joint bandaging or other linear crack filling methods.

Crack repair methods, e.g. bandaging and crack filling, are known collectively as 'crack sealing'.

Cracks with no signs of pumping, or only minimal pumping and no other failure, can be resealed. However, ensure at the time of reseal design that binder application is at a high enough rate to fully crack-seal the pavement surface.

Cracks with signs of pumping are generally caused by structural defects which must be remedied before any surface sealing can be done.

Reflective cracks can be treated effectively using these methods, but even after a successful repair some of the more severe reflective cracks may re-occur. Normally any such reflective cracks would be narrower and less extensive than those that had occurred on the initial defective pavement.

Opinion varies on the minimum binder application rate (regardless of traffic volumes or chip size) to waterproof a cracked pavement surface by sealing. Most sealing practitioners work within a range of 1.0 ℓ/m^2 and 1.5 ℓ/m^2 as a minimum amount of binder if crack sealing is a key reason for the planned reseal.

Very extensive pavement cracking, where crack filling is not an economic option, or the cracks are narrow but extensive and cannot be filled with a normal chipseal with a higher bitumen application rate, the use of a PMB (e.g. SAM or SAMI[4]), or a geotextile (fabric) seal can be an economic alternative to preseal repairs. More information about use of PMBs in SAM and SAMI seals is in Section 8.4.

Precautions when Crack Sealing

In areas where traffic may stop or park the bandage should be covered. This is normally done by applying a layer of small chip, such as Grade 5.

In areas subjected to high traffic volumes, the bandage can be peeled off the surface by tyre action. In these areas the covering of the whole pavement with a chipseal can protect the edge of the bandage. Although the resulting pavement may look unsightly because the bandage reflects through the chipseal, this technique has given seal lives in excess of 10 years.

If the surface surrounding the crack is dirty then a primer should be used to ensure a good bond. When crack sealing on concrete, it is recommended that a primer always be used, as recommended by the manufacturer of the crack-filling material.

On wider cracks the width of the crack will change with temperature. For example, in summer, crack widths will be narrower than in winter due to the expansion of the surrounding material. Therefore crack filling normally should be carried out in cooler weather when the cracks are larger, but without overfilling so that the binder will not squeeze out when the crack narrows in warm weather and be picked up on tyres.

4 SAMI – Stress Absorbing Membrane Interlayer.

7.3.3.2 Depressions, Wheel Ruts and Similar Deformations

Causes

Depressions, wheel ruts and similar deformations usually form in inadequate pavements that have been weakened, for example by the ingress of water (see Section 3.11). Pavements with these deformations need to be investigated to ensure they meet the standards for roughness set by many RCAs. If the road surfaces do not meet these standards, they require maintenance. Most surfacing treatments are expected to last at least 10 years, and this is a long time to live with an uneven surface.

Effects

As a general rule, the following faults need to be attended to before a re-surfacing treatment is applied.

- Deformations that affect safety, such as wheel ruts, which could cause:
  - vehicles to track;
  - bitumen to pond during resealing, creating a longitudinal flushed wheelpath (because chip along the sides of the rutting where application rate is low will pluck off, while chip along the trough will be 'drowned' with flushed binder).
- Deformations that hold water which could:
  - infiltrate the pavement layers through a permeable surface;
  - cause splashes that, especially in high speed situations, could reduce visibility for both oncoming and following traffic;
  - potentially cause aquaplaning;
  - freeze or cause splashes that could freeze;
  - cause ponding of bitumen when resealing and show as isolated bleeding or flushing areas later.
- Sudden change in the superelevation of a curve needs to be considered as a reason for repair, especially in high speed environments. This is distinct from a general out-of-shapeness through the whole of a curve which, normally, is fixed by an area-wide treatment such as shape correction.
- Intersecting roads or side roads which are not correctly constructed and interfere with the normal crossfall on the road to be re-surfaced. This situation will cause an uncomfortable ride in most situations and can be dangerous in high speed environments. It will require careful consideration to rectify the fault.

- Sunken service trenches, often found in urban situations but not necessarily isolated to those areas, need to be repaired and/or levelled.
- Low or high service covers are often the cause of a rough, uncomfortable ride and should be considered for adjusting to match the proposed surface or, as a minimum, for rectification by smoothing the surrounding area to improve the riding qualities.
- Low areas, either as isolated depressions or as a form of rutting alongside surface water channels which prevent surface water from running into the channels, need to be rectified. This fault often occurs in urban areas alongside K&C.

If such faults are not fixed, after some time water may find its way into the pavement causing a weak area. This may develop into a shear failure or may accelerate any edge break as previously discussed.

Remedies

Treatments will include pavement digout and replacement, or other methods of strengthening and should be carried out before chipsealing. Innovative treatments for ruts include filling ruts with slurry (Figure 7-6), or dry chipping a rutted area before chipsealing (Figure 7-9).

Type 4 slurry is suitable for treating wheelpath rutting (Figure 7-6). Longitudinal trenches up to 40 mm deep can also be effectively repaired, resulting in a surface that can be resealed with minimal risk of chip embedment in subsequent seal coats. This work is usually carried out with a specialised rut box, designed to deposit the larger chip in the deepest part of the rut and the fines on the edges. This ensures a very smooth ride with excellent transitions and smooth edge tapers which do not 'fret' (or ravel). This has been used successfully in the South Island but not so much in the North Island.

7.3.3.3 Potholes, Shear Failures and Weak Areas

Causes

Potholes form when patches of the pavement surfacing are lost and the underlying basecourse is exposed.

Their formation is briefly covered in Sections 3.11 and 7.2.1.1. Weak areas which can lead to potholes or depressions can usually be located by the presence of some surface distress, and cracking is often its first sign. While repairing such areas, the cause of the distress should also be attended to.

Moisture in pavements, whether through the surface, from the side (from poorly constructed drainage channels), or from below (by subsoil water or capillary rise), is usually the cause of these surface defects.

Figure 7-6 These ruts have been filled with slurry, after which the entire surface will be chipsealed.
Photo courtesy of Barry Gundersen, Gundersen Consulting Ltd

Remedies
Potholes and shear failures (explained in Section 4.7.4.2), and broken surface areas need to be repaired in preparation for sealing. Potholes may be repaired by digouts, either to the basecourse or just to the surfacing layers.

To avoid subsequent flushing and/or bleeding, the surface texture of repairs must match the texture of the adjacent surface as closely as possible.

Weak areas can sometimes be detected by carrying out a series of Benkelman Beam[5] or other relevant tests. Those familiar with this test and interpretation of its results can, by plotting a curve of a series of readings at a particular point, determine whether a weak zone exists in the upper pavement layers or is deep-seated.

A penetrometer[5] is another relatively simple instrument used to identify weak subgrade conditions which can lead to weak pavement layers.

The Falling Weight Deflectometer (FWD[5]) can be used to assess overall pavement strengths and strength characteristics.

5 See Glossary for explanations of these instruments.

In summary, when there is doubt about the appropriate treatment, some further investigation may be required before embarking on a particular type of repair for potholes and other failures caused by pavement weakness.

7.3.3.4 Rough Surfaces

Causes

Isolated rough areas (sometimes known as 'wash boarding') need to be fixed where the level of roughness is unacceptable, especially if they occur in areas where resealing is required. They can be caused by traffic, e.g. by braking vehicles, but can be caused by other deformations as discussed in Section 7.3.3.2. They may occur because the pavement is nearing the end of its life.

Effects

Such areas cause either an uncomfortable ride for the motorist or unacceptable effects on the environment, e.g. an empty stock truck travelling over a rough area in an urban situation can generate unacceptable noise.

Remedies

Smoothing with a mix material is not always possible where the areas are small and they do not cover a complete lane width. Often smoothing only changes the pattern from many small irregularities to two or more larger ones. If that is the case, removal and replacement of the offending area may be required. This repair may be in the form of rip and remake (or recycle or stabilise), and apply a first coat seal, or hot mix asphalt re-surface.

If high roughness is the result of the pavement nearing the end of its useful life, road re-construction such as pavement smoothing or Area-Wide Pavement Treatment (AWPT) should be considered.

If the area of preseal works (as a % total reseal area) and/or cost of reseal works (as a % of reseal cost) is so high that it is more economical to reconstruct, then pavement smoothing or AWPT should be considered. See Chapter 5 for more details on economics and asset management.

Where the area of roughness occurs on an asphaltic concrete surface which is to be resealed, and sufficient quantity of work is available to warrant bringing in a milling machine, milling-off of the offending area can be very effective. Some texturising before sealing may then be required.

7.3.4 Surface Texture Repairs

For chipseal treatments to work successfully, they must be applied to a uniform sound base layer. Sections 7.3.2 and 7.3.3 describe repair methods to form a sound base. This Section 7.3.4 focuses on achieving a uniformly textured surface on which a reseal is applied.

Four separate categories require consideration when determining if the existing top-surface texture is suitable for resealing. They are:

- Chip loss (also called stripping);
- Flushing (binder has risen up the chip leaving minimal texture depth);
- Uneven texture (e.g. repair patches with a different texture to the surrounding surface);
- Permeable surfaces.

7.3.4.1 Chip Loss

Causes

Repair of chip loss on an existing surface is essential before re-surfacing. The cause of chip loss or 'stripping' of new seals usually relates to insufficient binder application, high stress (e.g. caused by turning traffic), dirty chip. (See Sections 12.6.3 and 12.6.4 for repair of chip loss early in a chipseal's life.)

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Chip loss can also be related to ageing when it is much more likely to relate to bitumen hardening or embrittlement, or to a site-specific condition or event that has affected the otherwise normally performing chipseal. Shaded areas, such as under- or overpasses and bridges, large cut-faces, or near large trees, are more prone to chip loss as the seal ages. The seal may also be damaged by heavy machinery, e.g. during slip clean-up work after a major storm event, or at stock crossings.

Effects

Lack of pre-treatment of any chip loss areas before resealing may lead to either early flushing or further chip loss. The difference in macrotexture will also affect the surface ride and roughness.

The surface texture is also likely to differ from the surrounding seal, thus making the determination of an appropriate area-wide binder application difficult.

If the application rate is determined for an area that still retains chip, it will result in over-application in areas devoid of chip and thus result in flushing. If the rate is determined on the smooth texture where chip loss is apparent, then it will be insufficient for those areas with existing chip. This low application rate will lead to early chip loss of the new seal.

Remedies

The areas with chip loss either will have to be repaired before sealing the whole area, or different rates will have to be applied to affected parts of the area.

If the height difference between the chip loss area and the surrounding seal is obvious, repair will be required. This will involve re-spraying of binder and rolling in new chip. The replacement chip size is carefully selected to ensure that the post-repair surface texture and level closely match the surrounding seal. For example, a repair area in an old Grade 2 chipseal may require finer Grade 4 chip to make the surface levels match. The binder application rate will be based on the Grade 4 ALD and reduced to account for any free binder at the surface in the chip loss area (Figure 7-7).

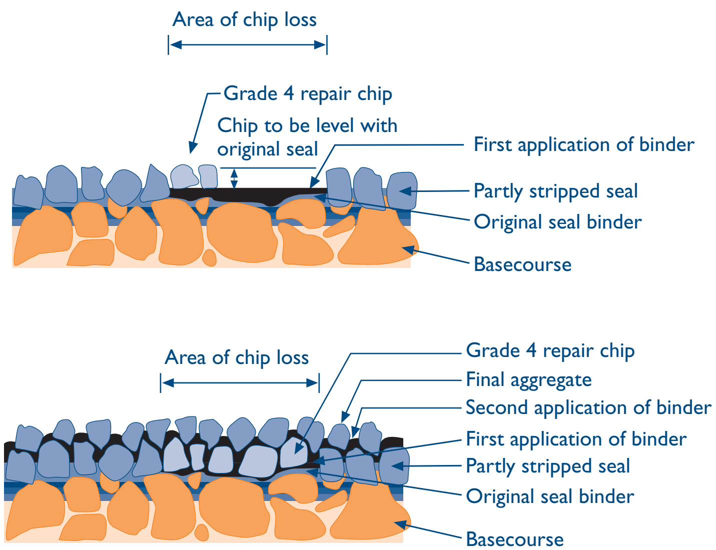

Figure 7-7 Method of matching areas of chip loss with surrounding surface levels. Top: Area of chip loss to be repaired. Bottom: Completed repair of area of chip loss.

Where the chip loss is intermittent and/or the height difference between the stripped area and surrounding seal is minimal (<5 mm), removal of excess or free binder from the stripped areas is recommended before making a preseal repair using fine chip, if fine chip is the chosen repair method.

A high pressure water treatment, as discussed below in Section 7.3.4.2, is the recommended repair method in this situation.

7.3.4.2 Flushing

Flushing creates a smooth pavement surface caused by excess binder rising to the surface for various reasons. Where the existing surface has flushed to the extent that the selected surface treatment cannot cope with the difference in surface texture or the quantity of surplus binder, the surface will need to be rectified.

Causes

Flushing can occur in isolated areas, often where repairs have been carried out, where the chips have either been pounded into unstable underlying repaired areas, or the quantity of binder needed to waterproof the work has been misjudged. It can also be quite general, for instance where all the wheelpaths have flushed (Figures 7-8 and 7-9).

Figure 7-8 A surface in which the wheelpaths have flushed. Note evidence of vapour venting (many small circles of bitumen) on the surface. Photo courtesy of Mark Owen, Transit NZ

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Figure 7-9 Dry chipping a flushed area before chipsealing the entire surface.
Clockwise from top left in order of construction: Original surface marked out to show area to be dry chipped. Top right: Dry chip laid in wheelpaths. Bottom right: Binder is laid lane by lane over the dry chip. The next step is to lay the chip over the binder as for a conventional reseal. Bottom left: The completed surface.

Photos courtesy of Lindsay Roundhill, Opus

Remedies

Various repair methods are available to deal with surface flushing. Some are directly applicable to preseal preparation works, and others are more suitable as a resurfacing alternative to standard resealing.

Flushing treatments suitable for preseal preparation include:

- high pressure water treatments;
- rolling in new chip after applying:
  - a bitumen cutter such as kerosene or mineral turpentine, although bear in mind this technique can cause flushing later, as explained in Section 4.7.4, or
  - a very light coat of heavy cutback bitumen.

Flushing treatments suitable as resurfacing alternatives are:

- sandwich seal;
- OGPA (Open-Graded Porous Asphalt); or
- SAM (Stress Absorbing Membrane) seal.

Sandwich seals and OGPAs can accommodate the excess binder in voids within the new layer.

Flushing occurs not only on chipsealed surfaces, and asphaltic concrete surfaces can suffer from the same trouble (Figure 7-10). Careful attention is needed to identify the cause of the problem before deciding on the next treatment, and whether or not any pre-treatment is required.

Figure 7-10 Flushing which has reflected through an asphaltic concrete surface.

Photo courtesy of Les McKenzie, Opus

'High pressure water treatment' is a collective term for water blasting and water cutting (Figure 7-11) which are relatively new techniques to New Zealand. Both use jets to direct very fine streams of water at the road surface.

- Water blasting uses a water pressure of approximately 15 000 psi at high volumes;
- Water cutting uses ultra-high pressure (up to 36 000 psi) but at low volumes, as the very high speed of the water provides the desired cutting action.

Many practitioners believe water cutting has advantages over water blasting and should be used where the equipment is available. Whichever is used, such high pressure water treatments can cause damage and reduce waterproofing if used incorrectly. Both techniques are capable of restoring macrotexture on a chipseal (Figure 7-12), although this may be more difficult to achieve on flushed PMBs.

These high pressure water techniques have replaced the pavement burner treatment which was phased out recently because of environmental concerns. A total ban on all

Figure 7-11 A road surface undergoing high pressure water treatment as a repair for flushing.

Photo courtesy of Les McKenzie, Opus

pavement burning came into effect in August 2004 as part of the National Environmental Standards (NES) relating to air pollutants, regulated under the RMA. The NES (2004) will override any existing permits or consents to use the pavement burner. Therefore road network managers will have to use other binder removal techniques for road maintenance and repair, e.g. these high pressure water treatments.

Water cutting is claimed to be more effective in restoring microtexture than water blasting. Skid resistance testing using the British Pendulum Tester (BPT), showed an increase in BPN (British Pendulum Number) directly after water cutting in a Fulton Hogan research project (Dr B. Pidwerbesky, pers.comm. 2002). However determining if the improvement in microtexture (and hence skid resistance) is associated with the removal of bitumen from the chip, or if the chip surface itself is being refreshed, is difficult. The life of the improvement in microtexture from water cutting is part of a current research project.

Water blasting uses much greater volumes of water than water cutting. On older surfaces this water can penetrate the seal layers and damage the upper basecourse, and also disrupt the seal to basecourse adhesion.

For small-scale operations, such as treating flushed patches in an otherwise sound seal, a small truck-mounted hand-lance system may be used. However, as required in TNZ P/26:2003 specification, the high pressure water equipment is to incorporate a collection system to uplift the removed detritus at the time of operation from the road surface.

Figure 7-12 A chipseal that is seriously flushed and requires restoration of texture.
Left side shows flushing several millimetres thick above the original chip surface, exacerbated by many layers of grit that have been applied to mop up bleeding binder. Right side shows the same seal after water blasting. The original surface with adequate texture depth has been restored.

Photo courtesy of Les McKenzie, Opus

The detritus of excess binder, grit and dirt must be collected and removed, and not make a mess of the roadsides, run into stormwater drains, or remain on the sealed surface to become re-attached to it. Self-contained machines have integrated vacuum pick-up systems to cope with these conditions. Using equipment without an integrated pick-up system needs screens to block the scattering of detritus, and sediment traps in drains.

For a generally soft surface and other area-wide flushed areas, the entire surface needs to be treated. To do this, purpose-built truck-mounted systems are used that can treat a wide strip of road surface evenly in each pass.

7.3.4.3 Uneven Texture

In an existing seal, isolated areas of texture that vary significantly from surrounding areas need to be pretreated before resealing.

The treatment for uneven texture is a 'texturising seal'. A texturising seal is used to prepare a surface for a reseal by reducing texture variation. It differs from a voidfill because in some cases it will reinstate texture and not just fill in the gaps between chips. It may be applied to only isolated areas within a reseal site to either fill texture or reinstate texture. The necessity for and amount of preseal texturising required depend very much on the reseal type that is selected.

Texturising involves either:

- filling existing deep-texture areas, e.g. road seal edge or centreline, where the chip is not normally trafficked, or
- reinstating texture, e.g. over an asphalt patch surface repair or trench line cut into a chipseal.

Texturising is usually limited to only those areas that are significantly different to most of the existing seal. Texturising should not be mistaken for voidfilling (see Section 3.7.9 for definition and use of a voidfill seal).

A texturising seal is a localised, situation-specific chipseal, involving a binder spray coat followed generally by a coat of Grade 5 or 6 chip. As it is likely that texturised areas will be covered by a reseal, careful attention must be given to selecting a suitable spray rate. The spray rate must be enough to ensure chip adhesion but not so much that flushing or bleeding results.

The normal reseal spray design algorithm is based on the voids between existing chip crowns being filled with binder. For texturising of deep-textured areas, the new chip will sit between the existing stone crowns. Therefore the texturising seal spray rate will need to be reduced.

Careful consideration should also be given to the binder type used. Heavily cutback bitumen should be avoided as the diluent content will most likely not have evaporated off before any subsequent reseal. The trapped diluent will soften the reseal binder and cause premature flushing or bleeding. Where available, emulsion is recommended for use as the binder in the texturising seal.

7.3.4.4 Permeable Surfaces

Just as variable texture surfaces require pretreatment before chipsealing, so do permeable or porous surfaces. Typical permeable surfaces requiring pretreatment will include OGPA (also known as friction course or OGA, open-graded asphalt) and OGEM (Open-Graded Emulsion Mix) (described in Section 3.9.1).

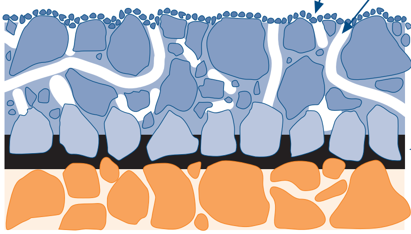

Figure 7-13 A permeable or porous surface, such as an OGPA or OGEM, requires pretreatment with a preseal Grade 6 or grit coat to prevent excess absorption of binder in the reseal.

As these open-graded mix surfacings are porous by design and have a large percentage of voids, they will readily absorb the reseal binder unless some pretreatment is carried out.

While these materials become less permeable with time because of traffic densification and choking of voids with road dirt and other deleterious materials, the voids remaining at the end of the useful life of the mix-surfacing will require treatment before chipsealing as they still absorb more binder than a non-porous road surface. A constant water-head test is used by some RCAs to determine the effectiveness of the drainage properties of the OGPA, and whether the surface is porous or clogged up.

The preseal treatment for permeable surfaces involves sealing off the top of the porous layer to prevent the binder from the reseal from being drawn down into it (Figure 7-13).

One treatment option involves spraying the permeable surface area with an emulsion binder (as a light application only), and then spreading a fine chip (Grade 6), grit or coarse sand over the sprayed surface area. The area is then rolled or trafficked to close off and tighten the surface ready for resealing.

Another option is a two-coat final surfacing using an emulsion binder (without the need for a preseal Grade 6 coat). The risk of failure is high when sealing over a porous surface without pretreating with a preseal Grade 6 coat or grit, because the amount of binder which will be 'sucked up' is unknown. The repair of the resulting failure is very difficult.

7.3.5 Removal of Deleterious Matter

To ensure adequate adhesion of the reseal binder to an existing surface, all contaminants, dust, organic and other deleterious matter must be removed first.

If removing deleterious material is the responsibility of the re-surfacing contractor, this responsibility should be clearly communicated to them, e.g. in the contract documents. They will need to make considerable extra effort to carry it out, and if they have been informed, they can plan for it and avoid unnecessary delays at the time of sealing.

Some treatments such as chemical weedspraying will need to be carried out well in advance of the reseal works because they may take time to become effective. This activity should be programmed a few weeks or months in advance of the re-surfacing treatment.

Using large quantities of chemicals for weed spraying is environmentally unfriendly, affecting road users, local residents and stormwater. Its use should be considered carefully and consultation with public or affected land owners must be undertaken. Run-off from sprayed areas must be controlled so that it does not contaminate the stormwater.

Use of weedkillers may not be appropriate in urban areas, and other treatments should be considered instead. Some authorities have found a light application of lime to be as effective and economical. Steam treatments have also been used. These treatments and final sweeping with rotary brooms may be carried out immediately before sealing. Hard sweeping with appropriate steel-wired brooms (without chemical treatments) may be useful for surface preparation in some situations, and may be all that is needed.

Lichen removal by aggressive brooming may be necessary on low traffic volume roads before a reseal treatment. The hot cut-back bitumen of the reseal will, in most cases, burn and kill any remaining lichen, so the binder will readily adhere to the existing stone below.

Emulsion chipseals and slurry seals do not adhere well in areas affected by lichen and in some cases have been observed to even accelerate the lichen growth. Therefore pre-treatment is essential in these situations.

Vehicles may pick up metal and debris along unsealed roadways and private drives, and then track this material across intersections and entrances onto newly sealed main roads. If this is likely, sealing some distance back along the unsealed road in the approach to the intersection should be considered. Then the tracked material should fall off the tyres before the intersection. The cost involved in extra sealing is low compared to the damage that the material will cause to the new seal.

7.4 References

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CHAPTER EIGHT

Chipsealing Materials

Previous page: A modern aggregate crushing and screening plant separating crushed aggregate into stockpiles of different sizes of sealing chip, at Whitford Brown Quarry, Auckland.

Photo courtesy of Joanna Towler, Transit NZ

Chapter 8 Chipsealing Materials

Chapter 8 Chipsealing Materials

8.1 Bitumen

8.1.1 Introduction

This section provides coverage of the basic practical details of bituminous binders. For greater detail, the reader is referred to *The Shell Bitumen Handbook* (Read & Whiteoak 2003).

8.1.1.1 Nomenclature

Bitumens (Figure 8-1) are black, pitch[1]-like materials obtained from refining crude petroleums which originated as organic deposits in the earth's crust. They are known for their waterproofing, sealing, cohesive and adhesive properties. In the US bitumen is referred to as asphalt and occasionally as asphaltic bitumen or asphaltic cement. (The mixture of aggregate and bitumen that is called asphalt in New Zealand is called asphaltic concrete in the US.)

Coal and wood tars, by-products from the production of coal gas for lighting and heating in the late 19th and early 20th centuries, are no longer available or used in New Zealand for road construction (see Section 1.4). Instead bitumen and bituminous materials are generally used on roads in New Zealand.

The bitumen in a chipseal is often referred to as a 'binder' in this book as it has a cohesive and adhesive function. The word 'binder' can also be used for bitumens which are diluted, e.g. cutback bitumen, or modified, e.g. emulsions.

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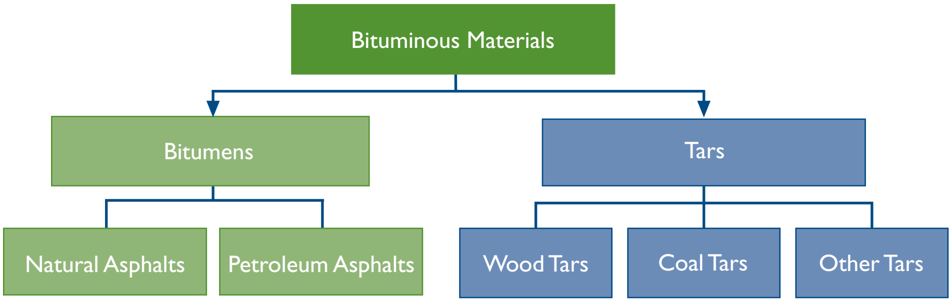

Figure 8-1 Types of bituminous materials available for sealing pavements. Note that tars are no longer used in New Zealand.

[1] Pitch – dark brown or black resinous substance, insoluble in water, soluble in some organic solvents; usually obtained as distillation residue of tar, turpentine and some oils.

When crude oil is distilled to produce such materials as petrol, diesel and lubricating oils, an asphaltic bitumen residue is left. Further refining of the residue yields roading grade bitumens.

8.1.1.2 Safety with Bitumen

This topic is covered in the Roading NZ Code of Practice BCA 9904 (NZ PBCA 2000), and in *The Bitumen Safety Book* (NZ PBCA 2001) referred to in Chapter 2.

8.1.1.3 Bitumen Specifications

Bitumen in New Zealand is specified in accordance with TNZ M/1:1995 *Specification for Roading Bitumen*. In Australia, the bitumen specification is AS 2008 which has important differences to the New Zealand specification, and the two are not interchangeable. The basic tests that are used in bitumen specifications in New Zealand are outlined in the following sections. Other properties that might also be measured are outlined in later sections.

8.1.2 Penetration Grading, Viscosity, and Other Properties of Bitumen

The properties of bitumen which are discussed here are penetration, viscosity, ductility, stiffness, age hardening and durability. These rheological properties[2] describe the way bitumen responds to an applied force by evaluation of its time–temperature dependent responses.

8.1.2.1 Penetration Grade and Testing

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The penetration test (ASTM D5) determines the hardness of a roading bitumen by measuring the distance, in l/l0ths of a millimetre, that a needle weighted with 100g will sink in 5 seconds into a bitumen sample kept at 25°C temperature (Figure 8-2). (Other temperatures are sometimes used.) For example, a 40/50 penetration grade bitumen allows the needle to sink or penetrate between 4 mm and 5 mm, and a 180/200 grade to penetrate between 18 mm and 20 mm into the bitumen.

New Zealand bitumens are graded by their penetration hardness, which is the result of the penetration test (carried out according to ASTM D5, and are therefore called Penetration Grade Bitumens). The two basic grades produced at the New Zealand Refining Company at Marsden Point (Whangarei) for use in New Zealand, are 40/50 and 180/200. Intermediate grades such as 60/70, 80/100 and 130/150 are produced for specific requirements at bulk stores by blending these two grades. Bitumen may also be imported into New Zealand.

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2 Rheology – the science of the flow of matter.

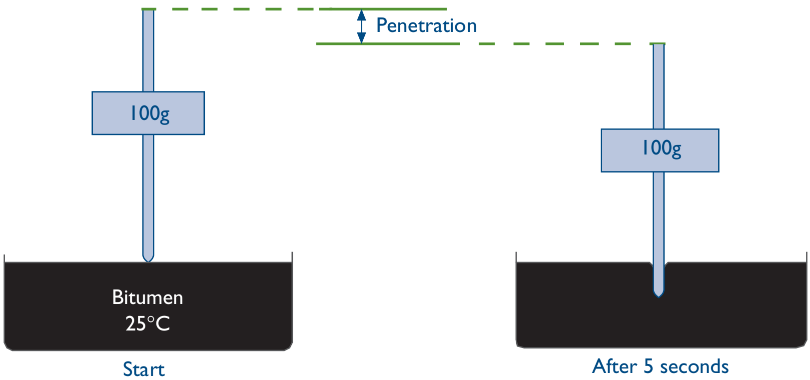

Figure 8-2 Standard penetration test used for TNZ M/1 Specification for roading bitumens.

8.1.2.2 Viscosity

Viscosity (η) describes the ability of a fluid to resist flow. For example, a very thick or sticky fluid has a very high viscosity, whereas a thin runny fluid has a low viscosity.

Viscosity is measured by a viscometer, of which there are many types. Most work on the principle of measuring the rate of flow through a narrow tube or orifice. The flow of a very viscous bitumen may be forced by an applied pressure or vacuum, but for a less viscous bitumen the liquid may be allowed to flow by gravity and its own weight. In the latter case the viscosity is known as the kinematic viscosity (ν) and is measured in mm^2/second (Figure 8-3). This is the SI (International System) unit for the identical older unit, the centistoke (cSt).

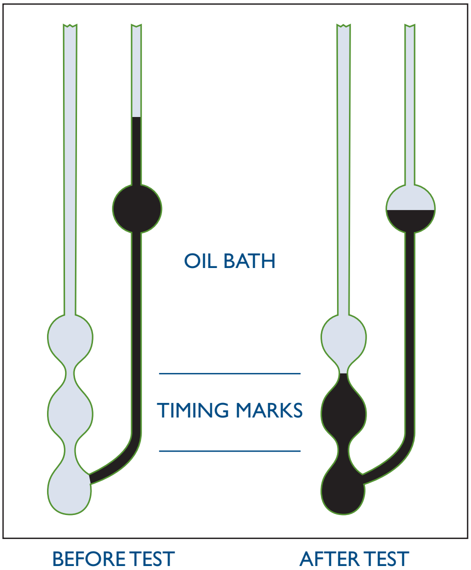

Figure 8-3 Measuring the viscosity of a bitumen by viscometer.

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The viscosity of a bituminous material changes as its temperature changes. For example, cold bitumen below about 60°C is very viscous, while hot bitumen has a low viscosity and is easily pumped and sprayed. Hence, if a viscosity value is to have any meaning, the exact temperature at which it was measured must be known.

Viscosity also depends on the shear rate at which it is measured. The shear rate is related to how fast the bitumen flows through the capillary tube, and viscosity tends to decrease as shear rate increases. For most bitumens at temperatures above 60°C the viscosity is however relatively independent of shear rate and the viscosity is said to be 'Newtonian' and hence is behaving as a 'Newtonian fluid'.

The viscosities of penetration-grade bitumens must be within specified limits, which are measured at both 70°C and 135°C according to TNZ M/1. Measuring viscosity at these two temperatures gives a better understanding of how the binder will perform at different temperatures. These numbers are specified as 70°C, which represents the hottest temperature likely to occur on the road, and 135°C, which is hot enough to display the properties close to those observed at spraying temperatures (150°C–180°C).

In TNZ M/1, bitumen is graded at 25°C because this temperature is close to the average road temperature. Bitumen grading is based on penetration rather than viscosity at this temperature as bitumen viscosities are very high and difficult to measure at 25°C.

Bitumen is applied hot, with a very low viscosity, to the road when chipsealing. Once the hot bitumen hits the comparatively cold road, the viscosity quickly rises as the bitumen reaches road temperature. Immediately, any volatile additives (e.g. kerosene) start to evaporate, causing further hardening of the bitumen which takes from days to months. This is called 'curing'.

8.1.2.3 Flash Point

The minimum flash point of bitumen is specified in TNZ M/1 to be 230°C. This ensures that, in the normal temperature range for handling bitumen, the danger of the material catching fire is minimised. See also the discussion on Flash Points in Section 2.3.

The test specified in TNZ M/1 to determine the flash point for roading bitumens is ASTM D92-97 (Cleveland Open Cup method), in which a sample of bitumen is heated at a specified rate in an open steel cup. The temperature at which a small flame passed over the cup ignites vapours near the surface of the hot bitumen defines the Flash Point.

8.1.2.4 Solubility

The solubility of bitumen in trichloroethylene test (ASTM D2042-01) is measured to determine the presence of contamination, e.g. by mineral matter or carbon. The bitumen must be at least 99.5% soluble in trichloroethylene to meet the TNZ M/1 specification.

8.1.2.5 Rolling Thin Film Oven Test (RTFO test)

Designed to simulate the hardening that occurs in the hot asphalt mix process, the RTFO test consists of placing 35 g of bitumen in a special glass cylinder which is placed horizontally in a carriage in an oven (Figure 8-4). The carriage revolves, and a film of bitumen is constantly formed on the walls of the cylinder. Hot air is blown into the cylinder for the duration of the test (85 minutes at 163°C).

Figure 8-4 RTFO test apparatus used to simulate hardening in a chipseal.

Photo courtesy of Shirley Potter, Opus

In the TNZ M/1 specification, the degree of hardening is measured by the change in the penetration values. Penetration grade bitumens must retain a minimum of 50% of the original penetration when subjected to the RTFO treatment.

The ductility test (see Section 8.1.2.6) is also performed to find if any colloidal instability results from the RTFO treatment.

This treatment has been shown to give a good correlation with the hardening that occurs in a bitumen during the manufacture of asphaltic concrete. Hardening occurs even when good plant practice and temperatures are used, because of the high temperatures required for asphaltic concrete mixing and laying.

8.1.2.6 Ductility

After carrying out the RTFO test, TNZ M/1 specifies the ductility of a bitumen to be tested by drawing a briquet of bitumen apart at the rate of 50 mm/minute, into a thin thread.

Although the relationship of this test to performance of the pavement is debated, generally low ductility values for 80/100 or 180/200 grade bitumens would indicate instability of the material. A bitumen of low ductility may be brittle and have a dead grainy appearance.

8.1.2.7 Durability

It is obviously desirable that bitumens used for seal construction do not oxidise and harden too rapidly in the field. On seals carrying low traffic volumes, hardening of the bitumen leading to chip loss and cracking governs the ultimate life of the seal (as discussed in Section 4.3).

A new test is now available in New Zealand to assess bitumen durability (Herrington 2000), and is described in the draft TNZ T/13 specification (Transit NZ in prep.) It involves oxidising thin films of bitumen at 60°C and under 2000 kPa of air for 80 hours. This test is intended to model oxidative hardening resulting from about 10 years in the field. It has the added advantage of acting as a de facto control on the low temperature modulus of bitumens imported into New Zealand. Low temperature behaviour is important for chipseal performance, as discussed in Section 4.2.3.

8.1.2.8 Modulus and Stiffness

8

A drawback with the traditional methods of characterising the physical properties of bitumen such as penetration, softening point, viscosity and ductility is that, with the exception of the viscosity, the results obtained are specific to the test method used and are not fundamental rheological properties. The different tests use very different modes and rates of loading which are poorly defined and which will vary with temperature. Additionally the tests cannot be used to characterise bitumens over the full range of in-service temperatures. (In theory viscosity can be measured at any temperature, but for bitumen this becomes impractical at low temperatures.)

An alternative measure of bitumen hardness is the modulus. The modulus can be conveniently measured at any temperature in the range of interest and under clearly defined loading conditions. It is thus possible, using a single parameter, to determine and compare the hardness of a bitumen or bitumens in the field over the range of in-service temperatures, and under loading rates that simulate traffic loadings.

At low temperatures (or for very short loading times) bitumen behaves approximately as an elastic material, in that deformation produced by an applied stress is fully recovered when the stress is removed. At high temperatures (or very long loading times) the behaviour of bitumen is essentially viscous, in that deformation from an applied stress is not recovered. Over temperatures and loading rates typical of in-service conditions, bitumen is viscoelastic, meaning it responds under stress with a combination of both elastic and viscous behaviour so that some of the applied deformation is recovered but not all. The measured modulus (stress/strain) of bitumen thus depends both on the temperature and time for which the load is applied.

To characterise the viscoelastic properties of bitumens, van der Poel (1954) introduced the stiffness modulus, which relates the stress (applied at time t = 0) to the resulting strain for bitumens subjected to a constant tensile load (called a 'creep experiment'):

$$S_{t,T} = \frac{\sigma}{\varepsilon_{t,T}}$$

where: $S_{t,T}$ = Stiffness modulus at a given time t and temperature T

σ = Applied constant uniaxial tensile stress

$\varepsilon_{t,T}$ = Resulting uniaxial tensile strain at a given time t and temperature T

(The stiffness modulus is the inverse of the creep compliance $D_{t,T}$, which is the more commonly used parameter in the wider literature pertaining to rheology.) At very low temperatures or short loading times the stiffness modulus of all bitumens approaches a constant value (the 'glassy' modulus) of about 3 GPa. In this region the stiffness modulus becomes almost independent of loading time and temperature and is thus equivalent to Young's modulus ($E = \sigma/\varepsilon$) for elastic solids.

Bitumen moduli can also be measured on films of bitumen in shear. In this case the shear modulus is defined as:

$$G_{t,T} = \frac{\tau}{\gamma_{t,T}}$$

where: $G_{t,T}$ = Shear modulus at a given time t and temperature T

τ = Applied constant shear stress

$\gamma_{t,T}$ = Resulting shear strain at a given time t and temperature T (shear displacement/sample thickness)

The relationship between tensile stiffness modulus (S) and shear modulus (G) is given by the relation:

$$S_{t,T} = 2(1 + \mu) G_{t,T}$$

where: μ = Poisson's ratio

It is usually assumed that bitumen is incompressible and that μ is 0.5. Hence:

$$S_{t,T} \approx 3G_{t,T}$$

Bitumen moduli are most commonly measured by dynamic shear experiments. A bitumen film between two circular plates is subjected to a sinusoidally varying shear stress of constant amplitude and frequency, by rotating the upper plate back and forth around its rest position. The resulting strain in the sample is recorded. The results of such an experiment are shown schematically in Figure 8-5. The deformation of the sample varies sinusoidally as does the stress but exhibits a time lag (the phase angle δ) between 0° and 90° (one quarter of a cycle). For perfectly elastic materials the strain would be instantaneous upon application of the stress and the phase angle would be 0°. For perfectly viscous materials the phase angle would be 90°.

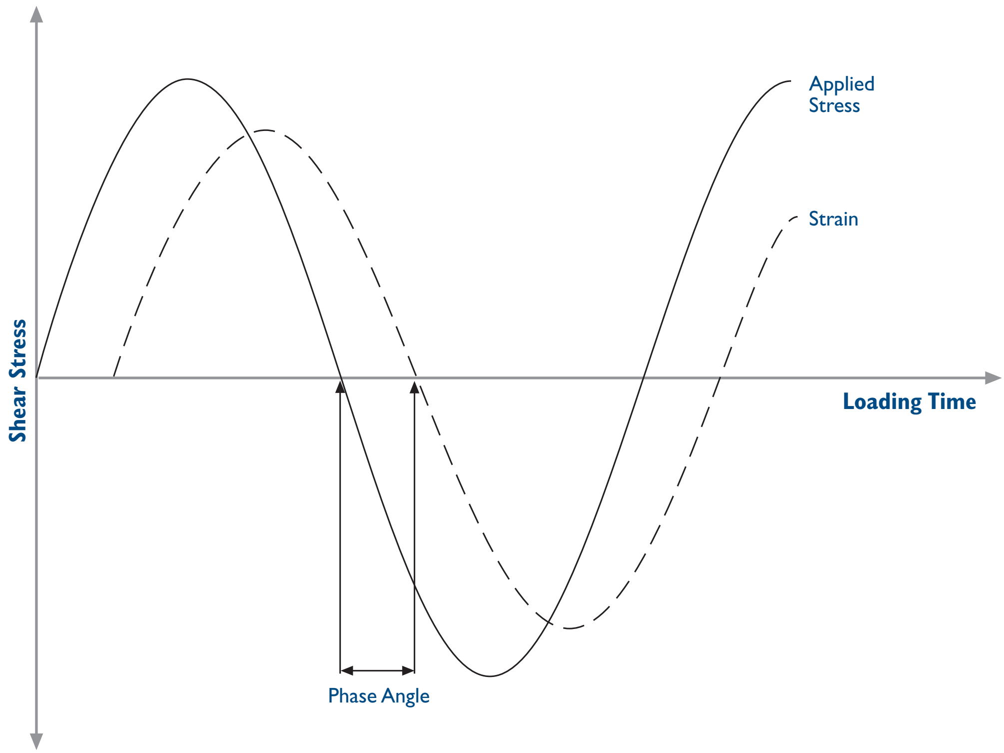

Figure 8-5 Dynamic test for measurement of shear modulus.

The resulting measured complex shear modulus ($G^*_{T,\omega}$) at frequency ω and temperature T is the sum of two components, the out-of-phase component (the loss or viscous modulus G''):

$$G''_{T,\omega} = G^*_{T,\omega} \sin\delta$$

and the in-phase (storage or elastic modulus G'):

$$G'_{T,\omega} = G^*_{T,\omega} \cos\delta$$

For bitumen at low temperatures or short loading times the phase angle is low and G' is large relative to G". At high temperatures or long loading times the opposite is true.

The above discussion relates only to experiments involving small strains where, at a given temperature and for a given loading time or frequency, the strain is linearly related to the stress (the linear viscoelastic region). At larger deformations the relationship between stress and strain is more complex.

By selecting an appropriate test frequency, the moduli of bitumen under vehicle loadings can be measured. At 100 km/h an average car or truck tyre patch contact length of 150 mm passes a given point in the seal in about 0.0054 seconds, corresponding to a frequency of 185 Hz. To obtain data at such high frequencies the principle of time–temperature superposition is used to construct plots (master curves) from data at lower frequencies but lower temperatures. Figure 8-6 shows master curves for Safaniya[3] 180/200, 80/100 and 40/50 bitumen grades at 40°C.

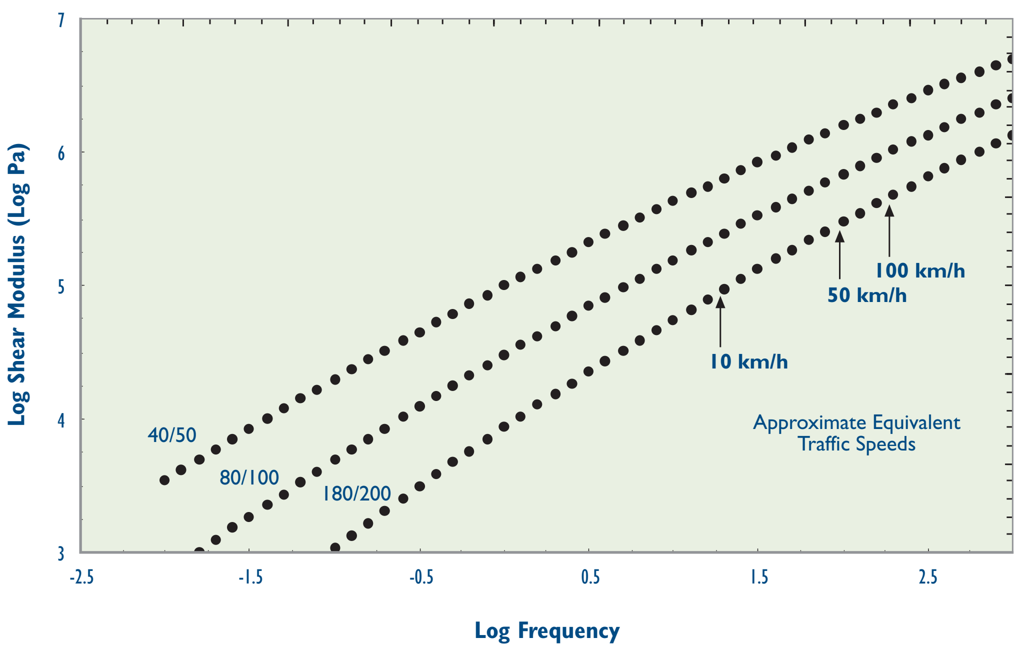

Figure 8-6 Master curves for Safaniya[3] bitumen grades (40/50, 80/100, 180/200) at 40°C, showing the effect of the frequency used in the test procedure on shear modulus.

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[3] Bitumen from Safaniya oilfield, Persian Gulf.

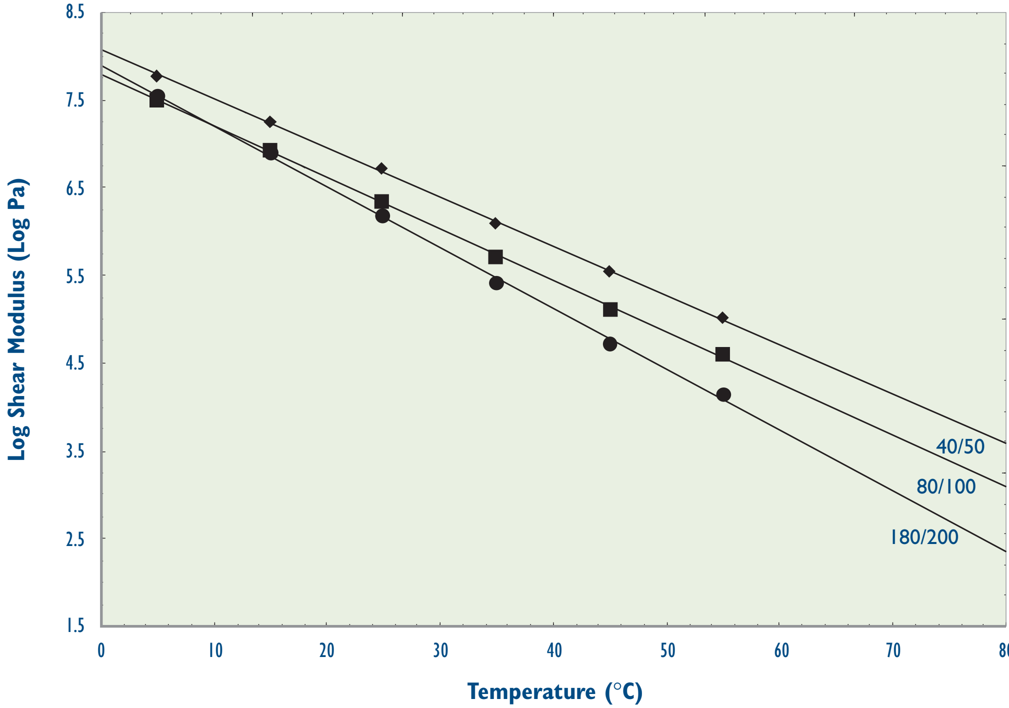


Figure 8-7 Modulus curves for three Safaniya bitumen grades (40/50, 80/100, 180/200) at 20 Hz frequency, showing the effect of temperature.

Figure 8-7 shows the effect of temperature on the modulus and phase angle for 180/200, 80/100 and 40/50 grades at a frequency of 20 Hz (corresponding to the tyre-patch loading rate for a car moving at 4 km/h). It is interesting to note that the differences in the moduli between grades become less significant as the temperature decreases.

As bitumens oxidise in the field their moduli increase and they tend to become more elastic, i.e. the elastic component of the modulus increases relative to the viscous component and the phase angle decreases. Bitumens modified with polymers such as styrene-butadiene-styrene copolymers (SBS) also become relatively more elastic, though the overall modulus may not increase significantly.

8.1.2.9 Ageing and Hardening of Bitumens

The ageing and hardening of bitumens are discussed in Section 4.3.

Hardening caused by oxidation, and to a lesser degree by loss of volatiles, will also occur in storage if the bitumen is held at high temperatures for too long a period (Figure 8-8). The rate of these changes is dependent on the bitumen type and storage conditions used. In particular, hardening is more rapid where the bitumen surface area to volume ratio is high. This effect is illustrated in Figure 8-8 which compares the hardening of bitumen stored in a full spray tanker compared to that when the tank is half empty (Tyne 1994).

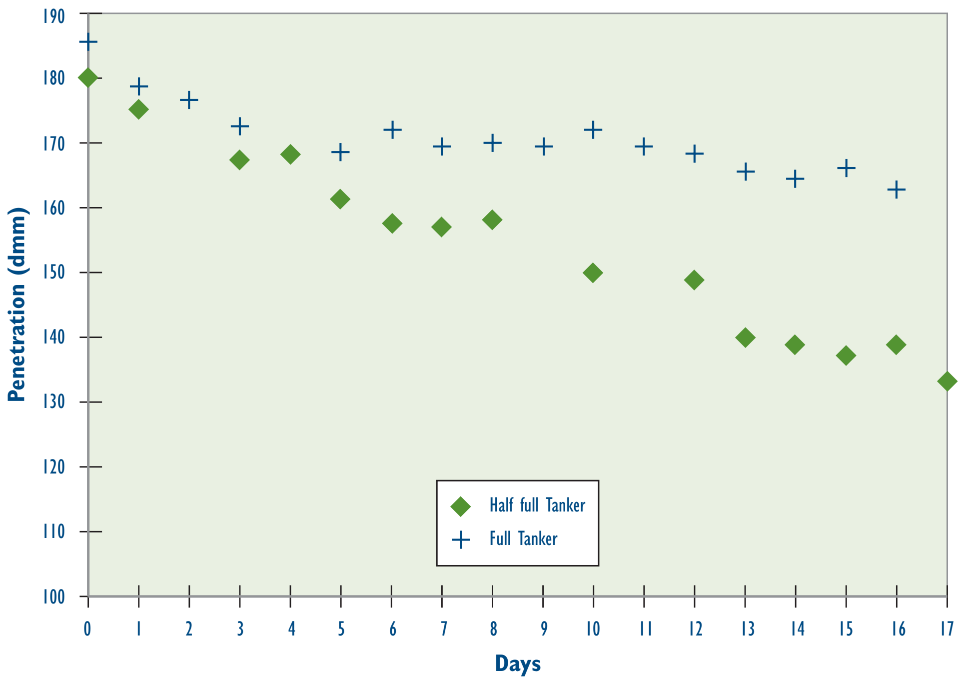


Figure 8-8 Changes in penetration (by needle at 25°C) of 180/200 grade bitumen stored at 170°C for 17 days in two bitumen distributor tanks, one tank half-full (and therefore more air), compared with a full tank (with little air) (from Tyne 1994).

8.1.2.10 Softening Point

Although the test for softening point (the 'ring and ball' test) is no longer part of the TNZ M/1 bitumen specification, it is included here for completeness and for comparison with tests used in other countries.

The complex mixture of chemical compounds which constitutes bitumen means it has no definite melting point. A 'softening point' can however be measured by the softening point test, also called the 'ring and ball' test (ASTM D36), the procedure for which follows.

A sample of bitumen is formed in a metal ring, and a 9.5 mm steel ball bearing in a special holder is placed on top. The assembly is immersed in water in a beaker, and heated at 5°C/minute. The temperature at which the ball bearing deforms the bitumen to a depth of 16 mm is the softening point.

The softening point of pure bitumen is equivalent to a hardness of approximately 800 penetration. The complex flow properties of bitumen do not allow an exact relationship between penetration or viscosity and softening point to be made. Nevertheless, the softening point can be used to indicate the flow properties of bitumen at higher pavement temperatures but, at 60°C or 70°C, viscosity gives a more useful measure. Softening point is also believed to be related to the temperature and viscosity at which vehicle tyres can pick up and track soft bitumen.

8.2 Additives to Bituminous Binders

These are products added to modify the properties of the original bitumen for specific purposes, such as reducing the viscosity of bitumen (i.e. cutting and fluxing), or improving the development of the bond (i.e. adhesion) between bitumen and chip.

8.2.1 Cutters and Fluxes

A cutter oil is a light petroleum oil added to bitumen to temporarily reduce its viscosity, and the resulting mixture is called a cutback.

A flux is a petroleum oil or cutter blended with bitumen to provide a reasonably long-term reduction in binder viscosity that is intended to stay in the binder, e.g. for the life of a surfacing. The function of a flux is to lower the penetration grade without using the alternative of a softer bitumen.

For chipsealing work in New Zealand kerosene is used as a cutter, and diesel (also called Automotive Gas Oil or AGO) is mainly used as a flux. How cutters and fluxes work and what they do are covered in Section 4.2.1. As explained in Chapter 4, research has shown that about 20% of the added cutter remains permanently in the binder, and about 30% of the AGO. Heavier oils (e.g. Heavy Fuel Oils) are available that will remain in the bitumen for a longer time.

Adding a lighter petroleum product to a bitumen greatly reduces the bitumen's viscosity. Hence the correct amounts of turpentine (no longer used in New Zealand), diesel or kerosene may be added to a binder to tailor the binder viscosity to the properties required for the new seal.

Another method of changing the viscosity is to heat the binder. These two methods are usually used together to produce a binder of the required viscosity.

Note: in describing the proportions of a cutback mixture, the convention in New Zealand is to express the amount of cutter, flux and other additives in terms of parts of additive per hundred parts (pph) of bitumen (explained in Section 11.3.5). Thus a binder that has 4/5ths (80%) bitumen and 1/5th (20%) kerosene is described as having 25 parts per hundred (pph) kerosene in the binder.

So 25pph is **not** 25% but is in fact $\% = \frac{25pph}{125} = \frac{1}{5} = 20\%$

and to convert from pph to %, where there is only one additive, use

$$\% = \frac{pph}{100 + pph}$$

Where there is more than one additive, follow the principles presented in Chapter 11.

8.2.2 Adhesion Agents

The most common method of improving adhesion between binder and aggregate chip is to add an adhesion agent to the binder. The effect of the agent is to increase the force of attraction or bond between the bitumen (with adhesion agent) and the chip, thus enabling the binder to resist the action of water or even to displace the water from the chip surface. In effect the binder becomes more attractive to the chip.

Adhesion agents may also reduce the surface tension of the bitumen, allowing the bitumen to wet the chip surface more easily.

Adhesion agents are typically fatty amine, diamine or amido-amine compounds and are now most commonly used in liquid form to enable in-line blending, at about 0.5 to 0.7% by weight. Adhesion agents tend to be unstable at bitumen handling temperatures. The storage stability will depend on agent type and the bitumen source but approximately half of a fatty amine or diamine agent will have reacted after 10 hours at 160°C. The half-life for a more heat-stable amido-amine type agent, at the same temperature, will be about 24 hours.

Some adhesion agents are in fact emulsions and more information on emulsions is given in Section 8.3.

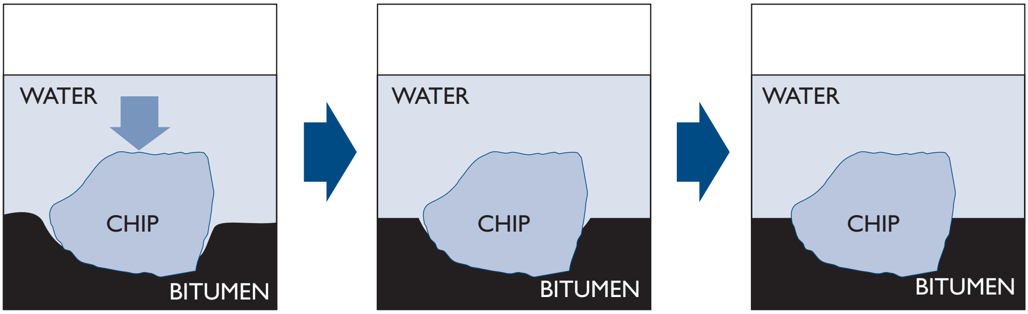
8.2.2.1 Adhesion and the Effect of Water

Water is more strongly attracted to stone (i.e. the chip) than to bitumen. If both water and bitumen are present near a chip surface, the water will wet the entire chip surface, forming a film that separates the binder from the chip.

A complete bond will not be formed unless the chip surface is dry. Even when the chip is successfully coated, water will tend to strip the binder from the chip by prising the binder from the chip under trafficking. Different types of aggregate (for chip) vary in their tendency to succumb to this displacement action, which is called stripping. In summary, if the chip is dry, bitumen will adhere to it, but if the chip is wet this will prevent the bitumen from adhering to the chip, because bitumen is repelled by water (Figure 8-9).

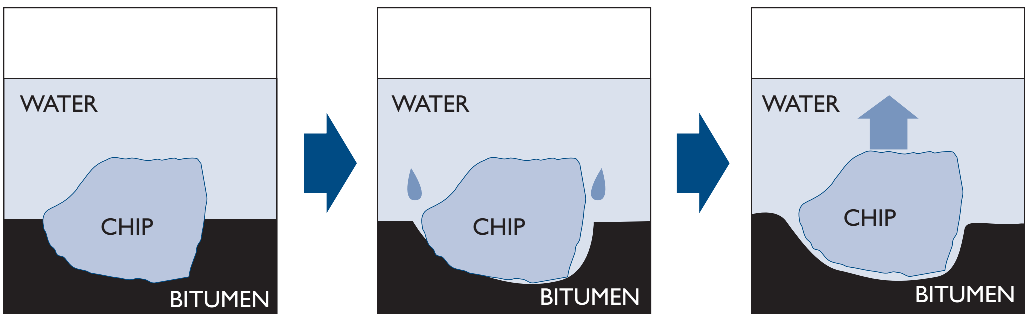
On surfaces with high volumes of traffic (i.e. heavily trafficked), the effects of stripping can be greatly accelerated because water trapped under fast rolling tyres is pumped through microscopic holes in the binder, building up very high pressures in the water trapped beneath the binder. This helps blast the thin bitumen films off the chips (Figure 8-9).

(a) Active Adhesion



The adhesion agent in the bitumen displaces the water off the chip surface, allowing the bitumen to wet up the sides of the chip.

(b) Water Stripping



Water slowly destroys the chip–bitumen bond from the edges, and the chip is lost.

Figure 8-9 Adhesion of binder to a chip is assisted by an adhesion agent which helps to displace water from chip surfaces. Conversely, water will strip binder from the chip causing chip loss.

If a too viscous binder is used, the bond between binder and chip may be irregular even though the chip appears fully coated (Figure 8-10). Traffic and rain easily damage this sort of bond. A viscous binder will gradually achieve a good bond given fair weather, but may remain at risk of damage for many weeks on heavily trafficked roads.

Once a bond is established, a hard (i.e. low penetration grade) binder is relatively difficult to strip. Very soft binder (higher penetration grade) on the other hand gives rapid bonding, but even with a good initial bond, it may be too soft to resist the force of water displacement and trafficking. The ideal binder would be soft for rapid initial bond and then harden quickly to resist stripping.

8.2.2.2 Adhesion and Cleanness of Chip

As well as providing a waterproof layer, the most important requirement of a bituminous binder is that it should act as an adhesive, gluing the aggregate particles together and binding them in the new surfacing and to the underlying layer.

For adhesion to occur, the binder must first completely wet the chip surfaces. The more fluid (or the lower the viscosity of) the binder, the more readily it can coat the chip. Too viscous a binder will be unable to wet the chip readily and formation of a bond will take too long.

This is particularly noticeable when the surfaces are dusty (Figure 8-10) because the high viscosity binder may not penetrate the dust layer particles coating the chip surfaces.

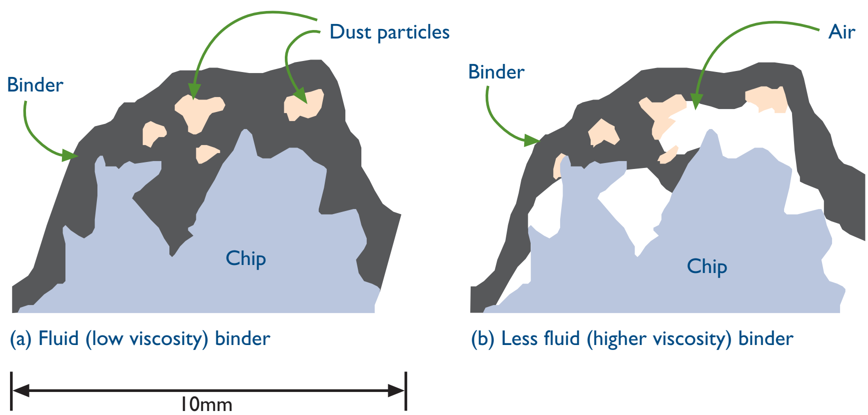


Figure 8-10 The success of adhesion of binder to chip in the presence of dust is related to the viscosity of the binder. This is how low viscosity prime coats work.

The action of the adhesion agent depends to some extent on the chemical nature of the chip used. For this reason, the amount and type of agent to be added should be checked in the laboratory whenever a new source of aggregate for chips or bitumen is to be used.

8.2.3 Precoating Materials

One method of preventing stripping is to precoat a chip with bituminous material. The natural affinity of the bituminous precoating material to the bituminous sealing binder ensures a good waterproofing bond even if a slightly less fluid binder is used. The bond between the precoating material and the chip is made in the controlled conditions of the precoating plant before they are taken to the site. Therefore it should be more reliable than a bond formed on the road.

Precoating materials often have an adhesion agent added to ensure that the bond between the precoating layer and the chip remains in place.

Precoating chips with bituminous materials, e.g. kerosene, was very popular in the past to assist with forming the bitumen–chip bond. Precoating has however fallen out of favour in New Zealand with the introduction of adhesion agents, which are generally used instead.

8.2.3.1 Materials used for Precoating

A wide variety of petroleum-based products are suitable for chip precoating, ranging from penetration grade bitumen through to light distillates such as kerosene.

The most common products to use are low-volatility oil such as diesel, sometimes with a percentage of bitumen added to increase stockpile life and to provide visual evidence of coating. (Too much bitumen will cause the chips to stick together during stockpiling and handling.)

To achieve an adequate coating, the precoat material must have a low enough viscosity to allow it to spread over the chip surfaces. In all cases, the precoat material should contain an adhesion agent (usually about 1%). The lower the viscosity of the precoat material the shorter will be the stockpile life because volatile materials such as kerosene that can be used in the precoat will evaporate relatively quickly and become ineffectual, unless the chip is used almost immediately it is coated.

Alternatively, higher viscosity bitumen-based materials can be used, applied hot to heated chips (usually in a hot-mix asphalt plant) and used immediately.

Bitumen emulsions can also be successfully used for precoating, but these must be specially formulated to achieve the functions discussed above. Conventional sealing emulsions are generally not suitable.

8.2.3.2 Manufacture of Precoated Materials

Precoating using low viscosity, cold-applied, precoated material is best done in a central plant or purpose designed portable mixing plant. However, stockpiles of chip can be successfully coated manually by picking up the chip bucket-load by bucket-load and slowly tipping it out onto a clean new site and meanwhile spraying the falling chip with a fine mist of the cold precoat. The new stockpile is periodically mixed with a loader. Care must be taken to protect personnel from the sprayed material and any run-off must be collected and prevented from contaminating the environment. Suggested application rates for precoating chip are given in Section 9.7.5.

Stockpiles of freshly coated chip must be left for a period to allow time for absorption to take place and, if necessary, to drain off any excess.

Precoating using heated, higher viscosity materials such as penetration grade bitumen is normally carried out in a hot-mix asphalt plant on dried and pre-heated chip. This type of material is best used while still hot to take advantage of the excellent hot-adhesion characteristics and to avoid handling problems of chips sticking together as they cool. Materials suitable for stockpiling can be produced by this method, but the coating must be very light and much lower viscosity coating materials should be used.

8.2.3.3 Handling Precoated Chip

Hot precoated chips must be covered during transport and spreading to minimise heat loss and prevent contamination.

If precoated chips are to be stockpiled before use, great care must be taken to avoid contamination with dust or other contaminants. Dust will adhere all too readily, counteracting some of the advantages gained by precoating.

8.2.3.4 Risks using Precoated Materials

Safety Risks

Precoating materials, in particular the precoating binder, can contain a high proportion of distillate oil and/or volatile cutter, which increases risk of flammability during blending and use. When using bitumen cutbacks follow the advice in BCA 9904 (NZ PBCA 2000). The following additional precautions are advisable:

- If heating of a precoating binder is required to reach the desired viscosity, this should be carried out under carefully controlled conditions at a blending plant before the precoating binder is transferred to a job site.
- Flame-tube heaters should not be used.
- On-site blending of the precoating binder should not be used.
- On-site precoating must only use materials below 60°C.
- A special safety plan must be developed and put in place to cover blending, storage, transport, and use of precoating binder and precoated materials.

Environmental Risks
Although much of any volatile cutter used evaporates into the atmosphere during and soon after the precoating process, the actual quantities involved are very small.

If rain occurs before full coating and absorption has taken place, a significant risk is that the precoat will wash off the surface and contaminate the ground water. Once coating and absorption is complete however, a well-designed precoat is remarkably water-resistant.

Risk of Tracking
Traffic can pick up precoated chip that has too thick or adhesive a coating and track it far and wide.

8.2.4 Antifoaming Agents

> Antifoaming agents are used to reduce foaming in bitumen that may contain water. Foaming is likely to occur during heating of the binder as it nears the boiling point of water, when the increase in volume from water to steam can create a dangerous situation.

They are used, for example, when a distributor tanker that has been used to carry emulsion is being filled with hot bitumen, or in an empty tank in which water could have accumulated through condensation over a period of time.

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Most antifoaming agents are silicone-based, diluted with AGO, and added to the bitumen at about 1.0% by weight.

8.3 Emulsions

8.3.1 Introduction

Emulsions are mixtures of two liquids that cannot be blended together, such as oil and water. Normally, if oil and water are stirred together and the mixture is allowed to stand, the oil and water will separate.

If surface-active chemicals called ‘emulsifiers’ are added to the oil and water, and the mixture is vigorously agitated, then a stable, creamy liquid is formed which does not separate. Emulsifiers are chemicals that act on the surfaces of, or the interfaces between, two liquids in an emulsion, and hence they are known as surface-active chemicals. Common examples of emulsifiers include domestic soaps and detergents.

An emulsion is thus a dispersion of one liquid within another (Figure 8-11), usually rendered stable by the presence of emulsifiers. Common examples of emulsions include homogenised milk, mayonnaise, and latex. The dispersed liquid is called the 'dispersed phase', while the dispersing liquid is known as the 'continuous phase'.

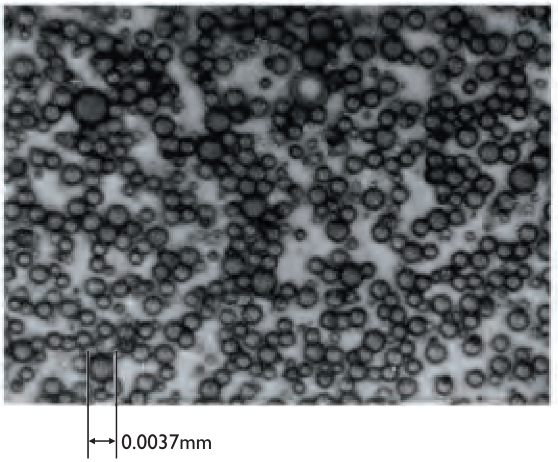

Figure 8-11 Droplets of an oily liquid dispersed in another liquid to form an emulsion (from Austroads 2004).

8.3.2 Bitumen Emulsions

Bitumen can be dispersed in water to form a bitumen emulsion. Bitumen emulsions are used by the road construction industry as an alternative to hot-mixed or hot-sprayed bitumen.

The use of emulsifiers is necessary to achieve a stable dispersion, and purpose-designed manufacturing plant is required. These bitumen emulsions may be formulated for a wide range of applications in the road construction industry, including chipsealing, tack-coating, aggregate mixing, slurry sealing and stabilisation.

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Bitumen emulsions may be applied at lower temperatures than most other binders, at ambient temperatures, and also contain less or no hydrocarbon diluents (e.g. kerosene) compared with hot-applied binders. In New Zealand the production, transportation and application of bitumen emulsions uses less energy and produces less carbon dioxide than using hot cutback bitumens (Slaughter 2004). Therefore the use of bitumen emulsions has health, safety, and environmental benefits.

8.3.2.1 Emulsifiers

Emulsifiers that are used for the manufacture of bitumen emulsions have two parts to their chemical structure. One end of the molecule is soluble in oily materials such as the bitumen, while the other end is able to dissolve in water. Thus, the emulsifier bridges the bitumen–water interface.

The water-soluble end of the molecule is either 'cationic' or 'anionic' in character (Figure 8-12). These terms designate the electrical charge that the emulsifiers confer on the bitumen droplet, i.e. cationic emulsifiers confer a positive electrical charge, while anionic emulsifiers confer a negative charge.

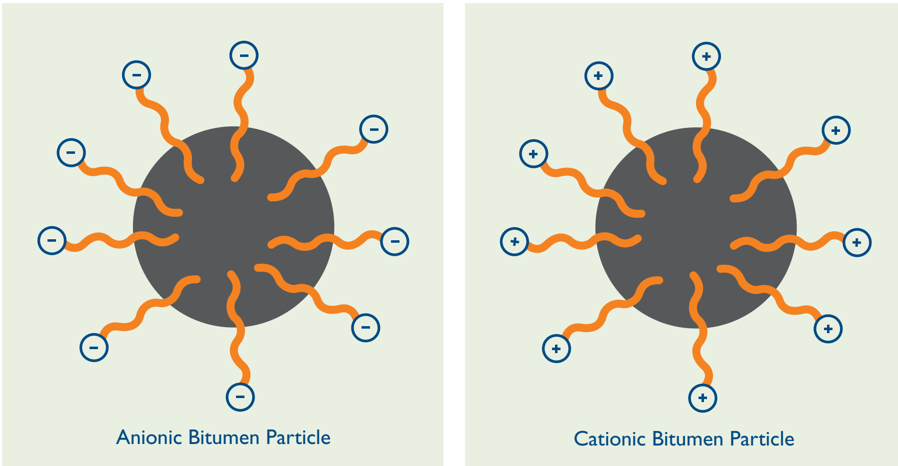

Figure 8-12 Concept of anionic (negatively charged) and cationic (positively charged) bitumen droplets.

Cationic emulsifiers are predominantly used for the manufacture of bitumen emulsions for road applications. This is because cationic emulsions generally exhibit better 'breaking' properties (i.e. separating into bitumen, and releasing water) and adhesion to chip than do anionic emulsions (see Section 8.3.2.3 for an explanation). Consequently, anionic emulsions are rarely used for seal construction.

8.3.2.2 Emulsion Manufacture

Bitumen emulsions are manufactured using purpose-designed plant. The binder may be penetration-grade bitumen, or may be bitumen blended with diluents such as kerosene or AGO or, for more specialised products, may contain polymer additives. The binder is heated sufficiently to reduce its viscosity to around 0.2 Pa.s before emulsification.

The binder is metered into a high-speed mixer, usually an in-line high-shear device called an 'emulsion mill'. Simultaneously, water mixed with emulsifiers is metered into the emulsion mill. The high shear action of the mill disperses the binder into the water in the form of tiny droplets, typically around 0.004 mm diameter. These droplets are coated with the emulsifiers present in the water (Figure 8-13), and the binder is thus prevented from separating from the water. A stable emulsion is formed, with the bitumen being the dispersed phase, and the water the continuous phase.

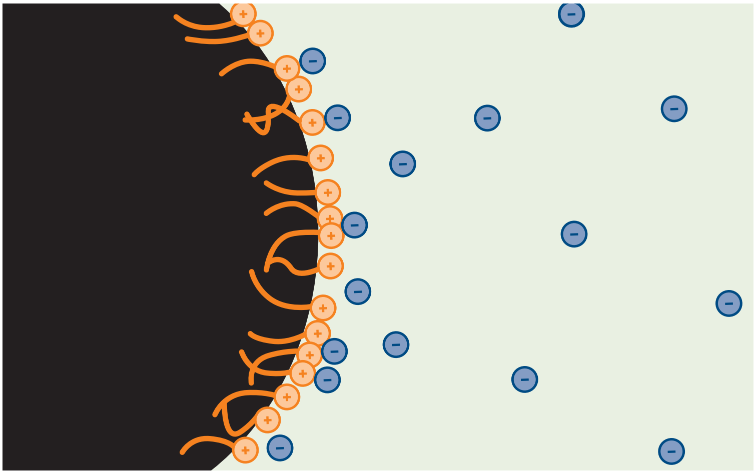

Figure 8-13 Bitumen droplet in a cationic emulsion.

The binder droplets do not merge together, or coalesce (Figure 8-14), because the emulsifier gives the surface of the droplets an electrical charge of one kind so that they repel each other (Figure 8-15). Because like-charges repel each other, the droplets cannot get close enough to coalesce, thus the dispersion is stable.

Bitumen emulsions are manufactured at temperatures up to approximately 95°C. Because they are water-based, they will boil if heated over 100°C. When transporting emulsions in higher altitude regions, remember that water boils at lower temperatures and boiling causes the emulsion to 'break'. Therefore boiling is to be avoided. Similarly, freezing an emulsion can cause breaking and should also be avoided.

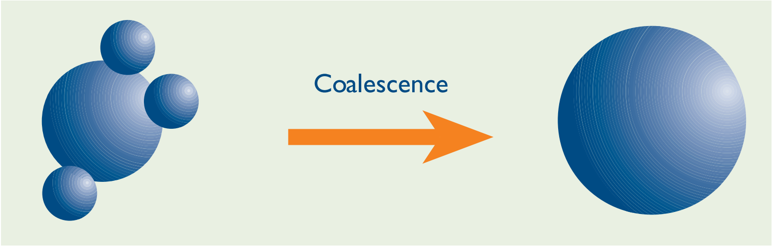

Figure 8-14 Emulsifier prevents coalescence of the droplets before it is sprayed onto the road. When the bitumen breaks on the road, droplets coalesce to form a film.

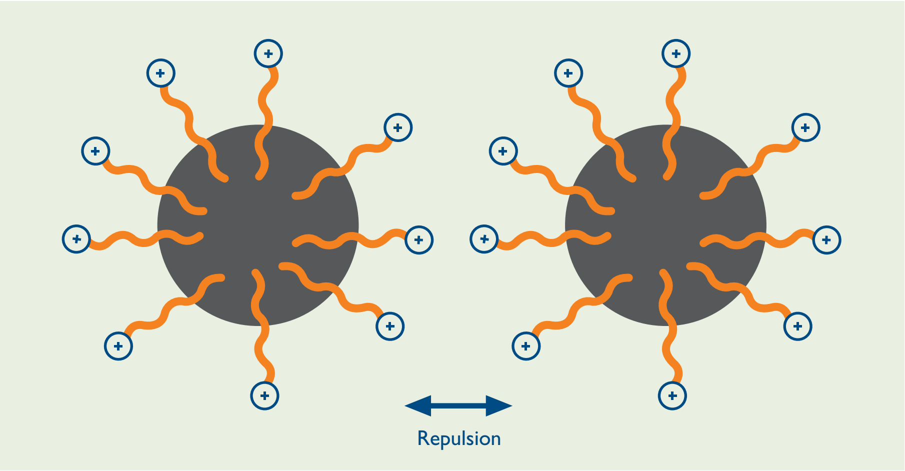

Figure 8-15 Repulsion of like-charged droplets in an emulsion.

8.3.2.3 *Breaking of Emulsions*

The process by which the dispersed phase (or bitumen) of an emulsion separates from the continuous phase (or water) is called 'breaking'. Well-formulated emulsions are stable in storage, and will not separate or break prematurely, but when bitumen emulsions are used in the field, they are required to break at the required time to release the bitumen to perform its intended function.

Breaking is a process that depends on the formulation of the emulsion, the emulsifier chemistry, temperature and the type of aggregates used. The predominant factor that controls the emulsion breaking characteristics (Figure 8-16) is the quantity and type of emulsifier used in the emulsion.

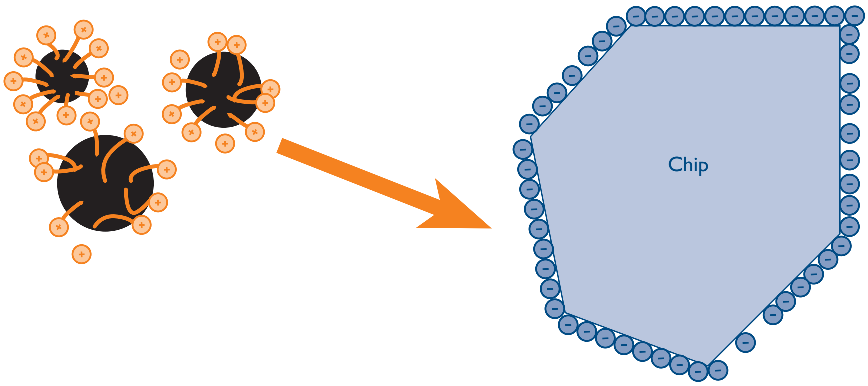

Figure 8-16 Attraction of cationic droplets to moist surface of a chip in the process of breaking.

Breaking is a complex, highly temperature-dependent process. Cool ambient temperatures will slow the break rate of emulsions, possibly requiring adjustments to formulations.

Breaking is different from the curing of an emulsion chipseal. 'Curing' is the development of strength in an emulsion seal as the water from the broken emulsion evaporates. The seal does not achieve full strength until all the water from the continuous phase has evaporated.

Anionic emulsions tend to break relatively slowly. Road-surfacing work carried out using anionic emulsions is at risk of failure until the water from the emulsion has completely evaporated and the bitumen has fully coalesced to form a continuous film.

In contrast to anionic emulsions, the positively charged droplets in a cationic emulsion interact with the surface of chip particles. Most chips, when moist, develop slight negative electrical charges on the surface (Figure 8-16). Because opposite charges attract, the positively charged binder droplets in a cationic emulsion deposit on, and adhere to, the chip surface and the emulsion breaks.

Thus road surfacings that use cationic emulsions develop strength earlier than those that use anionic emulsions. Nonetheless, full strength is not obtained until the water from the emulsion is lost by evaporation, i.e. the seal has completed the curing process.

8.3.2.4 Formulation of Emulsions

Producers have a wide range of options when developing emulsion formulations. Consideration is given to:

- Grade of bitumen;
- Addition of diluent to bitumen before emulsification;
- Emulsifier type and quantity;
- Percentage binder in the emulsion;
- Other additives in the binder (e.g. polymers).

All bitumen grades normally used for road surfacing can be emulsified. Generally, emulsions for road surfacing applications contain the same grade of bitumen that would be used for hot-sprayed or hot-mixed processes.

If needed, diluents such as kerosene or AGO may be added to the bitumen before emulsification, although this is less necessary with emulsified binders than it is, for example, in hot-sprayed cutback bitumen used for chipsealing.

Emulsifier type and quantity is usually proprietary information and not made available to users of emulsions. The producer will select from a range of emulsifiers from different manufacturers to obtain the performance properties needed from the emulsion by the user. This choice is based on laboratory tests, trial work and experience.

Emulsions used for road surfacing generally contain binder contents between 60% and 76%. Binder contents below 60% can be manufactured, but the emulsions have a low viscosity and the relatively high water content means the emulsions are uneconomic to transport in large quantities.

As binder content rises, emulsion viscosity increases (Figure 8-17). This is simply because the higher volume of binder droplets 'crowd out' the water in the continuous phase. Above approximately 76% binder, the emulsion viscosity is so high that the emulsion becomes paste-like, and is difficult to pump or handle. Note that emulsion viscosity is a function of the volume of binder in the emulsion, irrespective of whether it is a hard or soft grade of bitumen, and unrelated to the viscosity of the dispersed binder.

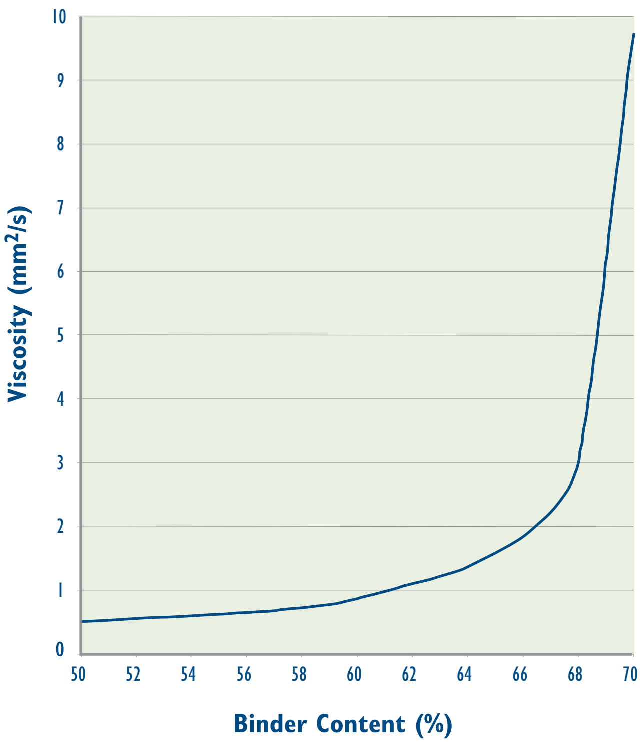

Figure 8-17 Effect of binder content on emulsion viscosity. As % binder increases, so does viscosity.

At higher binder contents, emulsion viscosity characteristics may be termed 'pseudoplastic'. This term means that, under conditions of high shear such as pumping or spraying, the emulsion behaves as if it has a lower viscosity. Conversely, under conditions of low shear, such as after application to a pavement, viscosity will be high. This means that high binder content emulsions will tend not to self-level after spraying, and will retain any streaks caused by the spraying process.

8.3.2.5 Emulsified Polymer Modified Binders

Polymer Modified Binders (PMBs) can now be emulsified using advanced plant and manufacturing techniques. The construction of modified binder seals using emulsified PMBs offers several advantages over hot-sprayed systems, including:

- Lower application temperatures, which reduce hazards from burns, and heat-induced binder degradation;
- Improved adhesion of binder to chip;
- Improved chip embedment and orientation in sprayed binder films.

The use of modified binder emulsions can reduce the risk of early failure of modified binder seals compared with hot-sprayed systems.

8.3.2.6 Emulsion Grades

Bitumen emulsions are classified broadly into grades depending on their type (anionic or cationic); break rate (fast, medium or slow), and binder content.

TNZ M/1:1995 specification defines the naming convention commonly used in New Zealand, which is as follows:

Type:

- Type A is designated as anionic emulsions, and
- Type C as cationic emulsions.

Break rate:

- Q is designated for rapid-breaking emulsions,
- M for medium-breaking emulsions, and
- S for slow-breaking emulsions.

Binder content is designated by % binder.

The base-grade of bitumen is appended as the upper limit of the penetration grade. For example, a rapid-breaking cationic emulsion containing 60% binder, using 80/100-grade bitumen, would be designated CQ60/100. Similarly, a slow-breaking anionic emulsion containing 55% binder, using 130/150-grade bitumen, is designated AS55/150.

Other naming conventions are used internationally. Table 8-1 sets out New Zealand emulsion grades, based on 80/100-grade bitumen in this example, and provides some cross-references to designations used in other countries.

Table 8-1 Naming conventions for bitumen emulsions.

TNZ M/2	Description	International Equivalents		
		AS 1160*	ASTM D244	BS 434
AQ60/100	Anionic, rapid breaking, 60% binder	ARS/170-60	RS-1	A1-60
AQ55/100	Anionic, rapid breaking, 55% binder	ARS/170-55	RS-1	A1-55
AM55/100	Anionic, medium breaking, 55% binder	AMS/170-55	MS-1	A2-57
AS55/100	Anionic, slow breaking, 55% binder	ASS/170-55	SS-1	A3
CQ65/100	Cationic, rapid breaking, 65% binder	CRS/170-65	CRS-2	K1-70
CQ55/100	Cationic, rapid breaking, 55% binder	CRS/170-55	CRS-1	K1-60
CM55/100	Cationic, medium breaking, 55% binder	CMS/170-55	CMS-1	K2
CS55/100	Cationic, slow breaking, 55% binder	CSS/170-55	CSS-1	K3

* Note that the '170' designation used for the Australian Standard AS1160 emulsion grades designates the use of AS 2008 Class 170 bitumen as the base bitumen in the emulsion. This is approximately equivalent to 80/100-grade bitumen used in New Zealand.

Examples of on-road uses for the different grades of emulsions are listed in Table 8-2.

Table 8-2 Uses for different grades of emulsion.

Emulsion Grade	Use
CQ65 (or CQ70)	Chipsealing
AQ60, AQ55, CQ55, CQ60	Tack coating Grit or Sand sealing Voidfill chipseals
AM55, CM55	Cold mixes
AS55, CS55	Cold mixes Basecourse stabilisation

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8.3.3 Handling and Storage of Bitumen Emulsions

After bitumen emulsions have been manufactured, they are transferred from the emulsion mill into a storage tank, or mobile tanker. Some grades, especially higher binder content grades used for chipsealing, e.g. CQ70, will be stored and used hot, while other grades may be allowed to cool.

The storage life of emulsions depends on the emulsion formulation and the manner in which it is handled during storage.

Emulsions that are designed to break rapidly when used, such as CQ grades, have the shortest storage life. They are sensitive to heating and cooling cycles, pumping and circulation. Consequently, they should be held only for limited periods of time and at a stable temperature. In addition, as surging in part-filled road tankers can initiate breaking, filled or baffled tankers are recommended for long-haul transportation.

Prolonged circulation or pumping will cause coalescence of the binder droplets for all grades of emulsion because of shearing forces within the pump, so pumping and circulation must be minimised. The use of high-clearance pumps, such as centrifugal pumps, for transferring emulsions from storage to mobile tankers can reduce these damaging effects.

As has been noted in Section 8.3.1, bitumen emulsions are dispersions of bitumen binder, possibly containing additives, in water. If the binder density (weight per unit volume) is greater than that of the water, the droplets will slowly sink and collect on the bottom of the storage vessel. This is called 'settlement'.

Conversely, if the binder density is less than that of the water, the droplets will rise or 'upcream'. Regular, gentle agitation will counteract settlement or upcreaming but avoid violent agitation as it can cause emulsions to break.

8.3.4 Sampling Bitumen Emulsions

As for all materials, careful attention must be paid to obtaining samples that are representative of the emulsion. In addition, emulsions that are designed to break rapidly (e.g. CQ grades) can change their properties during sampling and transportation. Therefore appropriate techniques must be used.

Cationic emulsion samples must not be stored or transported in metal containers as the acidic nature of some of these emulsions may cause reactions with the metal and destabilise the emulsion.

The shearing action of pumps and spray nozzles can also affect the properties of emulsions, so samples should not be drawn from the spray nozzle of a bitumen distributor.

The properties of higher binder content (>65% binder) emulsions can change if the emulsion is cooled and reheated. Samples of these types of emulsions should, where possible, be kept hot by using a vacuum flask (e.g. a Thermos flask) as the sample container.

The viscosity of some emulsions will change markedly during the first 24 hours after manufacture. Viscosity testing should be timed to coincide with the time that the emulsion is used, if possible.

8.3.5 Testing Bitumen Emulsions

A wide range of laboratory tests is used to assess the quality and predict the performance of bitumen emulsions used for road surfacings. In New Zealand, TNZ M/1:1995 specification requires emulsions to meet limits set for the following criteria:

- Viscosity
- Binder content
- Residue on sieving
- Storage stability
- Particle charge
- Diluent content
- Stability to mixing

Viscosity
The viscosity, or consistency, of bitumen emulsions, can be measured using different viscometers. Traditional orifice-type viscometers (Engler® or Saybolt-Furol®) determine viscosity by measuring the time taken for a sample to flow through an orifice into a calibrated receiver. More recently, the Brookfield® viscometer (Figure 8-18) has been used. This determines viscosity by measuring the drag on a rotating spindle immersed in the emulsion.

Binder Content
The Binder Content test determines the total volume of binder in a bitumen emulsion, i.e. the base bitumen plus any diluents or additives.

Residue on Sieving
The Residue on Sieving test is used to detect the presence of coarse particles or lumps of bitumen that could be an indication of a contaminated or broken emulsion.

Figure 8-18 Brookfield® viscometer. Photo courtesy of Dr Mofreh Saleh, University of Canterbury

Storage Stability
The Storage Stability test is designed to assess the likelihood of an emulsion to either settle or upcream, and the ease by which the settled particles may be re-dispersed.

Particle Charge
The Particle Charge test determines if an emulsion is anionic or cationic.

Diluent Content
The Diluent Content test determines the volume of volatile diluent (e.g. kerosene) blended with the emulsified bitumen.

Stability to Mixing
The Stability to Mixing test assesses the ability of an emulsion to tolerate mixing with a coarse aggregate. It is a crude method of estimating break rate.

8.3.6 Advantages of Emulsions

Whether the chipseal binder is sprayed as hot cutback bitumen, or in an emulsified form, the objectives are to:

- distribute the bitumen binder in a uniform membrane that adheres and bonds to the substrate, and
- allow the binder to wet and adhere to sealing chips so that the chips are retained throughout the design life of the seal.

Emulsification is a technique to:

- reduce the viscosity of the binder sufficiently to allow it to be sprayed at a practical temperature;
- allow the binder to contact, wet and adhere to the substrate and cover-aggregate (sealing chips).

Thus emulsifying chipsealing binders has the same intent and effect of the addition of volatile diluents (cutters) to bitumen for use in cutback chipsealing. The major differences are that:

- spraying temperatures are below 100°C;
- use of sacrificial volatile hydrocarbon diluents (cutters) to give short-term, temporary reduction of bitumen viscosity is eliminated;
- base binder properties are achieved within hours once the water has evaporated.

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While emulsified binders may contain diluents for storage reasons and to aid droplet coalescence and improve green-strength[4] of seals, levels are often less than those used in cutback bitumen sealing. Typically 2–3 pph is used; hence emission of hydrocarbons into the environment is reduced in those locations compared with those produced by cutback bitumen sealing. If shade, air, or pavement temperatures are high enough for good droplet coalescence, eliminating the use of diluent in the emulsified binders may be possible.

Consequently, there are environmental and performance advantages in using emulsions if sealing early or late in the season. At these times chipseals using bitumen binders require cutbacks with high diluent contents.

Also as spraying temperatures are below those used in cutback bitumen chipsealing, the severity of accidental burns to construction personnel will be greatly reduced.

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[4] Green-strength – strength of an emulsion chipseal before curing.

8.4 Polymers

8.4.1 Introduction

The term 'polymer' derives from the Greek word meaning 'many parts'. This describes the nature of polymer molecules, which are large molecules made up of smaller repeating molecules. The term 'polymer' in the context of road surfacing normally refers to the addition of polymer molecules to bitumen, to produce a 'polymer modified bitumen' (or PMB) with improved performance properties over that of the original bitumen.

A wide range of man-made polymers have been used for bitumen modification in the last 20 years, both for the modification of bitumen for chipsealing and for the modification of bitumen for asphalt applications.

8.4.2 PMBs in New Zealand

The first PMBs to be used in New Zealand incorporated natural rubber latex with bitumen. Natural rubber latex was initially used as it was readily available in liquid form, and relatively easy to add to bitumen. However, as the natural rubber latex contained water, its addition to hot bitumen caused foaming and had to be managed carefully, so its use today is mainly limited to polymer modified emulsions (PMEs) because they are also water-based.

In the late 1970s a broad range of new synthetic polymers became available which, once incorporated with bitumen as a PMB, were more convenient to use and allowed binder properties to be tailored for particular uses. Today, an extensive range of polymers is available which can be blended with bitumen to produce PMBs that have a range of properties to suit most roading applications.

With the wide range of properties that can be delivered by various PMBs, two major needs have arisen with the specifying consultants and road asset owner, namely:

- How to determine when and where the enhanced properties of PMBs are required;
- How to specify and verify the properties of the PMBs.

8.4.2.1 When and Where to use PMBs

Determining when and where to use PMBs can be best achieved through a partnership between the binder supplier and the client by performing and monitoring trials of new products. This is a slow and expensive learning process for all parties concerned, but one which must be undertaken to understand these superior, yet more expensive, products and to make economic use of them.

8.4.2.2 *How to Specify and Test PMB Properties*

Most Australian PMB specifications are method-based, i.e. they define the physical properties of the PMB to be used with various roading applications. Austroads in Australia have been working over the last 12 years towards a national specification framework, which includes tests that can be used to specify the properties of PMBs. This has resulted in the Austroads (2000) *Specification Framework for Polymer Modified Binders*, based on Australian experience. This document gives a very useful background and a range of tests that can be used to characterise PMB materials.

In contrast, because of Transit's philosophy, New Zealand has tended to concentrate on developing a performance-based approach to chipsealing under which the contractor is obliged to give a warranty (through the use of a maintenance period) on the entire sealing system, not just on the raw materials such as binder and chip. This approach allows for the use of the incredibly wide range of binders that are available in both hot and emulsified form, and which can be applied in a wide range of chipseal types, e.g. single coat, two-coat or racked-in.

New Zealand does not have a national polymer sealing specification, a formal system by which different polymers can be specified, or a formal testing protocol whereby the properties of the various polymer sealing products on the New Zealand market can be compared. The only measures which have been used to define a PMB are:

- Polymer type;
- Polymer concentration (%);
- Bitumen grade.

The individual New Zealand polymer manufacturers have published data sheets on their various products and these should be referred to when considering any polymer sealing project, to gain insight into the performance and nature of the available polymer products. The composition of most polymer products in New Zealand are proprietary, but all manufacturers are very willing to provide details and application advice on their products.

8.4.3 Manufacture of PMBs

The manufacture of PMBs primarily consists of blending the pure polymer, normally in the form of pellets or granules, into the base bitumen at high temperature (around 180°C). Section 8.4.6, Polymer Types, indicates the great range of polymers that can be blended into bitumen, and consequently the methods of manufacture for each can be quite different. However to be effective, most PMBs need to contain around 3–5% by weight of pure polymer in the bitumen. The polymers typically have molecular weights similar or greater in size to that of the asphaltene molecules present in the bitumen. These components (asphaltenes and polymer) within a PMB can lead to two-phase structures consisting of one polymer phase and one asphaltene phase. Such a structure can lead to instability or incompatibility as a result of differences in density and lead to a 'settling' of one phase during hot storage. This incompatibility or tendency to separate can be minimised by selecting bitumen with low asphaltene content, by adding selected oils or by cross-linking the polymer to the base bitumen when preparing the PMB.

8.4.4 Handling and Storage of PMBs

PMB manufacturing facilities use high shear mixers to ensure rapid and thorough dispersion of the polymer through the PMB. As indicated previously, some PMBs remain as two-phase systems, with the polymer dispersed in very fine droplets within the bitumen. The fine nature of this dispersion provides a period of time when the polymer remains 'in solution' and does not begin to agglomerate. Beyond this period however, if the PMB remains at elevated temperatures and is not continuously stirred, the polymer will begin to agglomerate and will eventually separate and float to the surface of the PMB.

Consequently, PMBs need to be handled and stored in such a way that the two phases do not separate but remain as uniform two-phase liquids until used. Any long-term hot storage facility needs to have equipment which stirs or circulates the PMB continuously, and is capable of stirring the normally highly viscous PMB product. The recommendations of the manufacturer should be followed when storage at elevated temperatures needs to be longer than 48 hours.

Most polymers are heat-stable at temperatures up to 190°C, but prolonged storage beyond 5 days at these temperatures is not ideal for these products. For long-term storage, lowering the temperature to around 130–140°C is advised.

Continuous circulation or stirring is required when heating PMBs as their high viscosity means that the PMB does not move away from the heat source as efficiently as bitumen. Consequently the product can be heat-damaged more readily than ordinary bitumen. For long-term storage facilities, hot oil heating is preferred as it is less intense than other forms of direct heating such as electric elements or gas-fired tubes.

For Polymer Modified Emulsions (PME), the storage and handling can be treated as for other high bitumen-content emulsions (see Section 8.3.3).

8.4.5 Safety

Hot PMBs should be handled using full personal protection equipment, as normally they are pumped, sprayed and transferred at higher temperatures than straight bitumen. (Temperatures up to 180–190°C are not uncommon because of the higher viscosities of PMBs.) Therefore all conventional safe handling techniques used with hot bitumen should be followed when handling hot PMBs, and safety advice should also be sought from the PMB manufacturer.

8.4.6 Polymer Types

8.4.6.1 Elastomers

Elastomers (Figure 8-19) are a group of polymers which are characterised by their ability to resist permanent deformation and their ability to elongate under load. They are used in chipseals and asphalt to make the binder more resilient and flexible, as well as in crack-sealing materials and some emulsion applications. Some of the common elastomeric polymer types are described below.

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Figure 8-19 Removing a chip from a PMB chipseal reveals a long string of binder with enhanced elasticity.
Photo courtesy of Les McKenzie, Opus

SBS (Styrene-Butadiene-Styrene)
SBS is the most common polymer type used in PMBs in New Zealand. It is a thermoplastic elastomer, which means it melts at the temperatures normally found with hot bitumen (130°C–150°C) and regains its elastomeric character on cooling. This polymer modifies the bitumen by making it more elastic in nature and is ideal for chipseal binders as it limits crack propagation and provides good chip retention.

The normal concentration range for SBS polymer in chipseal applications is between 3% and 5% by weight. At high concentrations (around 5% polymer by weight), it is particularly useful for the two special chipsealing techniques called SAM (Strain Absorbing Membrane) and SAMI (Strain Absorbing Membrane Interlayer) (see Sections 3.7.13 and 3.9.2). SBS is also used in modifying bitumen for use in the manufacture of asphalt. The addition of polymer, normally at 5% concentration, provides asphalt mixes with improved deformation performance combined with flexibility.

The maximum viscosity that can be satisfactorily sprayed from a chipsealing sprayer without giving rise to 'tram-lining' or streaking governs the concentration of SBS polymer that can be used in a chipseal binder. With normal hot SBS sealing formulations, this concentration is around 4% polymer, although this concentration can be exceeded if the SBS binder is cutback with cutters, or if the SBS binder is emulsified. Both the cutback and emulsion techniques lower the viscosity of the binder to enable it to be satisfactorily sprayed.

SIS (Styrene-Isoprene-Styrene)
SIS is a polymer closely related to SBS but is softer and more adhesive in nature. It is sometimes used in combination with other polymers, primarily SBS, to provide a polymer blend that is believed to provide improved chip adhesion.

SBR (Styrene-Butadiene Rubber)
SBR is somewhat similar in character to SBS, generally providing a softer flexible material and is particularly used in crack-sealing materials. The difficulty in using SBR is that its viscosity is normally much higher than either SBS or SIS, meaning that it is difficult to use except in processes requiring very high temperatures such as crack sealing.

PBD (Polybutadiene)
PBD is a polymer containing the same butadiene molecule as SBS and SBR, but normally the size of the PBD polymer molecule used in PMBs is smaller than that of SBS. This produces PMBs which are lower in viscosity and therefore easier to spray, with good chip and substrate adhesion characteristics. PBD is particularly suitable for HSS (High Stress Seal) applications. It is also used in other applications where cohesive strength and a moderate level of flexibility are required.

Natural Rubber

Some of the early versions of PMBs incorporated low levels of natural rubber to provide enhanced adhesion for HSS applications. Today, this polymer is rarely used in hot bitumen chipseals and asphalt applications because its poor heat stability leads to very short storage lives and can sometimes 'gel', i.e. form a blanket-like layer of natural rubber within the bitumen sprayer or transporter.

8.4.6.2 Plastomers

Plastomers are a group of polymers which form tough and more rigid structures compared to those of elastomers, and are closer in their physical properties to conventional plastics. Asphalt mixes made with plastomer-modified binders have increased stiffness, good deformation resistance, and are normally used for modifying bitumen for use in asphalt mixes. Some of the common types of plastomer polymers are described below.

EVA (Ethylene Vinyl Acetate)

EVA polymers are easily incorporated into bitumen, and provide increased stiffness and deformation resistance as well as improved cohesion and toughness. Although their elasticity is nowhere near that of the elastomeric polymers, changing the composition of the EVA polymer can vary their properties of elasticity and stiffness. When EVA polymers are used in hot systems, careful control of the temperature must be kept because EVA polymers can break down under heat to form acetic acid. This causes health hazards such as irritating rashes and sore throats when working with the PMB.

EMA (Ethylene Methyl Acrylate)

EMA binders provide even greater toughness than EVA binders, and are used primarily in asphalt mixes to give particularly high deformation resistance for use in pavements subjected to heavy loads. EMA polymers are extremely heat stable compared to the EVA types and do not breakdown to form acetic acid. EMA polymers are generally larger molecules than EVAs, which means they provide improved performance for equivalent concentration levels of polymer. They have all but superseded EVAs in most asphalt applications.

APP (Atactic Polypropylene)

APP polymers provide improved adhesion to chip and substrate, and are quite flexible in nature. APP materials are obtained as a by-product of polypropylene plastic manufacture, and can be contaminated with a solvent which can result in fuming when used in hot bitumen. For this health reason APP type polymers are not commonly used.

PE (Polyethylene)

Various forms of PE can be incorporated into hot bitumen, including recycled materials such as HDPE (High Density Polyethylene) from recycled milk bottles, and LDPE (Low Density Polyethylene) from injection-moulded containers and articles. Currently these PE materials are not commonly used in New Zealand for chipsealing because their use in roading binders has not proved to be economic, compared with recycling them into other plastic products. Being large molecules, PE also brings the drawback of high viscosity when used in hot bitumen systems, thereby limiting their use in chipsealing binders.

8.4.6.3 Crumb Rubber

Crumb rubber is obtained from the shredding and grinding of scrap rubber from vehicle tyres. The particle size, texture, and shape depend on the method of manufacture of the crumb rubber, and they in turn affect how it is assimilated in the bitumen. These physical attributes therefore have a major influence on the final performance of the resulting PMB. A consistent method of preparation of the rubber is essential if consistent performance is to be gained from the resulting PMB.

When blended with bitumen, the material behaves as a form of elastomer but, as the resulting binder is a composite of discrete rubber particles and dissolved rubber molecules, it behaves differently from the other elastomer PMBs. The molecule size and partial dissolution also lead to handling problems when spraying through conventional chipsealing sprayers. Modification of the sprayers to suit this polymer type is essential.

8.4.7 Uses of PMBs

Although bitumen has proven to be a very adaptable binder for use in roading, in a number of areas the addition of a polymer can enhance its performance. PMBs have been used for:

- Crack sealing and bandaging;
- SAM seals;
- SAMI seals;
- High stress seals;
- Severe climatic conditions.

8.4.7.1 Use of PMBs in Crack Sealing

In New Zealand, SBS-modified bitumen has been used for crack filling for the last 20 years. The treatment has generally proved successful and is now regarded as a cost-effective treatment. For details see Section 7.3.3.1.

8.4.7.2 Use of PMBs in SAMs (Strain Absorbing Membrane)

In the SAM system, the PMB is sprayed at quite high application rates over cracked pavements to provide a bitumen layer that will resist crack propagation through the PMB binder and thereby provide a waterproofing membrane. SAMs can be applied as a single coat or two coat seal, and the chip is spread as for a conventional chipseal.

The SAM technique is used where pavement cracking has become so extensive that crack sealing is not an economic option, or the cracks are narrow and cannot be individually filled. The use of a SAM treatment can be an economic alternative to reconstruction.

The basic principle of a successful SAM treatment is that the application of an appropriate thickness of a low modulus bituminous layer to the pavement results in the crack movement being absorbed by the SAM layer. The appropriate thickness for this layer is dependent on the crack width and movement of the crack caused by temperature changes and also traffic action. A minimum thickness of 2 to 3 mm is often required, which is equivalent to a binder application rate of 2 to 3 ℓ/m^2.

In a SAM system, if low viscosity conventional bitumen were used rather than a PMB, the traffic would re-orient the chip, resulting in a flushed or bleeding surface. Similarly, if conventional chipseal application rates of 1.5 ℓ/m^2 were used, the binder thickness over the crack would be relatively low and would prove insufficient to provide any crack-prevention properties. A SAM system overcomes these problems.

It is the elastic nature of the PMB in a SAM that maintains an appropriate layer thickness over a crack, although for the membrane to be effective it must bridge the cracks. In the SAM system this elastic characteristic also resists chip re-orientation, maintaining the voids in the chipseal and thereby preventing flushing.

SAM Design Principles
The general design principle is that the more extensive the cracking and crack width, the higher the binder application that is required.

At these high application rates a very elastic binder is required and SBS concentrations of 5% or more can be used. The more highly elastic binders can result in chip adhesion problems and, in order to retain the chip, a two coat seal is used. In this seal, the highly modified PMB binder is used in the first coat and a straight bitumen (or one with a maximum of 2% polymer) in the second coat. In this system the highest application rate is applied first and the second application is designed as a locking treatment. Alternatively the binder can be applied as an emulsion, usually in a racked-in seal.

The design philosophy is different from that used for normal sealing which traditionally has been based on the determination of an appropriate chip size. When designing a SAM treatment the main consideration is the binder application rate. When the polymer contents are sufficiently high, the elasticity of the binder prevents the chip from rolling on to its greatest dimension. This results in a high void content in the seal which enables a high binder application rate to be applied without causing bleeding.

8.4.7.3 Use of PMBs in SAMIs (Strain Absorbing Membrane Interlayers)

> In the SAMI system, the PMB is sprayed and covered with a light application of chip. It is then overlaid with a hot mix asphalt or open graded porous asphalt (OGPA) course. This treatment is used for reducing crack reflection from an existing cracked pavement through to the surface of the new overlaid asphalt layer.

To determine the appropriate SAMI design, a thorough pavement evaluation and design are recommended. Factors that need to be considered include:

- crack type and cause;
- cause of crack movement, e.g. by traffic and/or environmental stresses;
- existence and extent of shear;
- total pavement stiffness.

Where traffic volumes are high and the stiffness of the pavement is low, the fatigue characteristics of the overlay need to be considered in the design as it is likely that the fatigue limit of the SAMI and overlay will be quickly reached. The result will be premature fatigue cracking and reconstruction may be the only alternative.

8.4.7.4 Use of PMBs in High Stress Seals

In locations of high stress, such as tight corners and braking situations, the binder and the aggregate of a chipseal come under high shear stress. To be able to withstand these stresses, normally a PMB combined with a chip-interlocking technique such as a two coat seal or a racked-in seal is needed.

A number of polymer types increase the tensile strength of chipseal binders and, in doing so, provide strength to the seal in situations of high stress. As mentioned earlier, the addition of the polymer to a chipsealing binder can, however, inhibit the initial adhesion of the binder to the chip (because of the higher viscosity) and a balance between degree of strength gain and loss of chip adhesion is needed. Normally PMBs for these seals use a lower polymer content than SAM or SAMI treatments.

In New Zealand, SBS and PBD modified binders are commonly used to increase shear strength in these situations. The addition of higher concentrations of polymers increases the cohesive strength of the binder, thereby giving greater binder strength.

With SBS-modified bitumen, the cohesive strength increases with polymer concentration but so does the elasticity. This elasticity, although beneficial for some applications, does reduce the ability of the PMB to flow and wet the aggregate surface. Therefore all possible means must be taken to ensure chip adhesion, i.e. the use of adhesion agent is strongly advised and in most cases precoated chip and/or cutter should be considered.

8.4.7.5 Use of PMBs in Severe Climatic Conditions

Normal bitumen has a temperature performance range in which it is able to perform as a satisfactory chipseal binder for most New Zealand climatic conditions. This means that the binder can retain the chip under both winter and summer pavement temperatures. There are sites within New Zealand, however, where the extremes of temperature exceed the normal bitumen performance range and where the broader performance temperature range of a PMB can add benefit.

Sufficiently high pavement temperatures will cause the seal to bleed. This bleeding can lead to pick-up and tracking of bitumen over a section of new chipseal, especially on sites trafficked by large numbers of heavy commercial vehicles. Other sites are located in mountain regions where winter temperatures regularly fall so low that bitumen becomes hard and cracks. The use of PMBs on either of these types of site will extend the performance range (both high and low) of the binder enabling the seal to survive in such extreme climatic conditions.

High Temperature Seals
Bleeding of a binder in a chipseal in hot weather can result in the binder being picked up by vehicle tyres and tracked along the pavement. As well as creating an annoyance to road users and pedestrians, the tracked binder can fill chip microtexture, thereby reducing skid resistance.

The addition of polymer can significantly raise the softening point of a bitumen thereby reducing bleeding and tyre pick-up. Where the PMB is cut back with a diluent such as kerosene, the full PMB benefits will not be obtained until the cutters have evaporated. Limited field trials in New Zealand on the rate of loss of kerosene using normal bitumen have shown that, after one year, approximately 20% of the added kerosene still remains (Section 4.2.1). For example, if 5 pph of kerosene was added initially, 1 pph would remain after one year. The higher viscosity of a PMB could suggest that the rate of kerosene loss would be slower with these binders, though the softening of the binder and tyre pick-up (the major problems caused by retained cutter) are reduced with PMBs.

A chipseal binder can also be softened slightly by using a liquid adhesion agent. This should have a similar softening effect to that of an approximately equal amount of kerosene.

Low Temperature Seals
Low temperature seal performance is associated with the bitumen properties and polymer type rather than the polymer concentration. It can also be affected by any oils used to ensure bitumen–polymer compatibility. It is recommended as a rule of thumb that, for low temperatures, the same grade of bitumen used for sealing should be used but with polymer modification. However in considering these extreme conditions, the PMB manufacturer's advice should be sought.

8.4.8 Binder Application Rates

With low polymer concentrations normal sealing binder rates are used. Increasing polymer content results in increased elasticity, higher softening point and increased viscosity, which usually restrict the chip from re-orienting itself onto its AGD. This means that the void space between chip increases and normally higher binder application rates can be used to achieve the same amount of binder rise up the chip.

8.4.8.1 Adhesion Agent

As with all chipsealing in New Zealand, the use of adhesion agents is encouraged. However the decrease in chip adhesion with PMBs means that the use of adhesion agent is essential, and no work should be performed without incorporating a compatible adhesion agent.

Care needs to be exercised as the higher spray temperatures used for PMBs can lead to a rapid breakdown of the adhesion agent and therefore decreased performance.

8.4.8.2 Cutters

The use of kerosene should be discussed with the supplier of the PMB as each polymer system responds differently to the presence of kerosene-based cutters.

8.4.8.3 Diesel

Diesel (AGO) is not recommended as an additive to polymer systems, though it has been used successfully in Australia as a precoat for PMB seals.

8.4.8.4 Emulsion

PMBs applied in emulsion form are called Polymer Modified Emulsions or PMEs. For chipsealing, use of PMEs assists in obtaining a good adhesive bond to the aggregate even with higher percentages of polymer modification. Emulsion binder contents approaching 75% bitumen content can now be manufactured in New Zealand and these binders regularly contain up to 5% polymer and can be applied at over 2 ℓ/m^2 without run-off occurring.

Care needs to be exercised using these emulsions at high application rates in hot weather as the emulsion can 'skin', trapping the water in the seal. So, although the surface can appear black, the emulsion can remain in the weak 'cheesy' state beneath this skin for a number of hours, leading to a high risk of early chip rollover and tyre pick-up.

Polymer Modified Emulsions (PME) are an excellent means by which to apply polymer seals because the emulsion form overcomes a number of difficulties normally involved in hot polymer sealing. Advantages include:

- High application viscosity: emulsions immediately reduce the viscosity thereby improving ease of spraying and preventing 'tramlining'.
- Wetting the aggregate: the very low viscosity of emulsion enhances the wetting of the aggregate thereby giving improved adhesion.
- Susceptibility to early rain damage: the improved wetting of the aggregate by emulsions and thereby better adhesion is critical if rain is experienced in the days following spraying of a PMB or PME.
- Precoating of aggregate is not required if PME is used: though it is preferable to use PMEs in two coat seals rather than single coats.

8.4.9 Contract Specification Requirements

In general, Transit NZ's current specifications give little guidance on the use of PMBs. Rather the engineer must specify what he needs. The following paragraphs will give some guidance on the various aspects, which should be considered when specifying PMBs.

8.4.9.1 Base Bitumen

As a general guideline the base bitumen for a chipseal PMB should be the same as that used for normal sealing in the area. This general rule should be confirmed with the polymer manufacturers, as the formulation of PMB can incorporate a number of additional components which can change the original base bitumen properties. Refer to the supplier for advice, as they hold formulation data which is critical in resolving the selection of the correct base bitumen to make a PMB.

8.4.9.2 Softening Point

Where a treatment is required to minimise bleeding, the softening point test (Section 8.1.2.10) can be used to ensure that, after the maintenance period, the binder is unlikely to be picked up by traffic. The softening points of 180/200 and 80/100 grades of bitumen are approximately 40°C and 45°C respectively. To guard against bleeding, a higher minimum softening point of at least 50°C should be specified. Note that, although a higher softening point will help reduce the pick-up and tracking of binder by tyres, it will not prevent the rise of binder up around the chip. Therefore a slick surface can still result, i.e. PMB will not prevent the flushing of a chipseal, but will aid in preventing bleeding and tracking.

Consideration should be given to the impact of cutter and fluxing agents on the softening point of the binder. Some cutters can significantly reduce the softening point leading to early pick-up.

8.4.9.3 Penetration Test

The penetration test, along with softening point, gives a measure of the temperature susceptibility of conventional bitumen. The application of the penetration test to PMBs however can give a misleading interpretation. Some plastomeric polymers can harden a binder so that a high softening point is obtained but in doing so, can produce a binder which is significantly harder at lower temperatures and could possibly lead to brittle failure at low temperatures.

8.4.9.4 Elasticity

Some degree of elasticity is required for seals over cracked pavements. In this situation the aim is to have a high binder application rate which will provide a membrane that will slow crack propagation, and therefore maintain the waterproof nature of the pavement. The elastic nature of the binder will resist chip re-orientation thereby providing a greater texture depth (as the chip will not lie down on its AGD). This increased texture depth can be utilised by applying increased binder application rates, thereby providing greater binder film thickness which gives more elasticity.

Elasticity can be measured with instruments such as the ARRB Elastometer and Dynamic Shear Rheometers, or more roughly using the Torsional Recovery Test (Austroads Modified Binder Test MBT 22).

8.4.10 Risks of Failure when using PMBs

Hot-applied PMBs are not as tolerant of variations in application conditions as normal bitumen and their use requires care. Some of the areas of risk are outlined here.

Bond development has been discussed in previous sections but it is the main risk in using PMB. If the substrate is dusty or cold, then bond development may be poor, and the seal can peel from the substrate. In these situations a prime coat should be considered.

In practice it is impossible both to obtain dry chip (unless heated) and to apply it before the binder has cooled. Thus the use of precoated chip and two-coat or racked-in seals are normally used to ensure that sufficient early strength is obtained.

To help achieve an adequate bond, sealing should only be performed in warm settled weather. It should not be carried out near the end of the sealing season as binder rise around the aggregate (which helps resist chip loss) will not have time to occur before the onset of cooler temperatures.

Applying PMB in an emulsion form (as a PME) can minimise the risks outlined above. Both substrate and chip adhesion are dramatically improved if a PME is used because the emulsion system gives better wetting than that given by a hot-applied PMB.

8.4.11 Conclusion

The use of PMBs will continue to grow as traffic volumes and stresses on pavements increase. A wide range of polymer types can be used to modify bitumen, each of which will provide improvement in some properties, but can also in some instances increase the risk of early failure of a chipseal because of premature chip loss. The number of combinations of ingredients that can be used to modify bitumen are nearly infinite. The resulting PMB can be used as a hot binder or as an emulsion.

The broad range of PMBs available make specifying any one binder difficult, and it is advocated that, where possible, the system rather than the components should be specified, or a performance-based approach should be taken in partnership with the PMB supplier.

8.5 Sealing Chips

8.5.1 Introduction

Aggregates used for chips in bituminous surfacings are, with few exceptions, derived from high quality natural rock or stone.

The rock, which is in a variety of forms after being won from the ground, is processed by crushing, screening and washing into different well-defined size grades suitable for use as components in the bituminous surfacing. Thus, conversion of rock to sealing chip involves high energy processes, making chip production a costly process.

8.5.2 Aggregate Sources

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Most surfacing chip in New Zealand is produced from igneous or sedimentary rock as most of the highly metamorphosed rocks are unsuitable.

Examination by experienced petrologists[5] can often give a good guide to the potential suitability of rock for use as surfacing chip.

Aggregate suitable for processing into surfacing chip is either quarried from solid rock or excavated from sand and gravel deposits. Natural gravels are processed differently from quarried rock as the rounded natural fine fraction (material passing the 4.75-mm sieve) must be removed by screening before the aggregate can be crushed.

5 A petrologist studies rocks, especially their origins, chemical and mineral composition, alteration and decay.

The original source of all sealing chips is rock, and it is classified into four main groups depending on its mode of formation.

- IGNEOUS

Rocks in which individual minerals have crystallised from molten natural silicate materials.

– Intrusive (or deep within the earth's crust): e.g. granite and diorite (coarse-grained crystalline rocks);

– Extrusive (or at the earth's surface): e.g. basalt and andesite (fine-grained crystalline rocks).

- SEDIMENTARY

Sedimentary rocks are formed by the natural cementing together of individual particles derived from processes such as erosion, e.g. sandstone, greywacke, and chemical precipitation, e.g. limestone.

- METAMORPHIC

Existing rocks within the earth's crust that have been altered as a result of high pressure, e.g. slate; high temperature, e.g. schist; or both, e.g. marble.

- SYNTHETIC

Smelting of various ores to produce metals often gives a by-product of 'slag' resembling natural igneous rock. Special techniques can then be used to manufacture sealing chip from this raw material.

Calcined bauxite is a very high skid resistance chip produced by heating bauxite ore in a kiln.

8.5.3 Aggregate Types

Four main types of aggregate are used in surfacings:

- ALL PASSING (AP)[6]

Continuously graded aggregate, crushed, partly crushed or uncrushed, with a clearly defined top size and usually with an even distribution of size down to 75 microns. Typical examples are: AP5 (5 mm Crusher Dust) and AP20 (20 mm All Passing). (A subset of AP is PAP, or Premium All Passing.)

- GRADED CRUSHED (GC)

Crushed aggregate evenly graded between two nominal sieve sizes, with only a small proportion outside this range.
Typical examples are: GC 20-10 (20 mm to 10 mm graded chip) and GC 10-5.

- SIZED CHIP OR SEALING CHIP (SC)

Near single-sized crushed aggregate usually meeting the criteria for sealing chips specified in the TNZ M/6 specification.

- SAND

Sand used in bituminous surfacings is usually screened and washed from naturally occurring fine aggregates with rounded particles, and having little or no proportion below 75 µm. Top size is generally 4.75 mm or less.

Manufactured sands can be made by washing to remove the passing 75 µm fraction and some of the passing 150 µm fraction out of AP5 (5 mm) aggregate.

For roading work, aggregates or fractions of aggregates which will pass through a 4.75 mm sieve are classed as 'fine aggregate' and fractions above 4.75 mm as 'coarse aggregate'.

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[6] Often the prefix 'P' is used before the abbreviated description to denote premium quality rock complying with the source quality requirements of TNZ M/6 and M/10, e.g. PAP (premium all passing). Also used in NZS 4407, Test 3.8.2, The particle size distribution of an aggregate.

8.5.4 Extraction of Rock

Hard rock is usually quarried from a quarry face by drilling vertical holes down through the deposit in a predetermined pattern, loading the holes with explosives, and detonating the charges. If the rock produced is still too large to feed into a crusher, then secondary breakage is achieved by further drilling and blasting, or by impact with a drop ball or hydraulic hammer.

Some hard rock deposits have a jointing pattern that allows large bulldozers to rip the material out, with little requirement for secondary breakage.

Gravel and sand above water level is usually extracted by wheeled loaders, motor scrapers, hydraulic diggers or face shovels. If below water level, draglines, hydraulic diggers, suction dredges and bucket dredges are used as required.

8.5.5 Production of Aggregate

Right from the early days, obtaining an aggregate or chip according to specification was important (Figure 8-20), whether for basecourse or chipseal.

Figure 8-20 Screening aggregate for road use from a beach near Opunake, Taranaki, in the 1920s.
Photo courtesy of John Matthews, Technix Group Ltd

Figure 8-21 shows a typical crushing and screening process designed to produce various grades of crushed aggregate from quarried rock, and Figure 8-22 shows a typical crushing and screening process designed to produce various grades of crushed and uncrushed aggregate from natural gravel and sand.

It is important to note that the different types of crusher have markedly different actions, each of which is particularly suited to a specific function in the process.

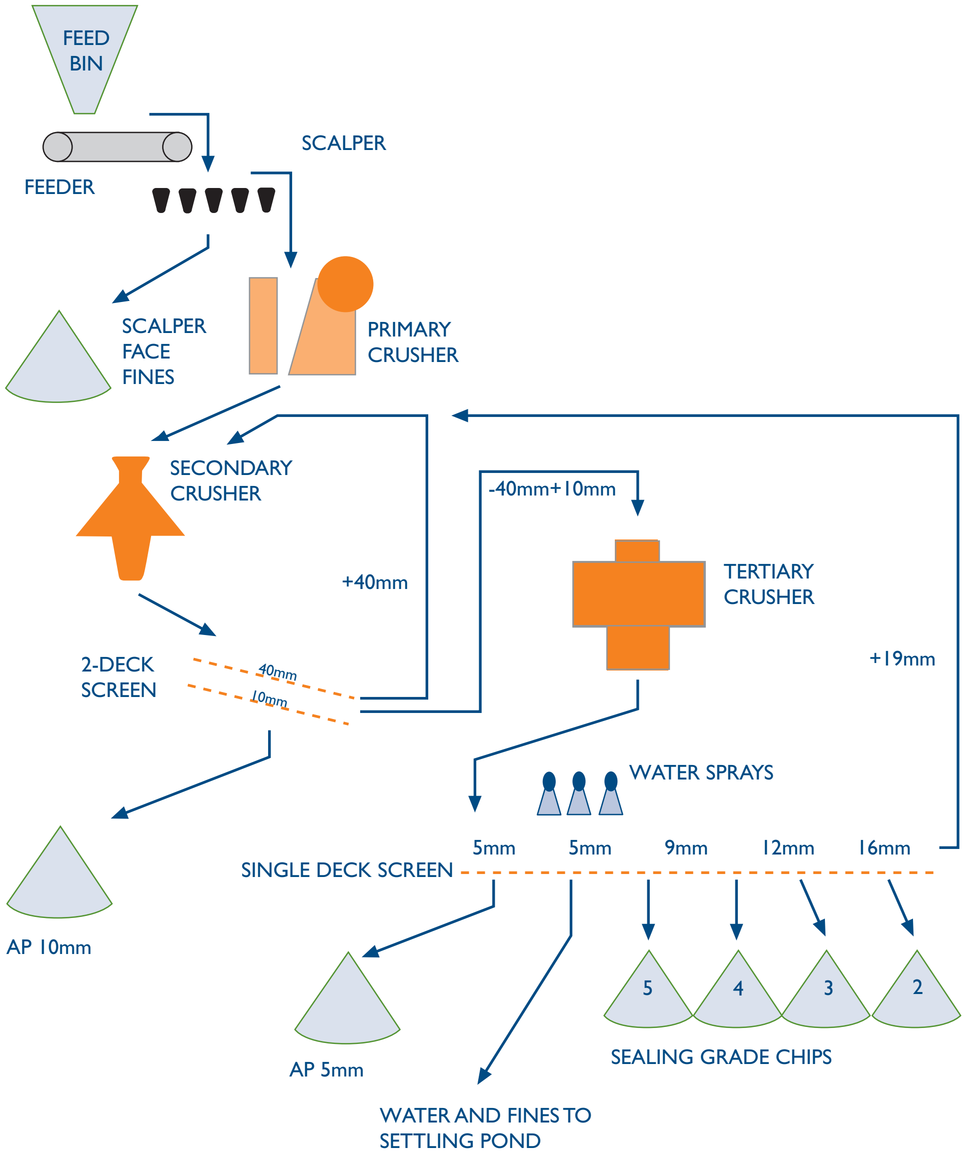

Figure 8-21 Typical crushing and screening process for quarried rock.

Typically, jaw crushers and large gyratory crushers are used for primary crushing, cone crushers for secondary, and hammer mills or impactors are used for tertiary crushing (Figures 8-21 and 8-22).

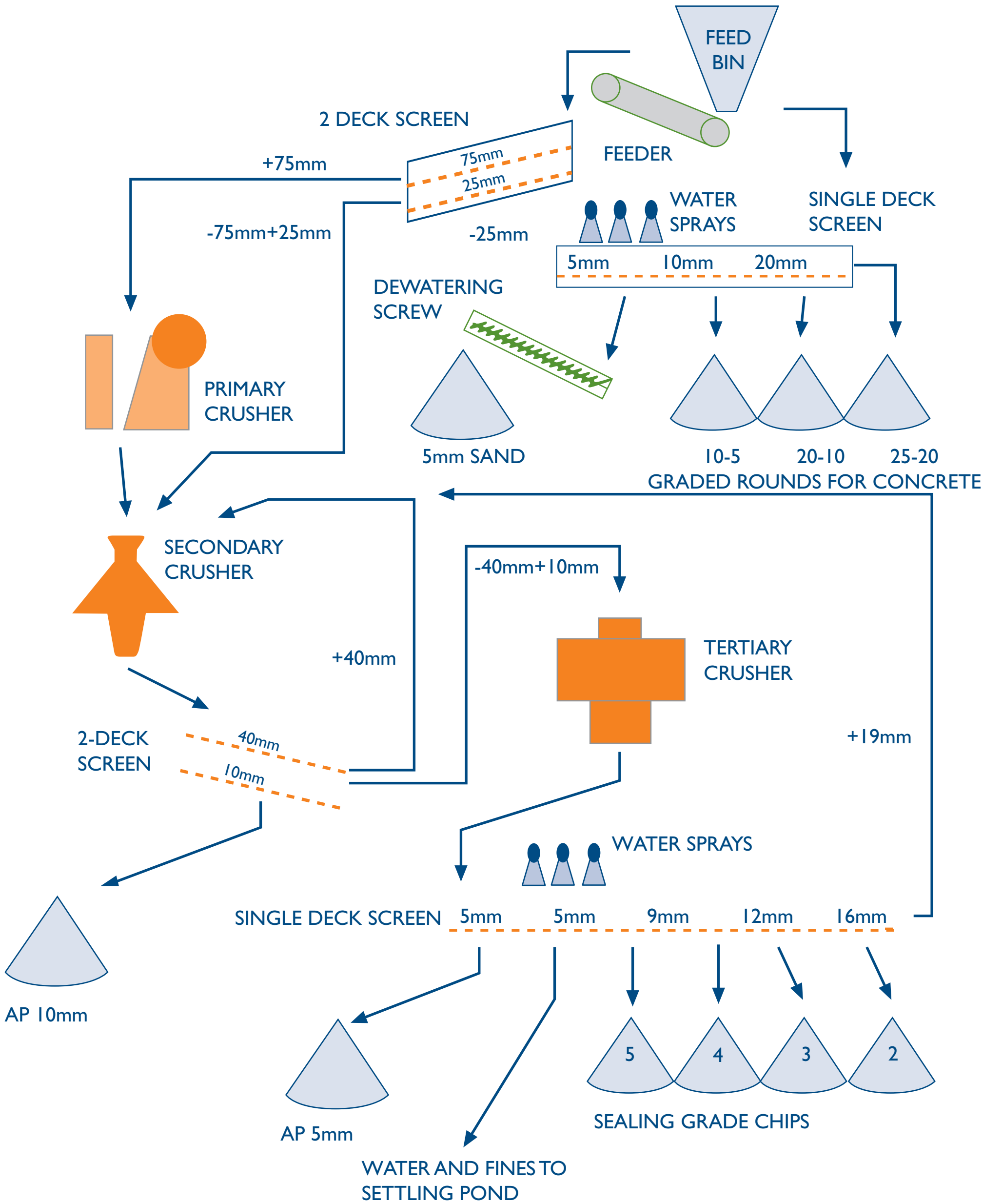

Figure 8-22 Typical crushing and screening process for natural gravels.

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8.5.6 Stockpiling

Much of the effort put in at the production stage can be wasted if insufficient care is taken in the subsequent handling and stockpiling of a product.

Segregation, especially of 'All Passing' products, can easily occur if material is tipped over high faces or allowed to free fall from a high conveyor discharge point without subsequent mixing. Segregation results in the different sized aggregates separating out, e.g. larger aggregates on the surface, so that any sample taken for analysis does not have the entire size range of aggregate in it.

Contamination with quarry floor materials or other products is a common problem where poor housekeeping habits and methods are allowed to develop in a quarry. Clean, washed products, such as sealing chip, should be stockpiled away from heavily trafficked, unsealed access roads. This reduces the risk of excessive contamination with air-borne dust.

8.5.7 Quality Control

The most effective form of quality control of quarry products is a regular in-house programme of laboratory testing of key parameters that is designed to detect significant changes and drifts away from established averages.

This type of programme is even more efficient if it is closely tied in with day to day quarry management decisions such as source rock location, crusher settings, screen sizes and feed rates.

When a purchaser requires proof of quality rather than requiring acceptance tests, the inspection of a producer's quality control data, where available, can usually give a much better idea of product characteristics and variability than a sample taken, however carefully, from a site stockpile.

It cannot be over-emphasised that testing of quarry products is not a precise science, and exact numbers can never be obtained. Even in the best quarries unavoidable variations in source rock and processing will occur. Samples can only represent small portions of a stockpile and testing itself also has inherent variability. When these factors are all taken into consideration, the test results will be, at best, only a good estimate of the true average.

The aim of a good quarry quality control programme should be to:

- produce materials which are as close as possible to the desired criteria; and
- minimise the total variability.

8.5.8 Aggregate Tests

Tests on aggregates for sealing chip are divided into two types:

- to assess the strength, durability and polishing properties of the source rock, called Source Property Tests; and
- to assess the cleanness, size and shape of the processed material, called Production Property Tests.

The following are referred to in TNZ M/6 specification for sealing chip.

8.5.8.1 Source Property Tests

Crushing Resistance

The Crushing Resistance test (NZS 4407, Test 3.10) measures the parent rock hardness and toughness. It can also give an indication of the ease of processing the material and the likelihood of the material breaking down on the road and during handling. If the chip is too soft or it breaks down in service, the action of vehicle tyres will grind down the top of the chip. Construction rolling can also cause severe crushing. A rapid loss of texture may occur, as the chip becomes flatter and the ground-off debris becomes incorporated into the binder causing it to flush up, or clog the voids (Figure 3-34).

The heavier the traffic the more important it is to use a hard, abrasion-resistant chip, yet these are often the chips that polish to produce poor skid resistance.

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The crushing resistance test consists of loading a sample of aggregate in the size range of 13.2 mm to 9.5 mm in a nominal 150 mm-diameter cylinder. The aim is to determine the load that will break it down so that 10% of the resultant material passes through the 2.36 mm sieve. The load in kN required to generate this percentage of fines is defined as the 'crushing resistance'.

The TNZ M/6 specification for sealing chip requires a minimum crushing resistance of 230 kN. However some sealing chip sources available in New Zealand (e.g. Dacite), although deficient in crushing resistance, have exceptional polish resistance. These sources may be used successfully but caution must be exercised and local experience carefully evaluated.

Weathering Resistance

The Weathering Quality Index Test for Coarse Aggregate (NZS 4407, Test 3.11) is designed to measure the long-term resistance to breakdown of an aggregate when it is subjected to repeated wetting and drying, and heating and cooling.

It consists of subjecting the aggregate to 10 cycles of heating, cooling, wetting and rolling. The degree of breakdown is assessed by the change in the percentage of material passing the 4.75 mm sieve and the cleanness value of the processed material.

A quality index is assigned to the material based on this value, and the percentage retained on the 4.75 mm sieve. TNZ M/6 specifies a quality index of either AA or BA which requires a cleanness value of 91 or greater, and the percentage retained on the 4.75 mm sieve of 91% or greater.

The quantity of unsound materials in sealing chip should be no more than 1%. The Weak Particles Test (AS 1141.32-1995) is suitable for measuring this.

Polished Stone Value (PSV)
This test (BS 812: Part 114) is a measure of the ability of the chip to provide an on-going safe, skid-resistant surface under heavy traffic.

When freshly quarried, most aggregate has a rough microtexture. However, once on the road, tyre forces and fine road grit combine to grind the surface of the aggregate to a smooth polished state. The skid resistance of the polished chip then fluctuates by season. See discussion and figures in Sections 4.9.3.4 and 4.9.3.5.

Chips that are composed of hard minerals, e.g. quartz and feldspar, are more prone to polishing than those in which the surface will abrade to expose a new face to the traffic.

To provide good microtexture, the chip must be resistant to this polishing process. Resistance of chip to polishing (indicated by the value obtained from the PSV test) becomes more important as traffic density increases. Some materials can cope with high traffic densities but other materials are unsuitable for any road, while some may be used only in lightly trafficked situations.

The PSV test, although carried out only on Grade 4 chip for consistency, is used to characterise the PSV of a chip source (quarry, river or pit) rather than that of the chip from single stockpiles. PSV testing is needed for new sources, variable sources (according to the producer's Quality Plan) or existing sources where accidents or skid testing on the road indicate possible problems.

Samples of the chip from a stockpile are prepared for PSV testing using an epoxy binder in curved moulds of a standard size and shape (Figure 8-23).

The samples, including a sample made using a control chip from a particular quarry reputedly always having the same PSV, are fitted round the circumference of a wheel (Figure 8-24). The wheel is rotated at a set speed and a solid rubber tyre is held against the face of the wheel. The pre-roughened chips are artificially polished by feeding water and grit (emery powder) over the chip–tyre interface for a specified time to simulate polishing by traffic.

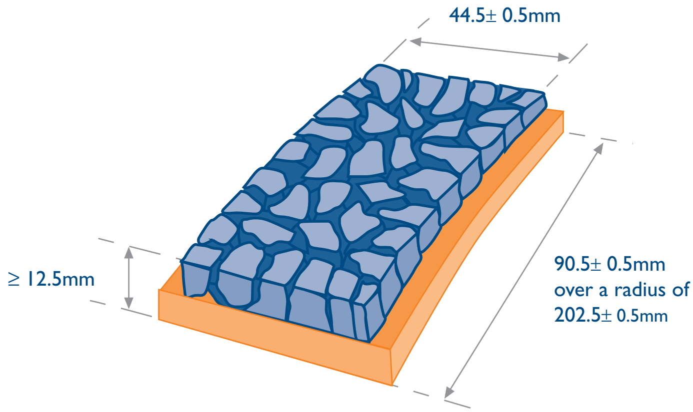

Figure 8-23 Prepared test sample showing chips embedded in epoxy.

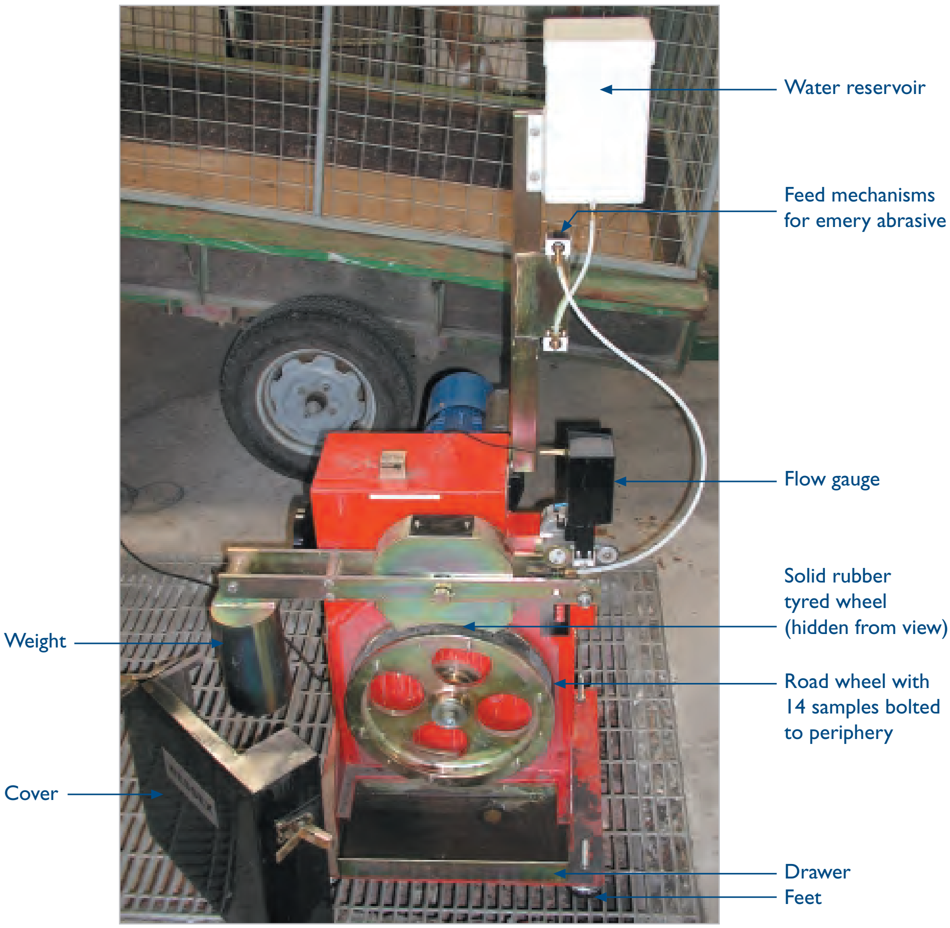

Figure 8-24 Polished Stone Value (PSV) Test apparatus. Photo courtesy of Shirley Potter, Opus

Note the PSV test should always be run on a solid base e.g. a concrete floor, not a grill as shown. The cover is put on before running the test.

The change in frictional resistance of each test sample is determined, using the British Pendulum Test (BPT) apparatus using a smaller rubber foot than usual (Figure 8-25), before and after the test. The PSV of that aggregate is calculated from the results of these and the control chip samples. The PSV of a chip gives an indication on a scale of 0 to 100 of how polish-resistant the chip is expected to be. A guide to the choice of appropriate PSV for a given situation is set out in TNZ T/10 specification.

Figure 8-25 Standard British Pendulum Test (BPT) Apparatus after a test. See also Figure 4-22 of a BPT in action.

Photo courtesy of Shirley Potter, Opus

8.5.8.2 Production Property Tests

Cleanness

The Cleanness Value (NZS 4407, Test 3.9) is a measure of the amount, fineness and character of the clay-like material coating the chip. The thicker this coating, the more it can inhibit the formation of a good adhesive bond between binder and sealing chip (Figure 8-26). A minimum cleanness value can be specified to control this detrimental effect.

The test consists of mechanically washing the chip, taking the wash water containing the suspended fines, allowing it to settle and measuring the quantity of fines. The lower the quantity of fines, the higher the cleanness value, up to a maximum of 100 for the condition when no fines are measured.

Figure 8-26 Clouds of dust when applying chips may indicate that they have low cleanness value.

Photo courtesy of Les McKenzie, Opus

Transit NZ has minimum requirements for chip cleanness in the TNZ M/6 Specification (Table 8-3). The cleanness value is influenced by the surface area of the chip, so the specification makes allowance for the fact that smaller chip has a higher specific surface area, and inherently therefore holds more fine material.

Table 8-3 TNZ M/6 requirements for cleanness.

Grade of Chip	Cleanness Value
2	89 min
3	87 min
4	85 min

In some performance-based specifications, cleanness is not specified as it tends to have an influence only during the construction and proving phase and has no long-term effect.

Chip Size (ALD)

Sealing chip size is specified in grades, from Grade 1 (coarsest) down to Grade 6 (finest) in terms of the Average Least Dimension (ALD) (Table 8-4). The ALD is the average thickness of the chips when they are lying on a flat surface in their most stable position.

Table 8-4 TNZ M/6 sizes (mm) for Grades 1, 2, 3, 4 sealing chips.

Grade of Chip	ALD (mm)
1*	11.5 – 14.0*
2	9.5 – 12
3	7.5 – 10
4	5.5 – 8

* Grade 1 is not specified in TNZ M/6 as it is not used for roads or highways but is sometimes used in off-highway situations such as forestry roads. It is included here for convenience.

The ALD is obtained by measuring the least dimension of each chip in a representative sample of at least 100 chips using a dial gauge (Figure 8-27) and averaging the results (NZS 4407, Test 3.1.13). The ALD gives an estimate of the thickness that a chipseal will attain after trafficking (see Figure 1-2) and is used in the design process (see Chapter 9).

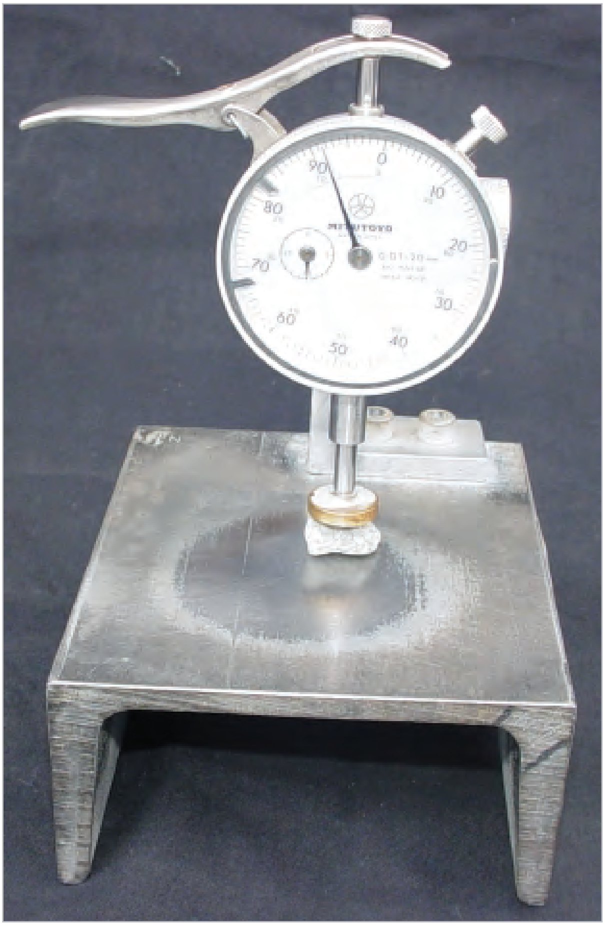

Figure 8-27 ALD (Average Least Dimension) apparatus. Photo courtesy of Joanna Towler, Transit NZ

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The ALD test is impractical to use for the finer Grades 5 and 6, so they are normally tested by conventional sieve analysis against an 'envelope' specification (Table 8-5).

Table 8-5 TNZ M/6 particle size distribution envelopes for Grades 5 & 6 chip.

Test Sieve Aperture (mm)	% Passing	
	Grade 5	Grade 6
13.2	100	–
9.5	95 – 100	100
6.7	–	95 – 100
4.75	8 max	–
2.36	2 max	15 max
300µm	0	8 max

The various grades cover fairly wide ranges of ALD that overlap slightly to take account of quarry production economics. If, in performance-based chipseal contracts, a narrower non-standard range has been specified by the designer, the aggregate producer may require some time for its processing. This factor must be taken into account when programming chipseals.

Chip Size Uniformity

Ideally, all chips in one stockpile should have close to the same least dimension. Chips that are too small will be 'drowned' once laid in the chipseal if the binder depth that suits the average size is used, while over-large chips will easily be dislodged.

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Very small stone fragments (grit) will fill the voids in the chip, causing the binder to rise up to cover even average-sized chips.

The problem of uneven chip sizes is aggravated by the tendency for chip to segregate in handling, often resulting in an uneven streaky road surface.

To ensure size uniformity, usually a high percentage of chips is required to fall within a range of $\pm$2.5 mm of the ALD, the percentage depending on chip size (Table 8-6) (NZS 4407, Test 3.13).

Table 8-6 TNZ M/6 Specification for chip size uniformity based on ALD.

Grade	ALD of Chip (mm)	% Least Dimensions within 2.5 mm of ALD
2	9.5 – 12.0	65 min
3	7.5 – 10.0	70 min
4	5.5 – 8.0	75 min

The proportion of fine grit is limited by controlling the percentage passing a 4.75 mm sieve to a maximum of 1.1%.

Chip Shape (AGD and ALD)

To limit the use of flaky or misshapen chips, which will not contribute properly to the interlocked stone mosaic or may break under trafficking, the shape of the chips must be controlled. This is achieved by specifying the maximum ratio of the AGD to the ALD.

The AGD of the sample of sealing chips (NZS 4407, Test 3.13) is obtained by placing the chips used for the ALD test end-to-end in a graduated trough, aligned in their greatest dimension (Figure 8-28). The AGD (mm) is the total length of chips in the trough divided by the number of chips, A maximum ratio of AGD:ALD of 1:2.25 has been found to give acceptable performance.

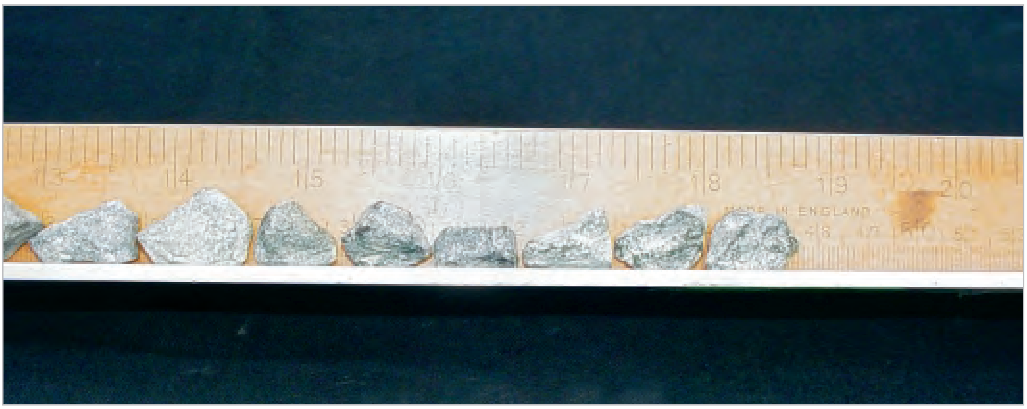

Figure 8-28 AGD (Average Greatest Dimension) apparatus. Photo courtesy of Joanna Towler, Transit NZ

Chip Shape (Angularity)

The stability of a chipseal is dependent to a large degree on the strength of the interlocking mosaic formed by the chips. If smooth rounded chips are used, a lower strength seal will result. Therefore the aim is to have as many crushed, angular faces as is practicable. This is usually achieved by requiring at least 98% of the chips to have at least two broken faces when tested (NZS 4407: Test 3.14).

8.6 Materials for Slurry Sealing

8.6.1 Aggregate

Aggregate used for slurry sealing consists of crushed rock or river gravel and may include some natural sand particles. The aggregate must be clean, hard, angular, durable and free from clay, soil, organic or other deleterious material.

In New Zealand, aggregate for slurries is generally produced from crusher dust (AP 5mm) that is a by-product of sealing chip manufacture. This may be washed to reduce the percentage of fine chalk-like dust material passing the 0.075 mm sieve to an acceptable level. The resulting product may then be blended with suitable size sealing chips (Grade 4, 5, or 6) to meet the specified particle size distribution limits for the various slurry types shown in Table 8-7 below.

Table 8-7 Particle size distribution for slurry aggregates.

Sieve Size (mm)	Percent Passing by Mass			
	Type 1	Type 2	Type 3	Type 4
13.20	100	100	100	100
9.50	100	100	100	85 – 100
6.70	100	100	85 – 100	80 – 90
4.75	100	90 – 100	70 – 90	60 – 85
2.36	90 – 100	65 – 90	45 – 70	40 – 60
1.18	65 – 90	45 – 70	28 – 50	28 – 45
0.60	40 – 65	30 – 50	19 – 34	19 – 34
0.30	25 – 42	18 – 30	12 – 25	12 – 25
0.15	15 – 30	10 – 21	7 – 18	7 – 18
0.075	10 – 20	5 – 15	5 – 15	4 – 8

Source materials for slurry aggregate should meet the same crushing and weathering resistance criteria as sealing chips complying with the TNZ M/6 specification (refer to Section 8.5.8). Specifications require a sand equivalent in excess of 65.

The most important aspect of slurry aggregates is compatibility with the emulsion. Many aggregate sources are incompatible with the emulsion even though they may otherwise meet all other criteria. Incompatibility can cause the slurry to break either too fast or too slow, or cause a poor bond to form between the binder and the aggregate. This can result in extremely fast wear of the surface.

Compatibility can only be ascertained by carrying out detailed mix design tests to confirm that the aggregate and emulsion will mix and break at an appropriate rate and, if they do, that the slurry has the necessary durability and wear characteristics. The latter is determined by a test known as the Wet Track Abrasion six-day soak test (ISSA A143:2004) where a trial mix is subjected to a wear test after being soaked in water.

8.6.2 Emulsion

The emulsion used for slurry seals is generally a cationic quick setting emulsion. A bitumen content of 62 to 65% is normal comprising 80/100 grade binder. A typical slurry mix will incorporate between 11% and 13% emulsion as a percentage of the dry aggregate weight.

A variety of different emulsifiers are available on the market for manufacturing slurry emulsion. As noted above, extensive laboratory mix design with the proposed slurry aggregate is essential to find one that results in suitable mix and curing times while still achieving the necessary durability and wear characteristics.

Where the emulsion is polymer modified, this is blended into the emulsion during the production process. The addition of up to 3% SBR polymer or latex (based on binder weight) is considered usual.

Quality tests that should be carried out on each batch of slurry emulsion include:

- Binder content (62% minimum by volume);
- Residue on 75 µm sieve (<0.05% retained).

The latter test is particularly important. A fail on this test can be an indication that the emulsion is unstable and could lead to difficulties mixing and laying the slurry in the field.

8.6.3 Cement

Cement is used in slurry as a filler and to improve the homogeneity of the mix. It also plays an important role in initiating the curing process and has an effect on break speed.

Normal grade Portland cement is commonly used but some brands will have different effects so it is important to use cement from the same manufacturer that was used in the mix design process, if possible. (Other materials such as hydrated lime can also be used effectively as fillers.)

The typical addition of cement is between 0.5% and 2% (as a percentage of the dry aggregate weight).

8.6.4 Water

Water is added to the mix in sufficient quantity to make the mix the right consistency for spreading. With too little water the mix will be stiff, possibly break prematurely and be difficult to spread. With too much water the larger aggregate particles will settle resulting in a flush surface.

The amount of water will vary from day to day depending on the moisture content of the aggregate and weather conditions, but is usually added at a rate between 0% and 6% (as a percentage of the dry aggregate weight). Any clean water that would be considered potable is acceptable.

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AS 1160-1996 Bitumen emulsions for the construction and maintenance of pavements.

AS 2008-1997 Specification for residual bitumen for pavements.

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American Society of Testing and Materials (ASTM), Pennsylvania

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ASTM D36-97 Standard test method for softening point of bitumen (Ring-and-Ball apparatus).

ASTM D92-97 Standard test method for Flash and Fire Points by Cleveland Open Cup tester.

ASTM D244-04 Standard test methods and practices for emulsified asphalts.

ASTM D2042-01 Standard test method for solubility of asphalt materials in trichloroethylene.

British Standards

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Part 1 Specification for bitumen road emulsions.
Part 2 Code of Practice for use of bitumen road emulsions.
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Methods of sampling and testing road aggregates. Part 3 Methods of testing road aggregates – laboratory tests. *NZS 4407.*

Test 3.8.2 The particle size distribution of an aggregate. *NZS 4407 Test 3.8.2.*

Test 3.9 The cleanness value of coarse aggregate. N*ZS 4407 Test 3.9.*

Test 3.10 The crushing resistance of coarse aggregate under a specified load. *NZS 4407 Test 3.10.*

Test 3.11 The Weathering Quality Index for coarse aggregate. *NZS 4407 Test 3.11.*

Test 3.13 The size and shape of aggregate particles. *NZS 4407 Test 3.13.*

Test 3.14 The broken faces content of aggregates. *NZS 4407 Test 3.14.*

8

CHAPTER NINE

Chipseal Design

Previous page: The road north of Punakaiki takes the traveller through spectacular West Coast scenery and as a result has to carry high traffic volumes and requires good chipseal design.

Photo courtesy of Terry Hann, Wreford Hann Photography Ltd

Chapter 9 Chipseal Design

Chapter 9 Chipseal Design

9.1 Introduction

This chapter describes the design for a seal coat once the pavement investigation has confirmed that the pavement needs resealing, that it is suitable for sealing, and that any necessary repairs have been made. For reseals and second coats, the design also assumes that a preliminary decision has been made on whether to use a small chip for a voidfilling chipseal or a larger chip for a conventional design. The detailed investigations discussed here may confirm the original treatment but in some cases the selected design for treatment may need to be changed.

9.2 Origin of Chipseal Design in New Zealand

9.2.1 Hanson's 1935 Developments

The first published work describing any kind of rational design of single coat seals was the paper by F.M. Hanson, presented to the New Zealand Society of Civil Engineers in 1935 (Hanson 1935; see also Chapter 1).

In his paper, Hanson introduced the concept that a successful seal required the partial filling of the voids in the covering aggregate, and that the volume of these voids was controlled by the Average Least Dimension (ALD) of the sealing chips being used.

Hanson found that chips when first placed on the binder had a percentage of voids of 50%, which reduced to 30% by construction rolling, and to 20% by traffic compaction. This resulted in a single layer of chips that bedded with shoulder-to-shoulder contact after trafficking.

In his research, Hanson graded the sealing chips recovered from a sample after trafficking, and it showed that considerable breakdown of the chips had occurred during service. This breakdown is presumed to have been caused by the crushing effect of steel drum rollers and the predominance of solid rubber-tyred trucks, steel-tyred horse-drawn drays and traction engines that were using the pavements in the 1930s.

He also found that in any seal coat, and with any size of sealing chip, the average compacted depth of the seal coat after trafficking was approximately equal to the ALD of the sealing chips, irrespective of the volume of traffic. He further stated:

> *Although sufficient binder to fill only 50% or 70% of the voids or air spaces between the stones is applied, nevertheless the road will be thoroughly sealed and waterproofed while the stone chips are held securely in position.*

Hanson's conclusion was that, for a successful seal on a smooth surface, the rate of binder application should be such that the 20% of voids volume after trafficking became 70% filled with binder. He expressed this as a simple formula:

$$\textbf{Residual application rate } R = ALD \times 0.20 \times 0.70 \quad \text{(Hanson's Equation)}$$

$$\textbf{or } R = 0.14\,ALD$$

where:
- R = residual binder application rate (ℓ/m^2)
- ALD = Average Least Dimension of the chip (mm)

9.2.2 1960s Development Work

Thirty years later, in the 1965–66 sealing season, trial lengths of sealing were laid on a number of state highways to investigate the effect of traffic and existing surface texture on Hanson's basic application rates. At each site a set of three different rates was applied:

1. the design rate (as estimated by the local sealing practitioners),
2. a lower rate, and
3. a higher rate.

The trials were visually monitored for three years. Then in August 1969, experienced sealing practitioners made inspections of each site, and they were asked to predict the future service performance of each of the three sections of seal.

The combination of these subjective observations with the known traffic volumes, pre-seal surface texture, chip ALD and application rates, enabled the production of a spray rate chart. This, in turn, led to the Transit New Zealand Design Algorithm known as RD286 (NRB 1971):

$$R = (0.138\,ALD + e)\,T_f \quad \text{RD 286}$$

where:
- R = residual binder application rate (ℓ/m^2)
- ALD = Average Least Dimension of the chip (mm)
- e = a surface texture correction factor (ℓ/m^2)
- T_f = an adjustment factor for traffic

This equation is very similar to Hanson's but includes an allowance for the existing texture and a varying application rate for traffic volume.

9.2.2.1 Effect of Texture

If the existing surface has significant texture depth (i.e. macrotexture), this first needs to be filled with binder before enough binder is left available to secure the new chip. Allowance for this is made by increasing the binder application rate.

The texture depth is determined by using the sand circle test in which the diameter of the circle that a standard volume of sand makes when spread on the substrate surface is measured (Figure 9-1). The test is described in TNZ T/3:1981 specification. The relationship between 'e' and texture depth was determined during the 1965–66 state highway trials and was defined as:

$$e = 0.21\,Td - 0.05 \quad \text{(T/3 equation)}$$

where: Td = texture depth (mm) derived from the sand circle test
e = the surface correction factor (ℓ/m^2)

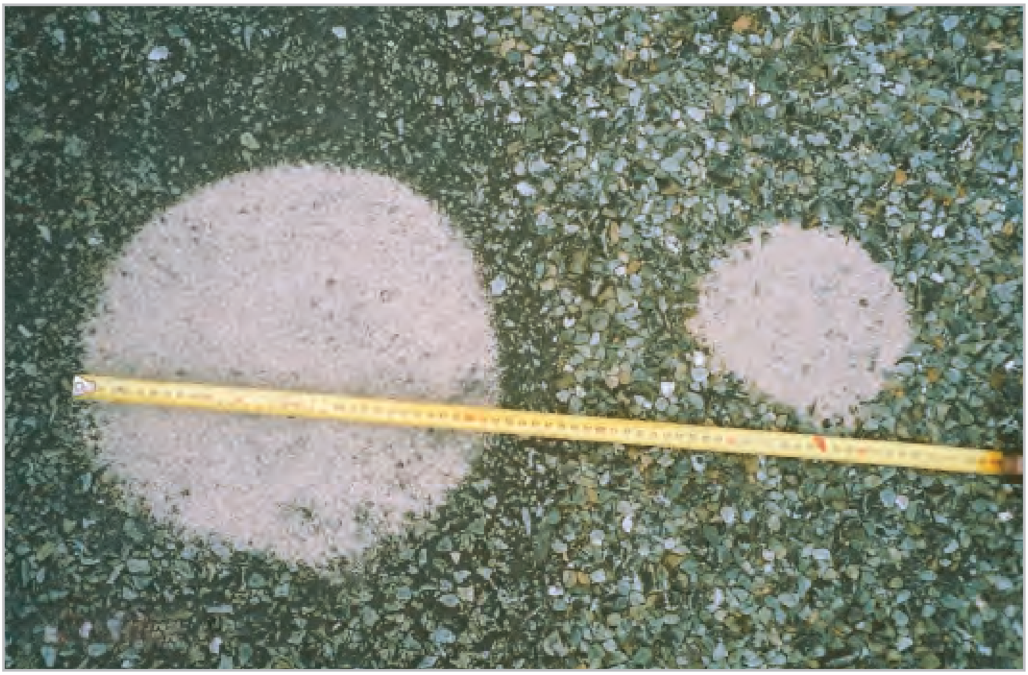

Figure 9-1 Sand circle test is used to determine the texture depth. Comparison of sand circles before (left) and after (right) a Grade 2/4 sandwich seal has been laid.

Photo courtesy of Lindsay Roundhill, Opus

9.2.2.2 *Traffic Factor*

The binder application adjusted for the surface texture depth was then further modified by a traffic factor 'T_f'. This factor takes into account the differences in chip orientation that occur under different traffic volumes, and that some embedment into the substrate will occur under high traffic loadings. The basic assumption that Hanson made about chips lying on their ALD was found not to occur, especially under light traffic, and therefore, as the chip layer is still thicker, it requires more binder to fill the larger volume of voids.

The traffic factor 'T_f' is related to the traffic volumes measured in vehicles/lane/day (v/l/d). The relationship determined during the 1965–66 trials reflected the practice that was satisfactory for the traffic volumes of the time.

9.2.3 1980s and 1990s Developments

The basic RD286 algorithm has essentially remained the same since its development in the 1960s. Modifications however were made in 1986, and again in 1993, associated with the traffic factor to reflect the experience at that time. At both times the effect was to increase the binder application rate at lower traffic volumes (less than 1000 v/l/d) but keeping the rate the same at higher traffic volumes (>1000 v/l/d).

The 1986 change increased the traffic factor by 17% for traffic volumes of 100 v/l/d and, in the 1993 Transit NZ *Bituminous Sealing Manual*, the factor for roads with traffic of 100 v/l/d was increased by another 15% (i.e. additional to the 17% in 1986). Also introduced in the 1993 *Manual* was the concept of equivalent light vehicles (elv). This was based on South African experience where a heavy commercial vehicle (HCV) was considered to be equivalent to 10 light vehicles or cars.

9.2.4 Two Coat Seals

Before the 1993 *Manual* was published there was no standard method for designing two coat seals. Practitioners had developed their own relationships such as adding the single coat binder application rates for the two chip sizes and then taking 75% of this rate.

In the 1993 *Manual* a design method was given for two coat seals. This method was adapted from French practice and developed for New Zealand conditions. Observations and trials were carried out in Dunedin and Lower Hutt (Houghton 1987).

9.3 Latest Developments

When developing performance-related chipseal specifications in the 1990s, considerable data was gained on the rate of change of texture with time. This information has allowed the basic Hanson criteria to be expanded to assist in obtaining a satisfactory seal.

9.3.1 Basic Voids Concept

The concept of voids in a single coat seal is illustrated in Figure 9-2, taken from Potter & Church (1976).

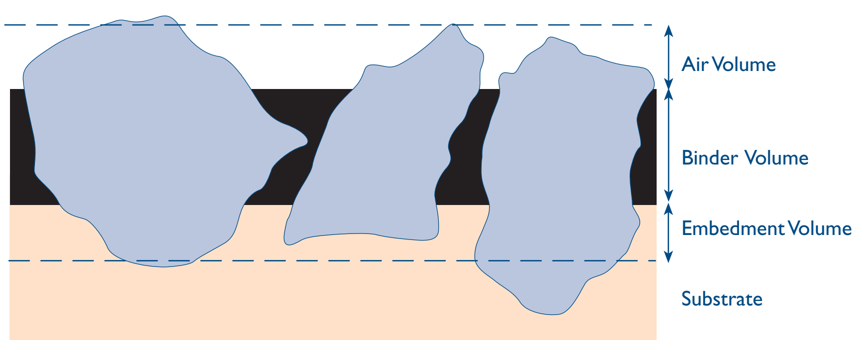

Figure 9-2 The voids concept as it applies to a single coat seal: spaces between chips are taken up by air, binder or embedment in the underlying substrate (from Potter & Church 1976).

The spaces (voids) between the sealing chips can be regarded as consisting of air, binder, and substrate (which is related to the amount of chip embedment).

Under traffic, the voids decrease in volume as the chip becomes re-oriented and embedded in the substrate and leads to reduced texture. On heavier trafficked roads this loss of texture, which ultimately leads to flushing, is the most common failure mechanism.

The extent that the chip embeds into the substrate is a function of the substrate hardness (i.e. of the existing seal). In New Zealand the hardness of existing seals is relatively constant and hardness has not been specifically taken into account in all previous design methods.

Care does need to be exercised when constructing first coat seals on unbound granular basecourse, or when sealing over asphaltic mixes, to ensure that the hardness of the underlying pavement is not significantly different from that of normal chipseals. If it is different, adjustments to the binder application rate may be required, and guidance is given in Section 9.4

Hanson's research indicated that the total volume of voids reduced under traffic to approximately 20%, and that the chip tended to lie on its ALD. Contrary to his research, later investigations (Potter & Church 1976, Patrick 1999) indicated that the total volume of voids is significantly higher than 20% in a compacted seal, and that the voids continue to decrease with further compaction under traffic.

9.3.2 Volume of Voids v Traffic Volume

The change in voids in a seal on New Zealand pavements is discussed in Chapter 4. The most comprehensive set of results was from research carried out on Lower Hutt (New Zealand) roads (Patrick 1999), and the best-fit line through the data is given in Equation 9-1. This equation is derived in Section 4.4.1.

9

$$\frac{V_v}{ALD} = 0.83 - 0.07 \log_{10}(elv) \qquad \text{Equation 9-1}$$

where: V_v = volume of voids

ALD = average least dimension of the sealing chip (mm)

elv = cumulative equivalent light vehicles based on assumption that one HCV is equivalent to 10 cars

Using this equation the change in the volume of voids under cumulative traffic is shown in Figure 9-3. The changes in the volume of voids as they are affected over time under different traffic conditions are given in Figure 9-4. The rate of change of voids, and therefore rate of change in texture, is very rapid after initial construction but then tends to slow.

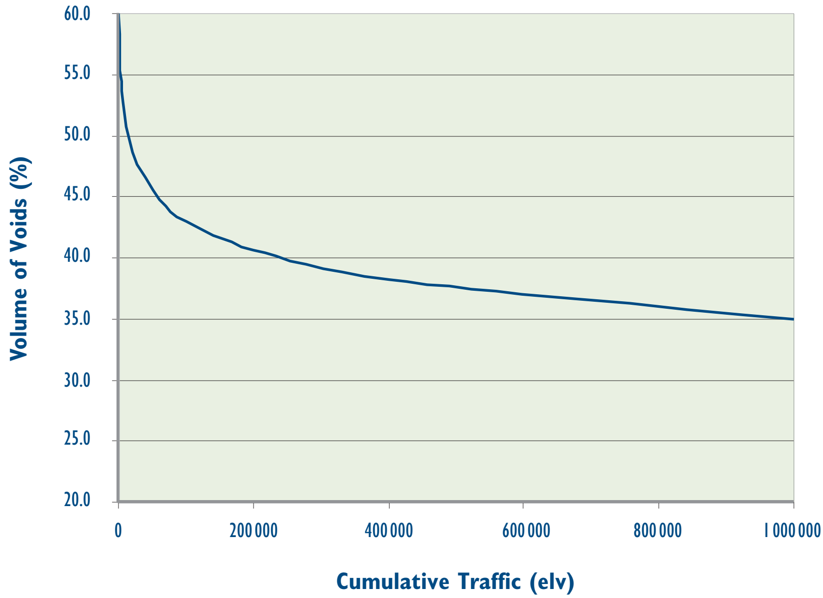

Figure 9-3 Rate of change in volume of voids (%) in a chipseal under different traffic volumes. The traffic volumes are shown as a cumulative total (in elv).

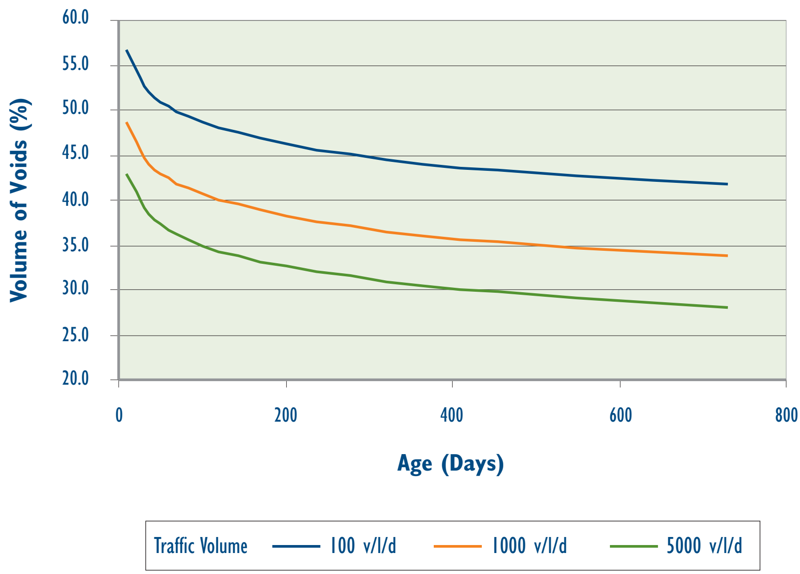

Figure 9-4 Change in volume of voids (%) with increasing time (in days from sealing for about 3 years), for low (100 v/l/d), medium (1000 v/l/d) to high (5000 v/l/d) volumes of traffic.

9.3.3 Derivation of the 2004 Chipseal Design Algorithm

Most international chipseal design methods use the void concept on the basis that in a durable seal the voids are filled to between 60–70%. The assumption is that the seal settles into a stable state after approximately one year.

The 2004 Seal Design Algorithm has been based on the philosophy of the performance-based chipseal specification (TNZ P/17:2002) which is in turn based on the premise that, if the chips do not dislodge during the first winter, there is a low risk that premature low-temperature chip loss will occur later. Likewise TNZ P/17 discourages excessive binder use as that could lead to premature flushing. This concept is illustrated in Figure 9-5.

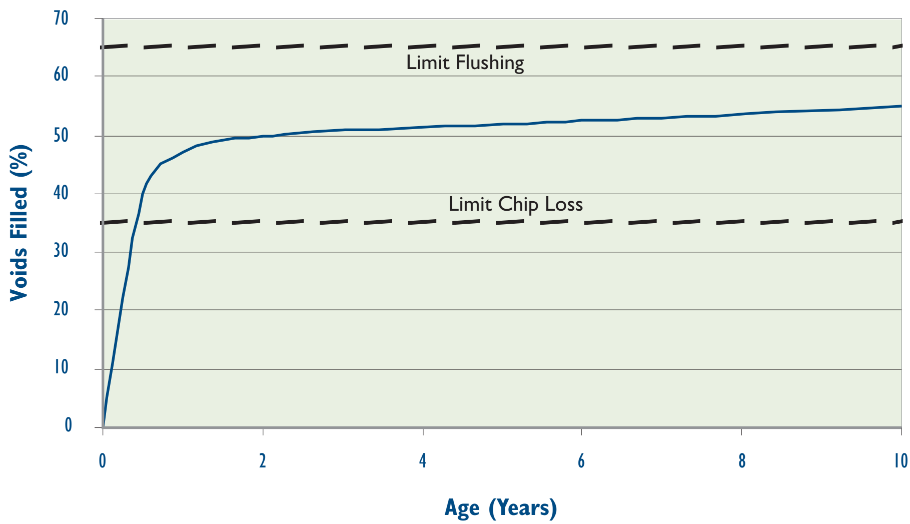

Figure 9-5 The binder application is a balance between too much binder which would cause flushing, and too little which would cause chip loss.

The effect of winter on chip retention was researched by Houghton & Hallett (1987). They found with single coat seals on roads in both Dunedin and Lower Hutt that, if the binder had not risen up the chip by 35% to fill the voids, chip loss would occur when the first cold snap occurred (and, as discussed in Section 4.2.3, this 35% value is not absolute for all conditions). The 2004 algorithm also requires that the voids must be at least 35% filled by the beginning of winter. If the seal is constructed so late in the sealing season that the binder has not had time to rise, then a softer binder will be required to reduce the risk of cohesive failure and chip loss.

The derivation of the 2004 chipseal design algorithm is as follows.

$$\frac{V_v}{ALD} = 0.83 - 0.07 \log_{10} (elv) \qquad \text{Equation 9-1}$$

where: V_v = volume of voids

ALD = average least dimension of the sealing chip (mm)

elv = cumulative equivalent light vehicles based on assumption that one HCV is equivalent to 10 cars

The volume of voids consists of:

$$V_v = V_b + V_{air} + V_e \qquad \text{Equation 9-2}$$

where: V_b = volume of binder

V_{air} = volume of air or texture depth

V_e = volume of chip embedment

Based therefore on the requirement to have 35% of the voids filled at the beginning of winter and the assumption that seals constructed in the middle of the sealing season have 100 days until the first major frost occurs, Equation 9-1 can be modified to form Equation 9-3 as follows:

$$V_v = ALD\,(0.83 - 0.07 \log_{10} (T \times 100)) \qquad \text{Equation 9-3}$$

$$V_b = 0.35 \times V_v \qquad \text{Equation 9-4}$$

$$= 0.35 \times ALD\,(0.83 - 0.07 \log_{10} (T \times 100)) \qquad \text{Equation 9-5}$$

$$= ALD\,(0.291 - 0.025 \times \log_{10} (T \times 100)) \qquad \text{Equation 9-6}$$

where: V_b = residual binder volume (ℓ/m^2)

T = elv per lane per day

The relationship in brackets can be regarded as similar to the 'Traffic Factor' in previous algorithms.

9

9.3.4 Impact of HCVs on Binder Application Rates

In practice the percentage of HCVs on most highways is approximately 10-11% and therefore the equation can be expressed in terms of v/l/d as follows:

$$elv = v/l/d \times (1 + 0.09 \times m) \qquad \text{Equation 9-7}$$

where: m = percentage of HCVs

$v/l/d$ = vehicles per lane per day

If the typical % HCVs is taken as 11% then:

$$elv = 2.0 \times v/l/d \qquad \text{Equation 9-8}$$

in which the factor of 2.0 can be considered to be a heavy vehicle factor 'T_f'.

In terms of v/l/d, Equation 9-6 can be expressed as:

$$V_b = ALD\ (0.291 - 0.025 \times \log_{10}(2.0 \times v/l/d \times 100)) \qquad \text{Equation 9-9}$$

If the HCV volume 'm' was very high, e.g. 40%, then the Heavy Traffic Factor 'T_f' would be:

$$T_f = (1 + 0.09 \times 40) = 4.6 \qquad \text{Equation 9-10}$$

and this would replace the value of 2.0 in the algorithm.

9.3.5 Adjustment for Texture

In the derivation of the relationships for the Lower Hutt research, the amount of binder used to compensate for the existing surface texture was excluded, i.e. the binder required to fill the existing texture was subtracted from the total volume of bitumen used.

However the road trials in the 1960s made a specific allowance for additional binder to compensate for the texture of the substrate. The adjustment developed in those trials was equivalent to increasing the ALD of the chip. As well it has been recognised that the chip does not sit proud of the existing texture and instead it interlocks with the existing texture.

In the 2004 algorithm the interlock embedment has been assumed at 30% and thus the ALD of the chip is increased by 0.7 × Td, where 'Td' is the texture depth measured by the sand circle test (as specified in TNZ T/3:1981).

The amount that the chip interlocks is a function of the chip sizes being used. On very coarse textured surfaces with a sand circle of <170 mm and a Grade 3 existing chip, then if a large Grade 2 chip is used, it will tend to bridge the existing texture of the underlying seal. This may need a larger adjustment for texture. On the other hand where the existing seal is already a Grade 2, and a Grade 4 is being used as a reseal, the finer chip may sit within the texture, and a lower adjustment for texture would then be required.

The basic equation that can be used for determining application rates (V_b) assuming 11% HCVs is:

$$V_b = (ALD + 0.7\,Td)\ (0.291 - 0.025 \times \log_{10}(2.0 \times v/l/d \times 100)) \qquad \text{Equation 9-11}$$

where: Td = texture depth (mm) derived from the sand circle test

This rate gives the volume of residual binder at 15°C. As was the case for the 1993 *Bituminous Sealing Manual*, this application rate should be regarded as a guide only, and adjustments need to be made for other variables, as discussed in Sections 9.4 and 9.8.5.

9

9.3.6 Comparison with Other Algorithms

As discussed in Section 9.2, a number of changes have been made to the original algorithm known as RD286 since it was published in 1968, and the effects of the algorithms on application rates are discussed here.

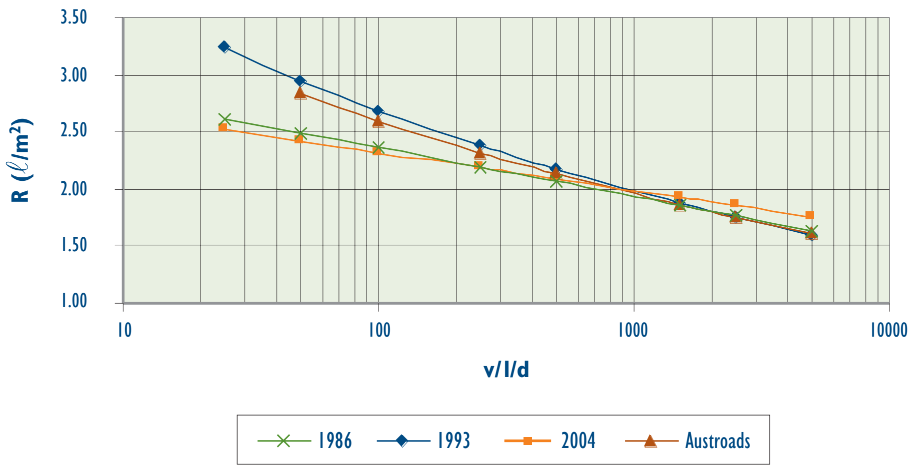

Figure 9-6 Comparison of bitumen application rates, R (ℓ/m²), for a range of traffic volumes and a Grade 2 seal, calculated using three Transit NZ algorithms and the Austroads algorithm.

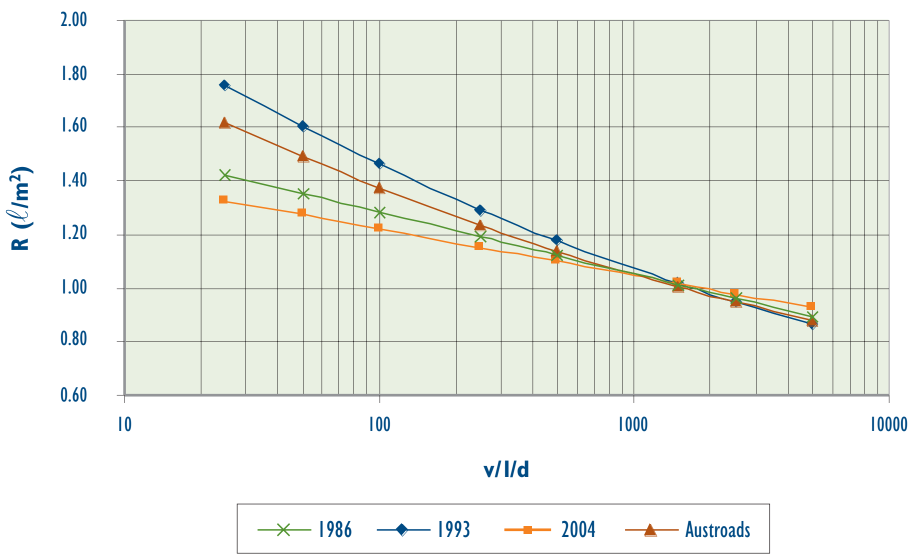

Figure 9-7 Comparison of bitumen application rates, R (ℓ/m²), for a range of traffic volumes and a Grade 4 seal, calculated using three Transit NZ algorithms and the Austroads algorithm.

Application rates calculated from the different algorithms over a range of traffic volumes are compared in Figures 9-6 and 9-7, for Grades 2 and 4 chips respectively on a relatively smooth texture. The figures show that all the algorithms are similar at higher traffic volumes but diverge at low traffic volumes.

At low traffic volumes the Austroads 2004 and the Transit NZ 1993 algorithms give similar results. The practitioners who were surveyed for this present book advocated variations in application rates greater than those in Figures 9-6 and 9-7 for low traffic volume roads.

For low traffic volumes, flushing would not be expected to occur and therefore the higher application rates can be seen as a safety factor in reducing the chance of chip loss in winter. Also the higher application rates would mean the binder may harden more slowly and, coupled with the higher binder rise around the chip, the higher application rate could assist in achieving a longer life.

On low-traffic urban roads, higher binder application rates can also assist in initially holding the chip in higher stress areas. Again with lower traffic volumes, the higher rates can be regarded as a safety factor for holding the chip and reducing the chance of chip loss, but care is required to avoid premature flushing.

In the site-specific adjustment discussed in Section 9.4, provision is made for an adjustment for low traffic areas.

9.4 Site-Specific Adjustments

The following describes other variables used in the 2004 Chipseal Design Algorithm to make site-specific adjustments.

9.4.1 Soft Substrate (Ss)

Soft substrates are occurring more often in New Zealand pavements which consist of multiple chipseals. They can also occur when resealing over asphalt or pavement repairs that have not fully cured or hardened. At present (2005), any allowance that is made in the application rate design for the extra embedment likely to occur over a soft substrate is derived simply from experience. The art is to apply sufficient binder to initially hold the chip and not lose it during the following winter before it is fully cured, yet not apply too much that will cause premature flushing to occur as embedment takes place.

In terms of the design algorithm the effect of a soft substrate can be modelled by increasing the traffic factor or decreasing the chip size.

TNZ P/17:2002 specifies the Ball Penetration Test apparatus for measuring substrate hardness. This test, which originated in South Africa and is also used in Australia, consists of measuring the penetration that a 19-mm ball bearing makes in a sample of the substrate when it is struck by one blow of a Marshall hot mix-compaction hammer (Asphalt Institute 1997). Typical ball penetration values for reseal surfacings in New Zealand are in the range of 2 to 3 mm.

Based on the South African seal design method, an adjustment for substrate hardness can be made by changing the ALD of the chip in the algorithm as follows.

If ball penetration values are:

- 1 mm or lower, increase ALD by 1 mm;
- 3-4 mm, decrease ALD by 1 mm;
- >5 mm, substrate is too soft for a normal chipseal; pavement repairs are required.

As discussed later in Section 9.6, the sensitivity analysis shows that such a change of 1 mm in ALD would be equivalent to:

- decreasing the binder rate by about 0.15 ℓ/m^2;
- for a 10 mm ALD chip;
- for a traffic volume of <1000 v/l/d.

9.4.2 Absorptive Surfaces (As)

On some surfaces binder can be absorbed, meaning that the binder ‘disappears’ into the surface and in effect results in a low application rate. Surfaces that may exhibit this condition are open graded porous asphalt (OGPA), an open-graded emulsion mix (OGEM), or a grader-laid asphalt. A similar absorptive effect occurs when first coat sealing over a unbound granular base.

9

As no method is available for assessing the degree of absorption, the preferred procedure is to seal the surface first with a small chip (see Section 7.3.4.4). If this is not possible, the basic application rate could be increased in the order of 0.1 to 0.2 ℓ/m^2.

9.4.3 Steep Grades (Gs)

On steep uphill grades, slow moving heavy vehicles can cause premature flushing of the surface. The Heavy Traffic Factor adjustment can be used for the application rates for crawler lanes (when these are provided), so the pavement can cope with the slow heavy vehicles.

A reduction of 0.1 to 0.15 ℓ/m² in binder application rate for these areas is commonly used to minimise the chance of binder pick-up from the truck tyres, which causes tracking and potential for flushing.

9.4.4 Chip Shape (Cs)

Chip shape is controlled by a maximum ratio of ALD:AGD of 1:2.25, although typical ratios of 1:2 have been found in practice. These shapes are preferred as they pack in with maximum shoulder-to-shoulder contact.

Some aggregate crushing systems can result in more cubical chip with ratios less than 1:2.0. The volume of voids, with this more cubical shape of chip, is higher than the voids between chips having the 1:2 cubical shape. Subsequently the binder application rate needs to be increased. Typically, the application requires up to 10% extra binder for chips with more cubical shape.

9.4.5 Urban and Low Traffic Volume Reseals (Us)

A significant number of urban Road Controlling Authorities (RCAs) and contractors are of the opinion that urban streets sealed with normal application rates suffer from chip loss along centrelines and in parking lanes.

A number of ways are available for dealing with this problem.

Generally, chip loss will be solved by increasing binder application rates from 10% up to 20%. However, apply this solution with caution especially in areas with higher traffic volumes, otherwise shortened seal life caused by flushing in the wheelpaths may result.

To reduce this risk of flushing using high binder application rates, two further options can be considered:

1. Dry-lock or wet-lock the centreline and parking lanes; and
2. Spray higher binder application rates on the centreline and parking lanes on their own. This option is more easily used on very wide streets.

As was discussed in Section 9.3.6, the 2004 Seal Design Algorithm gives lower application rates than the 1993 algorithm (Transit NZ 1993) at low traffic volumes. As the 2004 algorithm gives the minimum that should be applied, then there is scope for practitioners to increase the application rate at low traffic volumes. With traffic volumes around 100 v/l/d, then increases of 15% would give similar rates to that proposed in the 1993 algorithm.

A traffic factor that gives similar binder application rates to the 1993 algorithm is:

$$\mathbf{V_b = (ALD + 0.7\,Td)\,(0.42 - 0.0485 \times \log_{10}(2.0 \times v/l/d))}$$

Equation 9-12

9.5 2004 Chipseal Design Algorithm

The 2004 chipseal design algorithm is therefore:

$$\mathbf{R = V_b + As + Ss + Gs + Cs + Us}$$

Equation 9-13

where: R = Final residual binder application rate in ℓ/m² at 15°C

V_b = Basic application rate from Equation 9-11 with a heavy traffic adjustment if required:

i.e. $$\mathbf{V_b = (ALD + 0.7Td)\,(0.291 - 0.025 \times \log_{10}(2.0 \times v/l/d \times 100))}$$

Equation 9-11

As = Allowance for an absorptive surface

Ss = Allowance for a soft substrate

Gs = Allowance for a steep grade

Cs = Allowance for chip shape

Us = Allowance for urban and/or low traffic volumes

The 2004 seal design algorithm provides a basic design only. Site conditions and other site-specific reasons will dictate whether or not the application rate may need to be adjusted.

The RAMM database, which will contain data on application rates used locally, should be used to determine typical local application rates and therefore assist in determining the allowances that should be used.

9.6 Sensitivity of the 2004 Chipseal Design Algorithm

9.6.1 Introduction

The variables used in the main part of the 2004 Algorithm are discussed in this section. They are: ALD, texture, %HCV, traffic volume, and time before winter. The sensitivity of the algorithm to changes in these variables is discussed.

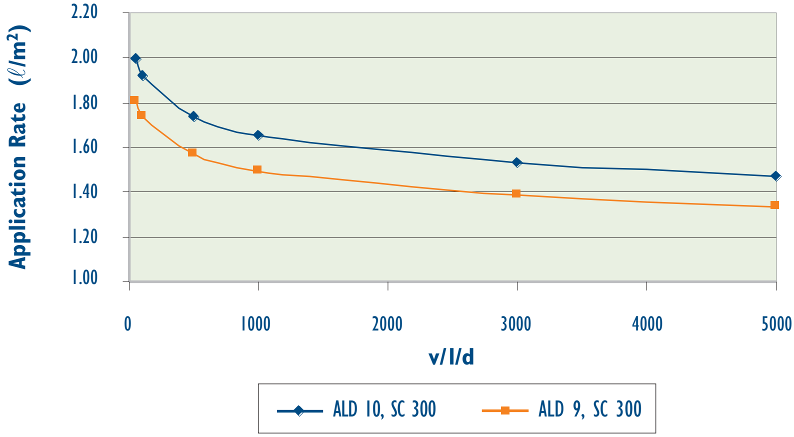

Figure 9-8 Effect of changing the ALD of chip from 10 mm (coarse) to 9 mm (fine).

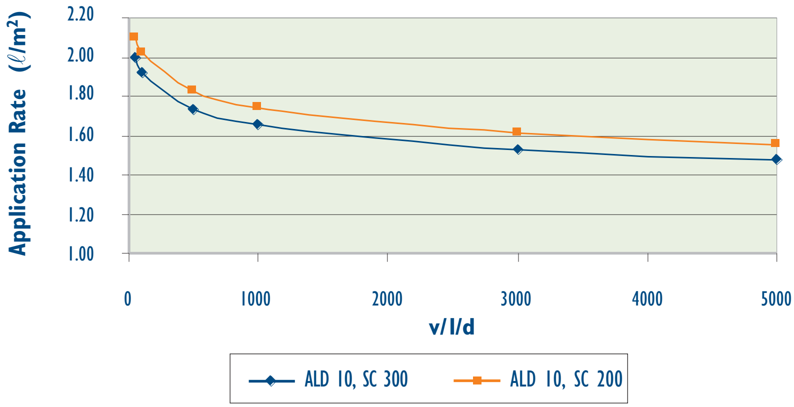

Figure 9-9 Effect of changing the texture depth of the substrate measured by a decrease in sand circle diameter from 300 mm (smoother) to 200 mm (rougher texture).

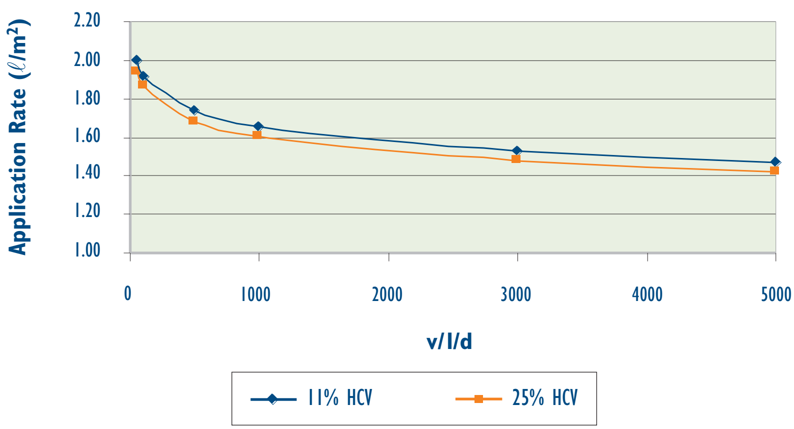

Figure 9-10 Effect of an increase in heavy vehicle traffic volume from 11% up to 25% for a pavement with chip ALD of 10 mm and sand circle diameters of 300 mm.

9

9.6.2 Sensitivity of Algorithm to Changes in Variables

A sensitivity analysis of the algorithm can give an indication of the accuracy required of the input. Figures 9-8, 9-9 and 9-10 illustrate the effect of changing the ALD of the chip, the texture depth of the substrate, and the % heavy vehicles respectively. The effects of changing these three inputs on the application rate of binder (V_b) are listed in Table 9-1.

Table 9-1 The effects of changes of chip ALD, texture and %HCV on application rate (V_b) for a typical road having 1000 v/l/d traffic volume.

v/l/d	Chip ALD (mm)	SC diameter (mm)	%HCV	V_b
1000	10	300	11	1.66
1000	9	300	11	1.50
1000	10	200	11	1.74
1000	10	300	25	1.60

The differences in traffic volume and texture are relatively easy to visualise. Figure 9-9 illustrates a difference between texture as measured by 300-mm and 200-mm sand circles, and Figure 9-10 a difference between 11% and 25% HCV, both of which have effects on the binder application rate that are very significant. However the difference between a chip ALD of 10 mm and 9 mm (a change of 1 mm), which is difficult to see in the field, has had the greatest effect on the application rate (i.e. 1.66 ℓ/m² decreases to 1.50 ℓ/m²). Such a change in ALD of 1 mm can be considered to have the same effect on the application rate as halving the traffic volume from 1000 v/l/d to 500 v/l/d.

From a practical sense, the chip ALD is the most critical component although variations or changes in application rate of the order of 0.2 ℓ/m² will be made for other conditions at the site. Experienced practitioners may also make greater adjustments for HCVs than the algorithm suggests.

The rationale of the algorithm, i.e. that the volume of voids must be filled to 35% by the beginning of winter, can be used to demonstrate the importance of not sealing late in the season. Figure 9-11 illustrates that, if only 30 days remained before significant cold weather occurs, in theory the application rate would need to be increased.

To help prevent chip loss, the application rate for the 1000 v/l/d pavement would need to be increased from 1.65 ℓ/m² to 1.79 ℓ/m². This change in application rate is just as significant as that required for a change in ALD of 1 mm.

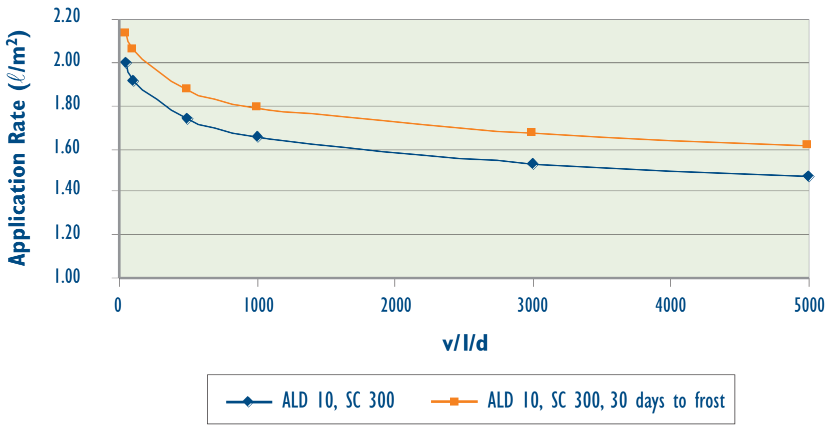

Figure 9-11 The theoretical increase in binder application rates related to traffic volume if sealing has to be done within 30 days of onset of winter conditions.

In practice such an increased application rate should not be applied as this could lead to early flushing, e.g. in the first summer. Instead a higher diluent content should be used to temporarily soften the binder so that it is not so hard at low temperatures.

On low volume roads (<1000 v/l/d) which are not expected to flush before cracking (see Chapter 4), some practitioners would argue that the increase in application rate would not affect the seal life and should be used rather than increasing the diluent content. This has been discussed in Section 9.4.5.

9.7 Design of Residual Binder Application Rates for Other Seal Types

9.7.1 Modified Binder Application Rate for Multiple Seal Coats

As discussed in Chapter 4 the volume of voids to traffic relationship for two coat seals is the same as for single coat seals.

This implies that the residual volume of bitumen that should be used in two coat seals is the same as for single coat seals. Therefore the formula used for application rate for two coat seals is calculated as for a single coat seal, with the ALD of the larger chips used in the formula.

As these seals are stronger than single coat seals, the increase in application rate for urban and low traffic seals (Us) is not as critical.

Two coat seals are considered to be more tolerant of surface texture variation than single coat seals, so the limitations given for single coats do not apply. However, extreme variations in surface texture should be avoided and, as for single coat seals, the recommendation is that a voidfilling seal should be used if the section has more than 10% of its area with a coarser texture than a 170 mm sand circle.

This binder application design is only applicable to two coat seals where the ratio of the ALDs of the two chip sizes fall within the shaded area of the graph in Figure 9-15 (see Section 9.11).

In the case of the racked-in or dry lock type of multiple seal, the binder is applied as a single application before any chip is added.

For two coat seals, the total amount of binder is applied in two applications immediately before the application of each chip layer. This split is normally at a 60:40 ratio, i.e. 0.6R is one binder application rate and 0.4R is the other (where R is the residual application rate). Some practitioners consider that the split should be 50:50 while others prefer a 40:60 split. When deciding what the split should be, it is wise to consider how the low rate will distribute through the chip. If the second rate is very low, most of the binder is applied to only one side of the large chip. Alternatively streaking could occur.

Where small chip sizes are being used, the first and/or second binder application rates may be too low for them to be accurately applied by the sprayer. If this is the case, then one or both of the applications will have to be applied as emulsions.

The above procedure is based on both coats of the two coat seal being constructed in succession on the same day. Where a gap in time of a day or more occurs between the construction of the first coat and the second, it is usually called a wet lock. In this case the first coat is designed as a single coat seal and the second as a voidfill.

9.7.2 Cape Seals

The sprayed binder rate for a cape seal should be as for a single coat seal.

9.7.3 Sandwich Seals

A sandwich seal is used to absorb excess binder on a flushed seal. The objective is therefore to use a binder application rate that is as low as possible.

The determination of the appropriate application depends on the quantity of excess binder but can be approximated by using the ALD of the small chip rather than that of the large chip when applying the application rate calculations shown in Section 9.5.

As sandwich seals are used only on flushed surfaces, no texture depth correction is required.

The binder is applied at the total application rate after the first layer of chip has been spread and before the second layer of chip is applied.

9.7.4 Geotextile Seals

The sequence of construction for a geotextile seal (see Figure 3-25) is to apply the first layer of binder at a rate sufficient to saturate the fabric mat, and as specified by the geotextile manufacturer. This depends on the fabric but is in the order of 1 ℓ/m^2. The fabric is then applied on top of the first layer of binder, and a conventional seal coat with application rates as calculated normally (Section 9.5) is placed over the fabric.

While 1 ℓ/m^2 may be required to saturate the fabric, care is required not to apply all of this in the base tack coat because, if the tack coat is too heavy, the saturated fabric will stick to tyres and lift off during the second application of binder.

9.7.5 Precoating

Precoating of sealing chip is a technique that produces good adhesion between binder and chip in the early stages of chipseal construction. It allows the cutter content of the binder to be reduced, can enable the use of stiffer binders, and lowers the risk of stripping and chip loss.

The coating should be as thin as possible to prevent the chips from sticking together as they then become difficult to handle and distribute.

Precoating materials should have an adhesion agent added to ensure that the bond between the precoating layer and the chip is adequate.

For cold-applied precoats consisting mainly of diesel oil, 6 to 8 ℓ/m^3 of precoat are required for a clean Grade 2 chip. As chip size decreases, the amount of precoat will need to be increased accordingly to compensate for the greater surface area and will be up to 10 to 12 ℓ/m^3 for Grade 6 chip.

If dust is present on the chip, and depending on how much there is, the amount of precoat may need to be increased by up to a further 2 ℓ/m^3. The aim is to produce a complete coating that cannot be washed off with water. If the dust is excessive, it should be removed before precoating by washing or pre-screening.

For hot-applied precoats with straight-run bitumen, the quantity of precoat may need to be increased from 10 to 12 ℓ/m³ or more) to get adequate coverage. Up to 2% by weight may be required and even then the higher viscosity may not give a continuous film over each chip, presenting a speckled brown appearance. This is acceptable and will produce satisfactory results provided that this chip is used within a short period, is not too dusty and the bitumen cannot be washed off with water or rain.

Note that precoating can add up to 0.1 ℓ/m³ residual binder to the chipseal. As discussed above in connection with Figure 9-11, this increase in application rate can be enough to lead to premature flushing. Therefore a reduction in binder application rate by 0.1 ℓ/m³ may be required when using precoated materials.

9.8 Practical Aspects for Seal Design

9.8.1 Spray Runs

The start and end positions, widths and tapers of the spray runs need to be planned and documented in advance in all but the very simplest situations. It is essential that the appropriate application rates are designed in advance for different parts of the pavement, and that the field construction personnel are absolutely in no doubt where each change in rate is to occur.

Details of spray run planning for longitudinal laps, at intersections and in wheelpaths are in Chapter 11. It is a two-stage process: to gain first an approximate layout for spraying, then to develop the detailed design requirements specific to sections.

9.8.2 Homogeneous Sections

9

The seal design is applied to a homogeneous section of pavement.

In assessing the homogeneity the following variables need to be considered:

- Traffic;
- Texture;
- Pavement hardness;
- Stress.

Wherever the surface condition changes, a new or modified seal design or seal type for the different condition in that segment needs to be considered.

In the surfacing selection process made at the first stage, detailed in Chapters 5 and 6, a preliminary assessment will have been made. In the specific design undertaken at the second stage in readiness for the operation, the available chip sizes, traffic volume, etc. will be used to determine the final design that will be used on the site.

9.8.3 Segmentation by Traffic

If the road has sections that carry different volumes of traffic, each of those sections must be investigated and designed separately. A 'one size fits all' approach will not result in the optimum design for any of the sections.

Examples of situations where it is always necessary to investigate breaking the road up into separate design sections are as follows:

- Wide shoulders and through-lanes;
- The fast and slow lanes of a multi-lane road;
- Turn bays and slip lanes at intersections;
- Parking lanes in urban areas;
- Uphill and downhill lanes on steep gradients that significantly affect truck speeds.

In some cases the sections may be too small or awkward to allow for separate spray runs. In those sections the design should still be checked to see how far the ideal design is likely to differ from the one chosen. The chosen design should be that which suits the section carrying the most traffic. If the designs differ a lot, the need for pretreatment to make the surfaces more uniform should be investigated, so that the binder application rate can be more efficiently designed.

9.8.4 Traffic Volume

In most locations, most of the heavy vehicle traffic will use the left hand of multiple lanes, except at right-turn bays.

This may not be the case in situations where the volumes of traffic are high and include high numbers of trucks. Light vehicle traffic will also use the left lane except when the traffic is heavy and/or significant numbers of slow-moving vehicles are in the flow. In these cases special traffic counts are warranted to ascertain the split of heavy vehicles, especially if they form more than about 20% of the total traffic flow.

9.8.5 Texture Variation

In most cases the texture depth will differ along the length to be resealed. The results of the sand circle tests are studied to determine how the surface should be divided up to achieve the optimum matching of application rate to surface texture, without requiring an excessive number of short spray runs.

Each type of seal differs in its sensitivity to texture variation and excessive texture. Voidfilling seals which are not sensitive to texture are specifically intended to be used on pavements where the texture is deep and variable. At the other end of the scale, conventional large- or medium-sized single chipseals are quite sensitive to texture and can tolerate only slight variation in texture.

If the section has more than 10% of its area with a coarser texture than 170 mm (estimated by sand circle), a voidfilling seal is the desirable seal type to select rather than a conventional reseal. This requirement should normally be picked up during the seal selection investigation but needs to be re-checked at the detailed design stage.

Application rate design has to steer a path between applying too much binder and applying not enough, as stated before. Enough binder is needed to securely hold chips on the lesser trafficked centreline between wheelpaths and road edge areas.

The situation can occur where the difference between the centreline texture and wheelpath texture is so great that the binder application rate required to hold chip in the wheelpaths will not be enough to hold chips either on the centreline or between the wheelpaths.

To cope with this variation, the designer checks the texture variation between sections with coarsest and finest chip size to determine if the seal can perform reasonably with the chosen application rate.

As a rule of thumb for deciding whether the difference between wheelpath and centreline textures is excessive, apply the following so-called 'ALD/16 rule' for single coat seals:

$$Td_{(coarse)} - Td_{(average)} \text{ shall be} < \text{Min } ALD/16 \qquad \text{Equation 9-14}$$

$$Td_{(average)} - Td_{(fine)} \text{ shall be} < \text{Min } ALD/16 \qquad \text{Equation 9-15}$$

where: $Td_{(average)}$ = average texture depth (mm) from all the sand circle measurements taken for each spray run section

$Td_{(coarse)}$ = largest texture depth (mm) from sand circle measurements

$Td_{(fine)}$ = smallest texture depth (mm) from sand circle measurements

If the difference between either $Td_{(average)}$ and $Td_{(coarse)}$ or $Td_{(fine)}$ is greater than ALD/16, then a texturising seal should be used. This rule is not applied to first coat seals.

For first coat seals, $Td_{(average)}$ should be limited to less than, or equal to, 1.5 mm.

If a pavement with a texture variation greater than ALD/16 is sealed, and the binder application rate is determined from the average texture depth, then sufficient binder rise may not have occurred by winter to ensure good chip retention. Multiple coat seals can tolerate a larger texture variation as they have increased strength through chip interlock that will assist them under normal traffic loading to resist winter chip loss, even if binder rise is less.

Care should be taken to ensure that the application rate being used is not so high that premature flushing results on low texture areas. The practice of using the wheelpath texture for two coat design rather than using the average between centreline and wheelpath assists in minimising the binder application rate, and in this way preventing flushing yet utilising the increased strength of this seal to resist early chip loss.

Traditionally the texture depth derived from average sand circles has been used in the calculations, although more recently some practitioners have been using the wheelpath texture depth. This can result in a lower application rate being applied, which is thought to help prevent premature flushing.

If the texture variation is excessive, the following measures should be considered:

- Determine if the area can be subdivided practically;
- If different application rates can be applied to each area;
- Try the effect of using a larger chip;

- Correct the extreme texture areas if they do not cover too much of the total area;
- Change design to a voidfilling type reseal or, if texture is not too variable, to another type of chipseal.

9.8.6 Pavement Hardness

The hardness of the existing pavement should have been considered in the treatment selection process.

For example, if the existing surface had been a hot mix asphalt, then provision should have been made to use an appropriate size chip or to ensure that the mix had hardened sufficiently to allow the construction of a seal. See also Section 9.4.1 to allow for the effects of soft substrate.

In the more detailed investigation for the final design, the hardness of preseal repairs and variations in the existing surface need to be considered in order to plan homogeneous spray runs.

A similar process to that used for a variable texture in attempting to obtain consistent spray runs should be considered to cope with softer areas. Also if a bridge deck is part of the chipsealing site, adjusting the spray rate for the harder substrate will have to be considered.

9.8.7 High Stress Sites

Although a site may appear to be suitable overall for, say, a single coat seal, it may include areas where turning traffic, driveways or sharp bends could impose high levels of stress.

In these areas a different seal system, e.g. racked-in or dry lock, may be more appropriate. These high stress areas are often small and can be accommodated in the spray run, and separate designs are not required.

9.9 Design of Residual Binder

Three bitumen grades are commonly used for chipsealing: 180/200, 130/150 and 80/100 penetration grades and they are used in First coat seals and Reseals.

9.9.1 Binder for First Coat Seals

In the past, first coats always used 180/200 grade bitumen but in recent years 130/150 grade has been used, and even 80/100 grade in some situations.

Assessment of the unbound surface cannot be done until the compaction rolling is complete. However, testing may be needed before the final brooming of the surface in preparation for sealing. If sand circle testing is required, several representative small areas of the trafficked surface are vigorously hand broomed to produce a surface that would be similar to the surface prepared for sealing.

In most cases after brooming, the texture of the surface will be appreciable and this may have to be allowed for in the design of the first coat application rate.

If the first coat chip to be used is fine and the texture of the surface is made up by large (20 mm plus) aggregate (which is the ideal case), the first coat will essentially be acting as a voidfiller for the basecourse texture.

If the texture is significant but made up of finer chip, the texture will need to be measured so that its effect on the application rate can be calculated.

9.9.2 Cutting Back for First Coat Seals

9.9.2.1 Developing a Good Bond

For first coat seals on an unbound granular base, a good bond must be developed that penetrates the dust layer which inevitably forms on a basecourse surface. It is advantageous if the binder can also penetrate into the top of the basecourse. For this reason the normal cutter content for a first coat seal is 6-8 pph of total diluent. In many places the diluent is all kerosene, although for some areas it may also include some AGO (Automotive Gas Oil).

The critical importance of establishing a good bond to the basecourse in order to achieve a waterproof seal has been discussed in Chapters 3, 6 and 7. The difference between a first coat seal and a second coat or reseal is that, with a first coat seal, the underlying base is inevitably dusty and somewhat porous. Hence total diluents in a cutback binder must be adjusted to compensate. For bases prepared with aggregates meeting the TNZ B/2:1997 specification, i.e. they are reasonably clean, the cutback content is about 3 pph higher than for a reseal which has a minimum of approximately 3 pph.

9.9.2.2 Temperature

The total diluents are not reduced to zero for higher air temperatures because the requirement for wetting the basecourse takes priority over the danger of bleeding. An adhesion agent should always be used in these situations.

9.9.2.3 Influence of Cutter

A primer used to penetrate dust and fine material on an unsealed basecourse has a high cutter content and low viscosity. A first coat binder must hold the sealing chip firmly and must therefore be less fluid than a primer. Because a first coat seal has more cutter, it should never be sealed with a second coat or overlaid with asphalt until the cutter has cured out. Otherwise the remaining cutter will seriously soften the second layer laid on top.

In circumstances where early overlay is the best option, use of emulsion first-coat binders would be desirable because they have little cutter and yet are more fluid. However, unless the emulsion has been specially formulated, as discussed for prime coats, it may not provide a reliable bond to the base.

9.9.3 Binder for Second Coat Seals and Reseals

To approve the area for sealing in the first place, normally the road asset manager will have had a detailed pavement assessment carried out. In the process, some sand circle testing will have been carried out to decide whether the new seal will be of the voidfilling type or not. Those investigations may well have been made some time in advance of the sealing season, and conditions could have changed in the interval between the pavement analysis and the sealing operation.

For the final seal design, the detailed design testing should be carried out as close to the actual sealing date as logistical decisions allow.

The final testing should be combined with a check of the surface to make certain that all repaired areas are in a fit state for sealing in regard to stability, curing and texture. Where clearly a voidfilling seal type is to be used, this visual check of repairs is all that is required.

9.9.3.1 Texture Testing

For reseals or second coats the texture of the existing surface must be accurately measured by sand circle so that it is allowed for in the seal spray rate design.

Instructions to the staff who are measuring the sand circles would usually include the preliminary spray run plans described in Section 9.8. The sand circle measurements and close observation may reveal the need for further segmentation or other modification of the spray runs. The testing staff need to be able to recognise this in the field and be able to undertake additional testing as required.

The sand circle measurements are made to determine the average and the two extremes which are representative of the length of road being sealed. To achieve this, the site of each sand circle measurement position needs to be carefully chosen. Measurements should be taken at approximately 100-m intervals along the road, with a minimum of five places being tested if the length of road being sealed is less than 400 m.

Where the shoulders are wider than 0.75 m, the texture should also be measured at 200 mm inside the seal edge.

For each spray run, two sand circle measurements should be taken at each cross section: one of the smoothest and one of the coarsest textures. The occasional area of extreme variability in wheelpaths maybe ignored.

9.9.3.2 Grade of Bitumen

Although 180/200 grade bitumen has been the most common grade used in the past in New Zealand, over the last 10 years the use of the harder 130/150 and 80/100 grades has increased.

The reason for using the harder 80/100 and 130/150 grade bitumens is to prevent chip loss caused by chip rollover during the summer and to minimise the risk of bleeding and binder pick-up.

9.9.3.3 High Temperature Considerations

Only limited research has been performed on binder pick-up by tyres but Figure 9-12 illustrates modelling of a truck tyre on a chipseal. It shows how a tyre can push into a seal for more than 1.5 mm. If the binder has risen to within 1.5 mm of the tops of the chip, the tyre can pick up that binder.

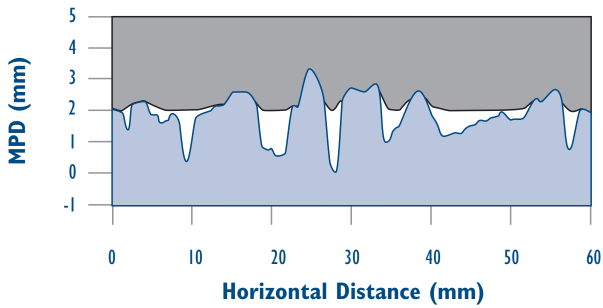

Figure 9-12 A model showing how a tyre can push into a seal and pick up binder. Tracking will occur if the binder is high enough up the sides of the chips.

The viscosity of the binder at which tyre pick-up under slow moving traffic will occur is about 200 Pa.s. Figure 9-13 shows the viscosity–temperature relationship for New Zealand bitumen, and that this viscosity is reached at 47°C for 180/200 and at 57°C for 80/100 grades. (This viscosity for a 130/150 grade would be at 52°C, but is not shown on the figure.) In practice the addition of kerosene as a cutter means that binder pick-up occurs at significantly lower temperatures in the first year after construction.

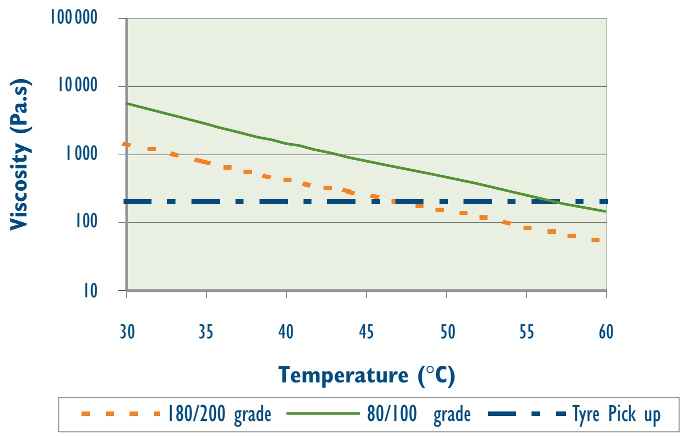

Figure 9-13 Viscosity (Pa.s) of binder for two grades of bitumen and its relationship to the temperature at which tyres pick up binder.

In deciding which grade bitumen to use, the temperature range for the location needs to be considered, and not just at the regional climate level but more at microclimate level because high or low extremes of temperature may occur near the pavement surface (see Section 4.2.3).

From the bitumen durability trial data (Ball 1998), a 180/200 grade bitumen will have hardened to approximately the penetration of a 80/100 grade bitumen within one year. However residual kerosene used in chipseal construction would tend to keep it softer for a longer time.

If the site is subjected to high temperature, slow traffic and/or heavy traffic, then the use of a PMB with higher softening points can be considered for resisting tyre pick-up.

The risk of bleeding and tyre pick-up decreases as the binder hardens and the seal ages, especially if harder binders and lower diluent contents are used (so the binder is harder to start with), and if traffic is faster (because slow-moving heavy traffic which aggravates bleeding is minimised).

Recent research by Ball (in press) has shown that under typical New Zealand conditions the binder grade does not have any effect on the rate of change in texture. This means that harder binder grades will not delay the onset of flushing.

9.9.3.4 Low Temperature Considerations

At the other end of the temperature spectrum, the need is to ensure that the binder is not so hard in winter that premature cracking or chip loss occurs. This concern has prompted the use of 180/200 bitumen and, in some areas, the use of a flux (e.g. AGO) to attempt to permanently soften the binder. As was noted in Section 4.2.1, 70% of the added AGO has evaporated after 5 years when, in the past, it had been assumed that the AGO did not evaporate. Therefore AGO is not now regarded as a permanent flux. If permanent softening is required, other materials (e.g. furnace oils) could be used.

The present manufacturing process being used to produce bitumen from the Marsden Point Refinery results in a reduction in temperature susceptibility as the bitumen goes from soft to hard grades of bitumen. This means that, although at 25°C the difference in hardness is significant, this difference decreases at lower temperatures so that at 0°C and below, the three grades are very similar in properties (see Figure 8-7). This relationship applies only to bitumen currently produced at Marsden Point.

The combination of the decreasing temperature susceptibility with control of durability has encouraged the use of harder grades of binder in colder regions. Although trials of harder grades in cold regions of New Zealand are only about 5 years old, no apparent increase has occurred in low temperature cracking.

9.10 Selection of Binder Type and Additives

9.10.1 Binder Type, Emulsion or Cutback

The basic characteristics of emulsions and cutbacks are discussed in detail in Chapter 8.

Emulsions are used less frequently than cutbacks for most seal types, principally because of cost. As design of emulsions to reduce their early tenderness or slow curing is not yet a science, it requires experience with the local aggregates and conditions.

> A claimed advantage of emulsions is that they allow good adhesion in cool damp conditions. Although good adhesion does occur, breaking time of conventional emulsions is usually delayed in cold humid conditions. The emulsion chipseal is then vulnerable if rain falls before the break occurs. This can result in a higher risk of failure than if a cutback binder had been used. In colder weather the tender 'cheesy' phase also lasts longer.

Emulsions can be formulated to cope with and reduce this risk. If it is too risky for even a well-made emulsion, then a cutback binder would also be a high risk treatment.

Fine Grade 6 chip is usually used with emulsions for voidfilling. The tenderness of emulsions in this case does not usually matter because fine chip is held within the voids of the larger chip. Almost any cationic emulsion complying with TNZ M/1:1995 specification will hold such small chip in reasonable weather conditions. Grade 6 seals require very low binder application rates that may be outside the application rate range of the distributors used for hot cutback bitumen binders. The higher water content of emulsions will boost the application rate, which then falls within the distributor's application rate range.

9.10.2 Binder Additives

9.10.2.1 Fluxes

AGO can be blended with the base bitumen to produce a softer residual binder by a process called fluxing. The addition of 2 pph of flux to 80/100 bitumen will produce a bitumen of approximately 130/150 grade, and an addition of 4 pph will result in a bitumen of approximately 180/200 grade.

The use of AGO is decreasing in New Zealand. Even for first coat seals where up to 4 pph has been added in the past, the realisation that the evaporation rate of AGO is faster than originally believed has lead to the use of kerosene rather than AGO as flux.

9.10.2.2 Adhesion Agents

The adhesion between bitumen and chips is a surface chemistry phenomenon. Given a low enough viscosity, a bituminous binder will usually spread across the surface of a dry chip 'wetting' it and thereby initiating a bond.

However, if a film of free water exists on the chip surface, the bitumen cannot adhere without first displacing the water (see Figure 8-9), as the chip–water bond is much stronger.

It is therefore good practice to use an adhesion agent (Section 8.2.2) to increase the ability of the hot bitumen binder to set up a good bond between the substrate, the binder and the chips in the presence of water. Tests can be used to determine the dosage rate of the agent, and typical dosage rates are between 0.5 and 1.0 pph of binder.

Adhesion agents are not required in emulsion binders as the emulsifiers used to produce the emulsion provide the same function.

Precoated chips often have an adhesion agent incorporated in the precoating agent, so that if precoated chips are used an adhesion agent is not needed in the binder (see Section 8.2.3).

9.10.2.3 Polymers

The use of polymers has been discussed in Section 8.4. If they are used, then care is needed when determining the correct percentage to be used for the binder application rate, taking into account all variables (as outlined in Section 9.4). The residual binder should have the same final application rates and properties regardless of whether the polymer-modified bitumen binder (PMB) is applied as a cutback or as an emulsion. Because of the many additives used in producing PMBs, the grade of bitumen used in their manufacture does not have as significant an effect as it does in straight bitumen sealing. Advice should be sought from the PMB manufacturer on the properties of the PMB blend.

9.10.3 Cutting Back

9.10.3.1 Objectives

Objectives in chipsealing design include obtaining:

- a binder viscosity on the road that allows the binder to adhere to the chip;
- cohesion to resist chip displacement after adhesion has occurred;
- a binder viscosity and expected % voids filled at the onset of winter that is enough to prevent chip loss;
- sufficient binder viscosity for the following season so that bleeding and pick-up on tyres will not occur.

Other factors that need to be considered when using high cutter contents include:

- binder pick-up by pedestrians;
- flow of binder into gutters and on steep pavements.

9.10.3.2 Process

The process of temporarily reducing the bitumen viscosity using diluents (as opposed to using an emulsion), termed 'cutting back', normally uses kerosene as the diluent. In calculating the binder application rate the kerosene is not included, and this is termed the 'residual binder', the assumption being that all the cutter evaporates.

When a binder is sprayed it very quickly cools to approximately the pavement temperature. Pollard (1967) found that the binder cooled within approximately two minutes to just above (5°C) the existing pavement temperature. Pollard pointed out that even in a relatively dry area of New Zealand (Canterbury) the humidity in stockpile was 100% and thus the chip was damp. The chip that is applied to the binder therefore will not adhere until the water has evaporated, and this takes time.

Once the chip has been applied the roller and traffic then will re-orient it. Throughout this process faces of the chip are being pushed into the binder and this process of re-orienting can take at least 24 hours or longer. When the chip embeds in the binder, adhesion needs to occur.

The above discussion indicates that binder–chip adhesion occurs over a period of hours to days rather than minutes, and relying on obtaining an on-road binder viscosity at the time of chip application can unrealistic. Pollard demonstrated, for example, that the arrival of a cold front could cause a rapid drop in pavement temperature. Another significant factor affecting pavement temperature is shade as the difference between the pavement temperature in the shade and in the sun can be greater than 20°C.

The rate of wetting of a binder on a chip has been shown by Forbes et al. (2000) to be an inverse function of the viscosity. Using Forbes' relationships and an estimate of the change of viscosity of bitumen with temperature, the ratio of wetting time for a 180/200 bitumen at 35°C is shown in Figure 9-14. This figure illustrates that, if the wetting time at 35°C for a 180/200 grade bitumen is taken as 1, then at 20°C the bitumen will take 7 times as long to wet the same area, and 30 times as long at 10°C. An 80/100 grade bitumen at 20°C will take 30 times longer than the 180/200 grade at 35°C. This shows that the exponential nature of the change in viscosity with temperature has a very significant effect on the time for wetting and adhesion to take place.

9.10.3.3 Effect of Shade

Figure 9-14 illustrates why initial adhesion problems can occur where the pavement is in the shade. The pavement in the sun could be at 35°C, but in the shade could be below

20°C. Thus while the chip in the sun-lit areas may have adhered by the end of the working day, the area in the shade will take seven times as long to adhere and is thus vulnerable to chip loss. Active traffic control can minimise this and in some regions, 48 hours of active traffic control is required after sealing. If sealing is performed near the end of the day followed by a drop in temperature overnight, chip loss may occur. Seals constructed earlier in the day will adhere and perform well, while those constructed late in the day may loose chip.

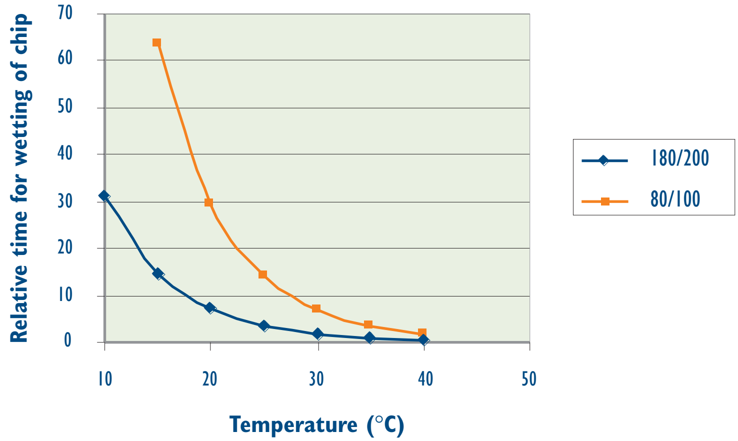

Figure 9-14 Relative increase in time required for wetting chip with decrease in temperature for two grades of bitumen.

9.10.3.4 Effect of Rolling and Traffic

The effect of rolling and traffic on the development of a good bond can be considered as similar to a pressure-sensitive adhesive. As the viscosity of bitumen is stress-dependent, the tyre stress results in the binder acting at a lower viscosity, and the stress also increases the rate of wetting. From the work of Forbes et al. (2000) the rate of wetting will be directly proportional to the stress imposed. Rolling and traffic will therefore assist the adhesion process.

9.10.3.5 Effect of an Emulsion

Even though the use of an emulsion will result in an initial coating of some of the chip with binder it does not result in mitigating all the variables associated with adhesion. After the emulsion has cured, chip re-orientation still takes place and, if sufficient wetting of the binder over the chip has not taken place before the construction crew leaves the site, then chip loss overnight can occur.

9.10.3.6 Desired Viscosity of Binder on the Road

Attempts to determine a target viscosity for the binder on the road are complicated not just by the rapid changes in temperature that can occur but also because approximately 20% of the added kerosene is lost during the construction process.

From the above discussion it is not surprising that a wide range of opinions and experiences exist in the determination of the on-road viscosity required for construction.

The decision on diluent content is therefore based on an assessment of risk. If binder has too little diluent, adhesion may not occur, but too much diluent and cohesive failure may occur. Either way the failure mode is chip loss.

Factors that affect the decision on the quantity of diluent besides the daytime temperature include:

- Time of year – in mid-summer the hours of sunlight and heat in the pavement are longer and the drop in temperature is less than in autumn, so less diluent is required.
- Time of day – if sealing in autumn or spring and low night-time temperatures are expected, then a higher diluent content is required when sealing in the afternoon.
- Settled weather – if a cold front is likely within 24 hours of sealing, then a higher diluent content could be required. If on the other hand, a cold front has just passed and temperatures are expected to increase, then a lower diluent content could be used.
- Traffic volume – where traffic volumes are higher, a lower diluent content can be used as long as traffic is controlled to track over the whole surface. Conversely where traffic volumes are very low then higher diluent contents should be used.
- Chip cleanness – if the chips are of borderline standard or do not meet the cleanness required by TNZ M/6:2004, then a higher diluent content would be required to ensure chip wetting and adhesion.
- Slow heavy traffic – a lower diluent content can be used to guard against binder pick-up caused by slow heavy vehicles pressing deeply into the seal.
- Precoated chip – if the chip is precoated, then a lower diluent content can be used.

In practice it is common for a sealing operation to use a 'recipe' approach, where a standard diluent content will be used in the beginning of the sealing season, another in the middle, and yet another at the end. For example, this maybe 4 pph of kerosene as cutter in the early and late season, and 2 pph in the middle of the season.

A starting point for deciding the diluent content to use is given in Table 9-2. This is considered appropriate for average traffic conditions, so that at low traffic volumes the diluent contents can be increased by 2 to 3 pph and at very high traffic volumes diluent can be decreased by 2 to 3 pph.

Table 9-2 Diluent contents recommended for a reseal at 24h maximum air temperatures and three bitumen grades.

Expected 24h Maximum Shade Air Temperature (°C)	Reseal Bitumen Grade		
	180/200	130/150	80/100
	Diluents - parts per hundred		
15.0	6	8	10
17.5	4	6	8
20.0	2	4	6
22.5	0	2	4
25.0	0	0	2
27.5 and over	0	0	0

9.11 Design for Chip Application Rates

9.11.1 Design Using 2004 Algorithm

Chip application rates are traditionally specified in terms of area per volume (m^2/m^3). This allows the sealing crew to easily estimate the area (m^2) that will be covered with a truck load of chip (of a known volume in m^3).

A theoretical chip application rate can be calculated based on the total void volume and this was used in the past to estimate the 'correct' application rate.

As discussed in Section 9.3.1, the volume of voids is significantly higher than 20% in a single coat seal. 9

Using the relationships in the algorithm given in Section 9.5, the voids on a lightly trafficked road are likely to be approximately 40% after two years. This equates to a chip application rate of approximately 830/ALD m^2/m^3. Using the above analysis procedure, the theoretical application rate and a rate with a 10% allowance for loss by whip off is given in Table 9-3.

If the thickness of a seal is assumed to equal the ALD of the chip, then the volume required to seal a square metre is equal to:

$$V_T = 1 \times \frac{ALD}{1000} \text{ m}^3 \qquad \text{Equation 9-16}$$

where: V_T = total volume of the seal (m^3)

The volume of chip is a proportion of the total volume:

$$V_S = (1 - V_V) V_T \qquad \text{Equation 9-17}$$

where: V_S = volume of chip (m^3)

V_V = proportion of voids as defined in Section 9.3.1

Combining Equations 9-16 and 9-17:

$$V_S = (1 - V_V) \times \frac{ALD}{1000} \ m^3 \qquad \text{Equation 9-18}$$

The chip in a truck has a void content of approximately 50%. Therefore the loose volume of chip that needs to be delivered and spread on the seal is double that of the compacted chip.

$$V_l = 2\,(1 - V_V) \times \frac{ALD}{1000} \ m^3 \qquad \text{Equation 9-19}$$

where: V_l = volume of loose chip (m^3)

In terms of m^2/m^3 Equation 9-19 can be expressed as:

$$R_C = \frac{1000}{2 \times ALD \times (1 - V_V)} \ m^2/m^3 \qquad \text{Equation 9-20}$$

Hanson's research indicated that the voids in a compacted seal were approximately 20%, i.e. $V_V = 0.2$. Substituting this value into Equation 9-20:

$$R_C = \frac{1000}{1.6ALD}$$

$$= \frac{625}{ALD}$$

This is the basis of the chip application rate recommendations made in earlier publications (NRB 1971).

Table 9-3 Chip application rates for single coat seals.

V_v	V_s	$\frac{x}{ALD}$ m^2/m^3	+10% allowance for whip off
0.20	0.80	625	560
0.25	0.75	667	600
0.30	0.70	714	640
0.35	0.65	769	690
0.40	0.60	833	750

where: V_v = volume of voids; V_s = volume of chip; $V_v + V_s = 1$

Recent research by Alderson (2001) indicates that an application rate of 900/ALD m^2/m^3 appears appropriate for most chipseals, and that when excess chip is applied it quickly disappears by whip off. The Austroads research also indicated that the loss was not associated with traffic volume. This research does not support the findings of Major (1993) who found that over-application of chip was a significant factor in poor seal performance.

The chip application rates required for single chipseals, multiple seals and special seals are the same for first coat seals, second coats or reseals.

The 1993 Sealing Manual considered that a chip application rate of $\frac{1000}{ALD}$ m^2/m^3 was a 'theoretical' optimum and that a numerator of 700 to 750 should be used to estimate the total amount required. This compares well with the Table 9-3 numerator of 750 for a V_V of 0.4. Although there are various options on the optimum application rate for chip, in practice it is visually assessed as discussed in Chapter 11.

9.11.2 Selection of Chip

Selection of chip size is covered below but chip properties should also be considered by the seal designer.

The chip chosen must comply with all requirements of TNZ M/6 *Specification for sealing chip* (Section 8.5.8). In particular, the PSV of the chip must be adequate to resist on-road polishing, taking into account the requirements of TNZ T/10 and the previous actual on-road performance of chips in relation to predicted on-road performance (Section 6.6.1.2).

9.11.3 Single Coat Seals and Cape Seals

For conventional single chipseals which require Grades 2 to 5 sealing chip, an estimate of the chip rate as calculated above is given by:

$$\text{Rate} = \frac{750}{ALD} \ m^2/m^3 \qquad \text{Equation 9-21}$$

This allows for approximately 10% for whip off but assumes a good standard of uniformity of chip spread. See Figure 11-4 in Chapter 11.

9.11.4 Voidfilling Seals

The chip application rate for a voidfill seal is approximately 80% of the rate for a conventional seal, i.e. 950/ALD m^2/m^3 for Grades 4 and 5 and approximately 250 to 300 m^2/m^3 for Grade 6.

Selection of the correct chip size is essential so that it fits into the texture of the old seal. Taking actual samples of several chip sizes on site and physically observing how they interlock with the substrate allows the optimum chip size to be selected.

9.11.5 Racked-In Seals

In a racked-in seal the chip application rates of both layers are given as 1050/ALD m^2/m^3 for Grades 2 to 5 and 350 m^2/m^3 for Grade 6 chip. These rates are 70% of those for a conventional seal. After the optional rolling of the first layer of chip, the second chip layer is added and it should just fill the surface voids of the first.

The compatibility of sizes between the two layers of chip is important, and Figure 9-15 shows a guide that can be used, based on the second chip being approximately half the size of the first chip. The intersection of the size of the first chip and the size of the second chip should lie within the shaded area on Figure 9-15. This should be checked on-site using the chips that will be used on the job.

Chip combinations with ALD intersections above the shaded area should be used very cautiously because the binder application rates derived for these seals has been based on seals conforming to the above relationships.

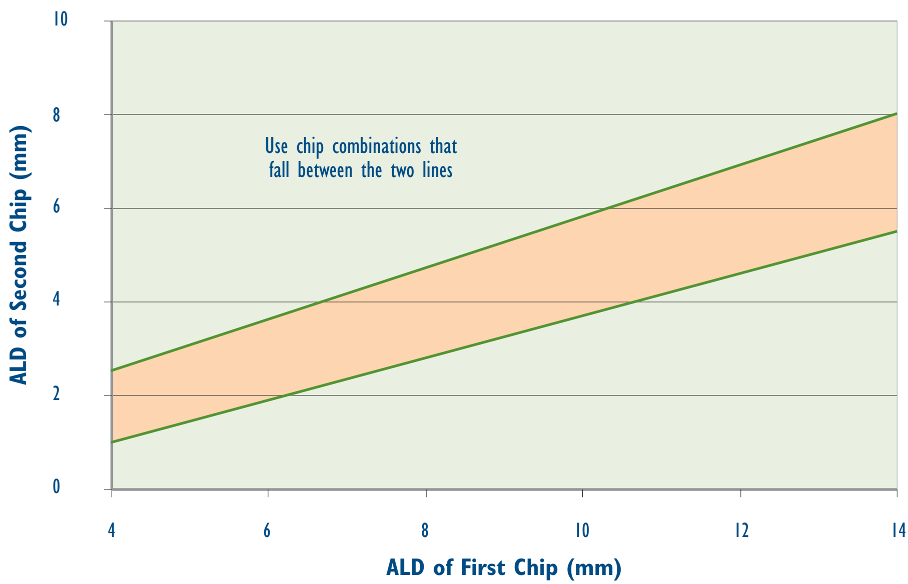

Figure 9-15 Compatibility of first chip and second chip of a two coat seal.

9

9.11.6 Two Coat Seals

The first application rate controls the extent of interlock with the second chip. There are differences of opinion on the extent that the second chip should fall within the interstices of the first chip. As there should be no allowance for 'whip off' for the first chip application the theoretical application rates are used. If the first chip is spread at approximately 920/ALD m^2/m^3, i.e. about 90% of the single seal rate, then the second chip will not be interlocked to the same extent that would occur with a lower application rate of 1100/ALD m^2/m^3.

The lower application rate will result in a seal that has similar chip mosaic to a racked-in seal but with two binder application rates. After the first seal has been well rolled, and after the second binder application has been made, the second chip layer is added. The second chip application rate is the same as for a racked-in seal second application.

The compatibility of sizes between the two layers of chip is checked, using Figure 9-15 in the same way to determine the recommended relationship as for the racked-in seal design.

9.11.7 Sandwich Seals

The chip application rate for the first chip of a sandwich seal (laid without binder) is as for a single coat, in that shoulder-to-shoulder contact is required but the layer of chips is to be not more than one chip thick. Opinion differs however on whether or not the first layer of chip needs to be rolled. The second chip is applied immediately after the application of the binder, as for a two coat seal.

The compatibility of sizes between the two layers of chip is checked using Figure 9-15 in the same way as for the racked-in seal design.

9.11.8 Geotextile Seals

A geotextile seal is simply a conventional seal, either a single or multiple coat, laid over the geotextile layer. The design of chip application rates therefore follows exactly that used for the equivalent conventional seal type, but binder application rates include the additional binder that is required to 'fill' the fabric.

9.12 Worked Example for a Single Coat Seal

The following worked example is for a single coat reseal. The design procedure for a single first coat seal is very similar.

Basic Design Information

Location: The road is a state highway in a small urban area, central South Island, and is subject to frost and ice.

Geometry:

	Length:	1150 m
	Intersections:	3 major intersections included in the 1150 m length
	Width:	9 m (average)
	Lanes:	2
Current surface:		a 4-year-old Grade 6 chipseal.
Reason for sealing:		inspection has shown 95 lineal metres of fine cracking.
Traffic:	ADT:	1200 vpd
	HCV:	10%

Chip Selection

Available materials: typical ALDs of local chips:

Chip ALDs:	Grade 3	=	8.0 mm
	Grade 4	=	7.0 mm
	Grade 5	=	5.0 mm

Treatment selection: A Grade 4 single coat seal was chosen as appropriate for the site using criteria from Chapter 6. In particular:

- The 4-year life for the Grade 6 seal indicated that seal stability was unlikely to be a problem.
- The fine cracking was not sufficient to warrant a specific crack treatment seal.
- The noise generated by a Grade 4 chip would be acceptable.
- As the site was not in the centre of the shopping area, the amount of loose chip and binder pick-up that a single coat seal would cause would be acceptable.

Chip Selection *(continued)*

Chip Application Rate:

The chip application rate for Grade 4 (7mm) chip (from Table 9-3) should be about

$$\frac{750}{7.0} = 107 \text{ m}^2/\text{m}^3$$

The area being sealed = (1150×9) m² = 10,350 m².

Therefore the quantity of chip = $\frac{10{,}350}{107}$ = **97 m³**

To allow for some loss of chip through stockpiling, 10 to 20% extra chip should be ordered, i.e. **110 m³** of chip will be ordered.

Binder Selection

Binder Type:

Because the local contractor cannot yet obtain emulsified bitumen at a cost that is competitive with hot bitumen, this decision is simple. Hot bitumen will be used.

Binder Design:

Bitumen: The traditional binder used in this central South Island area has been 180/200 bitumen with 1 pph of AGO. It is decided that, as binder pick-up through the urban area needs to be avoided, the harder 130/150 grade will be used.

Flux: After considering the basic information, the decision is to use no AGO in this reseal.

Adhesion agents: The arguments for using adhesion agents to promote binder–chip adhesion are considered valid for this area where unsettled weather is common during the sealing season.

Binder Application Rate:

ALD of sealing chip: The assumed ALD of 7.0 mm will be used as the chips that are available have not yet been stockpiled or tested.

Use of multiple spray rates: An inspection of the site shows that it is not practical to use different spray rates across the job because of the traffic patterns involved. Therefore the spray run will be a full lane width.

9

Texture Considerations

Texture depth: The local laboratory is asked to carry out sand circle testing so that the texture depth correction could be calculated.

The laboratory is asked therefore to take tests at 100m intervals along the road. At each interval, they are asked to take one test in the finest textured wheelpath, and another along the centreline because prior inspection has shown that the extreme texture levels are in these positions. Results of the tests are in Table 9-4.

The average Td value for a sand circle diameter is calculated (TNZ T/3) as follows:

$$Td = \frac{57{,}300}{D^2}$$

where: D = is the sand circle diameter (mm)

The $Td_{(average)}$ for both centreline and wheelpath is 1.18 mm.

The smallest and largest texture depths are taken from the table as $Td_{(fine)}$ and $Td_{(coarse)}$ as 1.04 mm and 1.26 mm respectively.

To determine whether the difference between wheelpath and centreline texture is excessive, the ALD/16 rule (Section 9.8.5) is applied:

$$Td_{(average)} - Td_{(fine)} = 1.18 - 1.04 = 0.14 \text{ mm}$$

$$Td_{(coarse)} - Td_{(average)} = 1.26 - 1.18 = 0.08 \text{ mm}$$

Table 9-4 Results of laboratory tests for texture depth using the sand circle test at 100m intervals along the sealed area.

Displacement	Texture Depth Td (mm)		Displacement	Texture Depth Td (mm)	
	Wheelpath	Centreline		Wheelpath	Centreline
0	1.24	1.26	600	1.12	1.26
100	1.10	1.23	700	1.18	1.18
200	1.18	1.24	800	1.15	1.23
300	1.12	1.25	900	1.10	1.25
400	1.15	1.18	1000	1.04	1.13
500	1.04	1.13	1100	1.24	1.24
Average = 1.18 mm					

Texture Considerations *(continued)*

From the ALD/16 rule, the greatest difference is 0.14 mm. With a 7 mm ALD chip the maximum allowable value is calculated as:

$$\frac{7}{16} = 0.44$$

The texture depth difference of 0.14 is less than this value and, therefore, the texture variation is not excessive for this sized chip.

The above check has shown that the difference in textures is acceptable if the 7.0 mm chip is used.

Re-arrangement of the ALD/16 rule shows that the ALD of Grade 4 chip would have to be less than 2.6 mm before it would become unsuitable for the range of textures concerned, i.e.

$$0.14 \times 16 = \text{Allowable ALD} = 2.24 \text{ mm}$$

This could never occur as the minimum ALD allowed for a Grade 4 chip is 5.5 mm so the $Td_{(average)}$ value of 1.18 mm is used in the design.

Traffic factor: The traffic information shows that 1200 vpd/2 lanes = 600 v/l/d use each lane, which includes 10% HCVs. As such a % HCV is not excessive, the basic equation for V_b without adjustment for high % HCV can be used.

Application rate, R:

$$R = Vb + As + Ss + Gs + Cs + Us \qquad \text{Equation 9-13}$$

where:	R	=	Final residual binder application rate in ℓ/m² at 15°C		
	V_b	=	(ALD + 0.7 Td) (0.291 – 0.025 × $\log_{10}$ (2.0 × v/l/d × 100))		
	Td	=	Texture depth (mm) from the sand circle test	=	1.18
	v/l/d	=	Vehicles per lane per day	=	600
	As	=	Allowance for an absorptive surface	=	0
	Ss	=	Allowance for a soft substrate	=	0
	Gs	=	Allowance for a steep grade	=	0
	Cs	=	Allowance for chip shape	=	0
	Us	=	Allowance for urban and/or low traffic volumes	=	0.05

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Calculation V_b = $(7.0 + 0.7 \times 1.18)\,(0.291 - 0.025 \times \log_{10}(2.0 \times 600 \times 100))$

= **1.28 ℓ/m²**

As the substrate is an existing unflushed chipseal, no allowance for absorption (As) or embedment affected by soft substrate (Ss) is required.

The site is flat and therefore no allowance is required for a steep grade (Gs).

Chip sourced in the area has a typical shape factor of 2:1 (AGD:ALD) and no allowance is required for shape (Cs).

With the intersections and relatively low traffic, the concern is that the rate of chip take may be too slow and the decision is that an urban factor (Us) of 0.05 ℓ/m² needs to be added.

When compared to traditional application rates recorded in the RAMM system the use of a higher application rate with traffic volumes less than 600 v/l/d has been used.

No other allowance is considered appropriate.

Therefore the final application rate is:

R = V_b + Us

= 1.28 + 0.05

= **1.33 ℓ/m²** residual binder at 15°C

This may need to be adjusted based on the ALD of the sealing chip ultimately used, once the decision on the chip size is made.

9.13 References

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CHAPTER TEN

Chipsealing Plant

Chapter 10 Chipsealing Plant

Previous page: Placing chips using a self-propelled chip spreader. Note the receiving hopper at the rear being fed with chip from the truck. After chip is spread, the fresh seal is compacted by the roller on the right.

Photo courtesy of Lindsay Roundhill, Opus

Chapter 10 Chipsealing Plant

10.1 Introduction

Construction equipment plays a key role in the success or otherwise of a safe chipseal. The need for safety has never been higher because traffic loadings increase in intensity every year in numbers, speed, weight and power. This means the margins for error in chipsealing design and construction have narrowed greatly and, in order to construct a safe chipseal successfully, correct operation of the complex specialised sealing plant is vital.

Sealing is a highly mechanised mobile operation (Figure 10-1). A single well-orchestrated chipsealing crew can use in excess of 70,000 litres of bitumen in a day, and lay up to 50,000 m^2 of seal per day (between 2.5 and 8 km, depending on road width).

To maximise these daily outputs, not only must each machine meet the performance specifications required, but also it must be able to do its job without delaying the plant used for the rest of the sealing operation.

Successful sealing demands the delivery of the exact quantities of binder, precisely and evenly spread. A good distributor is necessary but is not enough on its own. It must be operated by skilled operators who fully understand the principles and requirements of spraying bitumen.

Figure 10-1 A sprayer in operation showing the spray fans. Note the different shape of the fan coming from the end nozzle. Photo courtesy of Lindsay Roundhill, Opus

10.2 Bitumen Distributors

Bitumen sprayers are traditionally known as bitumen distributors (even though they usually carry binders). They are built specifically for the purpose of spreading or distributing bituminous binders evenly across the road surface at the desired application rate. They comprise a truck on which is mounted:

- an insulated tank;
- heating equipment;
- pump and circulating system;
- hand-spray lance and/or fully circulating spraybar, fitted with multiple nozzles mounted on the rear of the unit;
- control system.

Small truck-mounted maintenance distributors with capacities usually under 2,000 litres are used for sealing smaller areas such as maintenance patches.

Distributors typically ranging in capacity from 2,000 to 16,000 litres capacity are used for large-scale sealing.

Given the right conditions, a typical 16,000 litre bitumen distributor is capable of spraying out its load in under 20 minutes and can spray up to 70,000 litres per day, provided all other sealing plant and operations can operate at a comparable rate and support the efficient operation of this machine.

Bitumen Distributor Certificate of Compliance

The specification for performance of bitumen distributors is BCA E/2 (1992 or latest version). This covers legal, safety and performance requirements, and includes a rigorous annual safety inspection and a performance test.

The Certificate of Compliance with BCA E/2 is mandatory for bitumen distributors in use on New Zealand state highways.

A Quality Assurance (QA) Manual should be developed for each distributor and always kept with it. The QA Manual contains various useful documents including a diagram showing how the outer spray fans should overlap the previous spray run. The QA Manual also includes a Spray Application Rate Chart (spray chart) supplied at the time of manufacture, which is checked annually as part of the BCA E/2 tests.

Allowing the contractor to begin expensive sealing operations without requiring evidence of this certificate is most unwise.

10.3 The Spraybar and its Operation

10.3.1 The Spraybar

10.3.1.1 Spray Nozzles

Figures 10-2 and 10-3 show different kinds of nozzles that are used in a spraybar. The swirl or conical nozzles (Figure 10-2) are mostly used on hand-spray lances in this country. They are also favoured for spraybars in Europe where they are run inside a shroud to contain the over-spray. These nozzles have an advantage when spraying some types of emulsions but have the disadvantage of leaving heavy black lines where the spray impinges on the ends of the shroud and then falls to the road. They deliver a hollow circular pattern. The size of this circular pattern is controlled by the height of

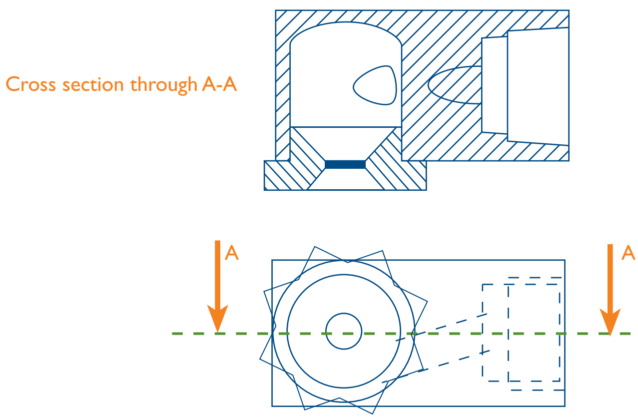

Figure 10-2 A conical nozzle shown in cross sectional view (top) along section A-A, and a plan view (bottom). The conical nozzle is rarely used in New Zealand except for hand spraying.

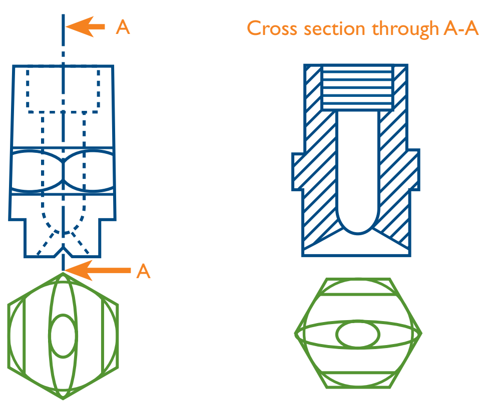

Figure 10-3 The slotted nozzle is the most commonly used type in New Zealand. It is shown in elevation (top left), and a plan view (bottom left), with a sectional elevation along section A-A of the nozzle (top right), and a plan view (bottom right).

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the nozzle above the road and the pressure applied. The shape of the conical nozzle is like that of a conical jet lawn sprinkler.

The slotted jet-type of nozz1e (Figure 10-3) is preferred for spraybars in this country. These slotted jets give a flat fan-shaped spray that is relatively unaffected by wind. But spraybars with these nozzles must be carefully set up with the output of every nozzle overlapping to provide a relatively even distribution.

To get the required distribution of binder across the road width, every nozzle must be identical and its flow and pattern matched to all the other nozzles in the spraybar. Only high quality nozzles can be used.

V-jet nozzles have a sharp edge at their orifice and are easily damaged by incorrect clearing methods which result in incorrect transverse distribution.

New nozzles must not be used alongside worn ones as a substantial difference in flow rate will most probably occur, meaning that the designed spray rate is not achieved consistently across the road width. Spare nozzles should be carried with each distributor and regularly swapped with the nozzles in use to equalise wear.

The fans of spray are strongly affected by the viscosity of the product being sprayed and viscosity is strongly affected by temperature. A reduction in fan width caused by reduced temperatures can be offset by increasing either the spraying pressure or the binder temperature, so it is important that binders are heated to their recommended spraying temperatures.

However using excessively high pressures will cause large amounts of atomised spray (or 'spraydrift') that are likely to drift and cause problems off-site. On the other hand, using low pressures will cause the nozzle output (spray fans) to be reduced in both width and force, which will be more susceptible to drift in high winds.

Therefore the spraybar must be operated within the parameters set out on the BCA E/2 test certificate.

10.3.1.2 Spraybar or Gangbar

The conventional spraybar (also called the gangbar) contains the spray valves in a line parallel to the truck or trailer axle, with the spray jets directed at the ground. Pipework supplies the spraybar with binder and it also has provision to circulate the binder while the spraybar is idle to maintain the operating temperature.

In order to achieve and retain its Certificate of Compliance, the spraybar must demonstrate compliance with the parameters required by the annual BCA E/2 test.

10.3.1.3 Spraybar Types

Each nozzle has a valve which is opened simultaneously by an actuating linkage. Individual nozzles may be selected and closed off to set the spray width before the spray run.

Many spraybars are equipped with some (or all) remotely controlled individual valves. This allows the operator to alter the spray width during the spray runs, and a tapering road can be sprayed in a single pass of the distributor.

Control systems with capacity for data logging must compensate for these changes, otherwise it will appear that a greater or lesser distance has been covered by a known quantity of binder, and calculations of actual binder application rate will be affected.

Leading technology uses telescopic spraybars incorporating variable application capability. This allows the width of the spray and spraybar to be altered without the spraybar overhanging the edge of the road, and also allows the application rate to be altered across the spraybar while the spraying operation is in progress.

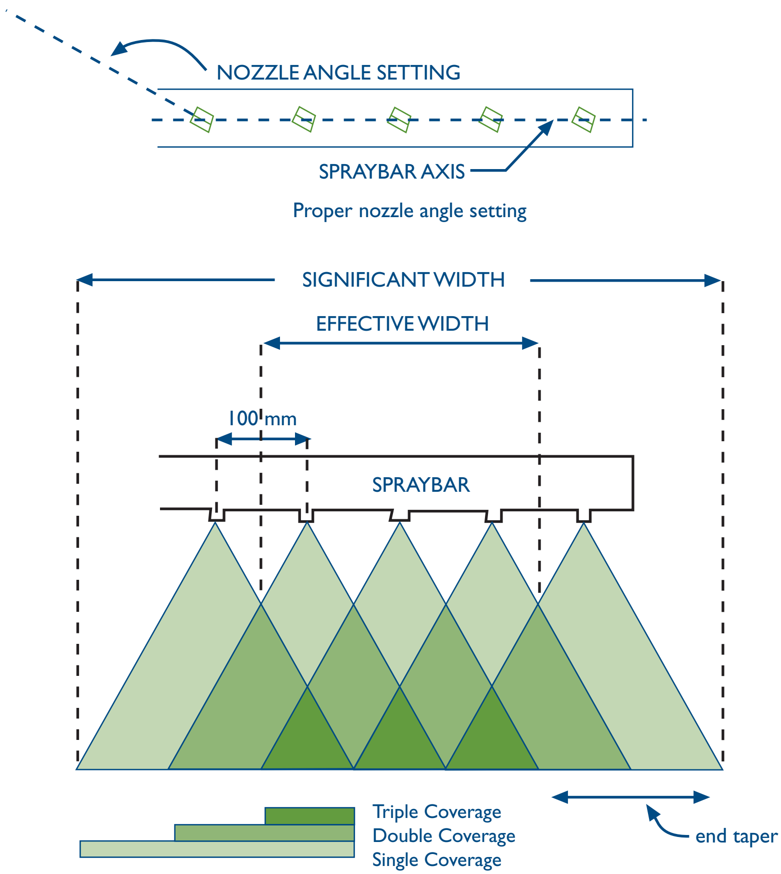

Figure 10-4 Spray fans overlap to give triple coverage of binder on the road.

10.3.2 Spraybar Operation

10.3.2.1 Spray Coverage

The spray fan widens as it sprays from the nozzle towards the ground. The width covered by each nozzle depends on the height it is above the road and the angle of the fan generated (Figure 10-4). For triple overlap spraying the spraybar is set so that the fan covers three times the nozzle spacing (i.e. 1½ times the nozzle width each side of the nozzle). Typically more than triple overlap is achieved.

The individual nozzle spray pattern tends to feather out towards each end with a narrow heavy streak on the outside edge. This triple overlap pattern allows a little latitude in setting the height of the spraybar.

Longitudinal joints between two parallel spray runs should overlap by the width of the spraybar end taper. This can be difficult to estimate in the field, and the QA Manual developed for the distributor (and always kept with it) should always contain a diagram showing how the outer fans should overlap the previous run.

The outer edge of the sealed surface receives only a double, not triple, overlap (Figure 10-4). This light application of binder can lead to stripping problems, which can be avoided by using an end nozzle (Figure 10-5). Some effort should be applied to ensure that the spraybar height does not change too much during a spray run. Provision should be made to correct spring deflection and truck body roll (to comply with the requirements in the BCA E/2 certification that limit this). (Figures 10-6 and 10-7 show the effects of mechanical problems.)

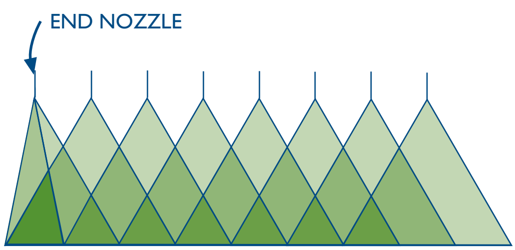

Figure 10-5 Effect of using an end nozzle to avoid a light application of binder along the road edge.

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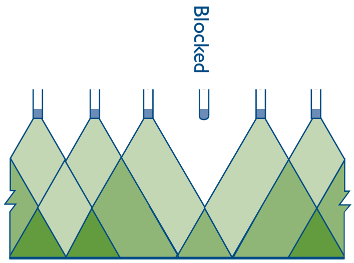

Figure 10-6 When just one nozzle is blocked, three overlaps are receiving reduced binder application, leading to streaking and potential chip loss.

Figure 10-7 Tilting of the spraybar caused by soft suspension. Photo courtesy of DCS Penny Ltd

A gauge should be carried so that the nozzle height can be checked regularly. Another gauge should be provided to ensure that the slot in a nozzle is set at an angle that prevents the fan from interfering with the adjacent fan. The jet angle is generally set in the range of 15° to 30° to the centre line of the bar (with all nozzles set to an identical angle).

Distributor operators must check the nozzle angles whenever a nozzle is changed, using the correct angle-setting gauge (Figure 10-8).

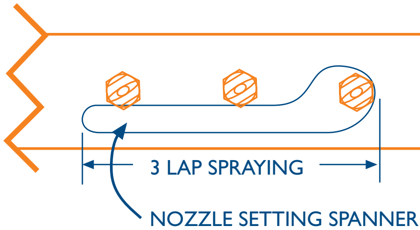

Figure 10-8 Nozzles are adjusted by appropriate gauges (kept near the spraybar) for correcting their spacings and angles to ensure fans do not intersect.

In circulating mode the binder is pumped from the tank along all parts of the spraybar and back to the tank to heat the valves, nozzle and pipework to spraying temperature. Circulation takes about 10 to 20 minutes, depending on the weather, and spraying must not start before the spraybar is up to operating temperature. Some modern sprayers monitor pipework temperature and do not allow spraying to commence until minimum temperature is achieved.

In spraying mode, the spraybar on/off control simultaneously sets the spraying pressure, closes the return to the tank, and opens the nozzle valves. The binder is fed to the bar at several points along it to minimise pressure variations (Figures 10-13 and 10-14).

10.3.2.2 Spraybar Control

Most modern distributors incorporate electronic systems to control the binder application rate. This may not be true on small maintenance sprayers and older machines.

From the driver's seat the operator should be able to set and adjust the following during spraying:

- application rate;
- spray width (number of nozzles);
- spraybar lateral position relative to the truck.

It can also be useful to be able to:

- lower and raise the spraybar bodily;
- lower and raise or extend the ends of the spraybar;
- raise or lower either side of the spraybar to accommodate changes in road undulations or truck body roll.

10.3.2.3 Hazards with Spraybars

Apart from the usual dangers involved with traffic control where trucks are operating among people, traffic and other machinery, bitumen sprayers present several unique hazards.

Figure 10-9 A bitumen distributor with an old-style lever-operated spraybar.
Photo courtesy of John Matthews, Technix Group Ltd

The spraybar is always potentially dangerous and should be under the control of an experienced operator who is fully conversant with the dangers of hot binder when it is under pressure.

Spraybar operators are not to stand on the platform at the rear of the truck, where they are exposed to considerable hazards. To avoid this unsafe practice (which was necessary for old-style lever-operated spraybars, see Figures 1-6 and 10-9) alternative control systems have been available for some time.

Care should be taken at first start-up in case a slug of cold binder has blocked the spraybar or transfer hose.

Procedures for preventing and dealing with these hazards are given in detail in Chapters 5 and 6 of the Roading NZ Code of Practice BCA 9904 (NZ PBCA 2000)[1].

Procedures for controlling traffic while spraying are given in Transit NZ's Code of Practice for Temporary Traffic Management (COPTTM, Transit NZ 2004). It provides details for the set-out of a site during these operations. More information is in Chapter 11 of this book.

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1 NZ PBCA (NZ Pavement & Bitumen Contractors' Association) is now Roading New Zealand, as from 26/06/2004. However COP BCA 9904 was published in 2000 by the then NZ PBCA, so keeps its original publication number.

Figure 10-10 Use paper to make an accurate start line when starting a spray run.

Photo courtesy of Les McKenzie, Opus

Figure 10-11 Hand spraying an extra width near a side road.

Photo courtesy of Fraser Ellis, Fulton Hogan Ltd

10.3.2.4 Spray Start and Finish

The transverse joints between successive spray runs can be very obvious unless the joint is made accurately. To make an accurate start, runs must always be started and stopped on paper laid transversely across the surface at both the start and finish (Figure 10-10). When using lighter application rates it will be necessary to back over the paper to ensure the sprayer has achieved the required forward speed before the spray start. Adequately preheating the spraybar by circulation is also vital in establishing a sharp clean start for the spray run.

10.3.2.5 Hand Spraying

Most bitumen distributors carry a hand-spray lance for sealing odd-shaped and inaccessible areas that are not practical to spray with the spraybar, e.g. in corners, around posts, and other restricted areas (Figure 10-11). As it requires a skilled operator, the amount of hand spraying needs to be kept to an absolute minimum and should be avoided in wheelpaths wherever possible. Using telescopic spraybars dramatically reduces the amount of hand spraying required.

Tests on carpet tiles have proved that even an experienced hand-spray lance operator does not achieve a satisfactory application rate over the entire area, so a good hand-spray job is poor compared to that obtained with a spraybar.

Figure 10-12 Calibration of bitumen distributor. Photo courtesy of Bryan Pidwerbesky, Fulton Hogan Ltd

10.3.3 Calibration of Bitumen Distributor

All bitumen distributors are supplied with a Spray Application Rate Chart (spray chart) at the time of manufacture which is specific to that distributor. Distributors produced by different manufacturers will have different characteristics, such as nozzle output in litres/minute on which the spray chart is established. These charts are always carried with the distributor. They are checked annually by laboratory personnel who conduct the BCA E/2 tests. These spray charts are mandatory for all distributors. Figure 10-12 shows the method of calibrating the spray rate onto the road surface.

10.4 Pumping and Circulation Systems

Three types of sprayer control systems are in common use on distributors in New Zealand. In BCA E/2, they are designated Types A, B and C.

Type A system (Figure 10-13): in these systems the spraybar pressure is held constant and the application rate is achieved by precisely controlling the speed of the vehicle. The binder pressure in the spraybar is controlled by a simple pressure control valve. During spraying, excess binder must continue to be bled off through the control valve.

To date, type A sprayers have been found to be difficult to operate accurately because of limitations in the accuracy of the bypass valve control, and limitations in precisely measuring the pressure of a viscous, temperature-dependent binder.

Types B and **C systems**: in these systems all the binder passes through the spraybar nozzles when the distributor is spraying (i.e. none is circulated back to the tank). A pressure relief valve must be fitted in case of a spraybar blockage during spraying and should be set at approximately twice the spraying pressure. Both B and C systems use a metering binder pump.

In a Type B system the metering binder pump speed is precisely controlled to give constant output per nozzle for the number of nozzles in use. The desired application rate is achieved through precise control of the pump and precisely controlling the speed of the vehicle.

Type C systems are hydraulically identical to type B systems. However, the metering binder pump is driven at a speed proportional to the road speed of the vehicle by a power take-off from the distributor's motor or transmission. The vehicle needs to be controlled to within ±5% of a predetermined road speed to achieve the desired binder application rate.

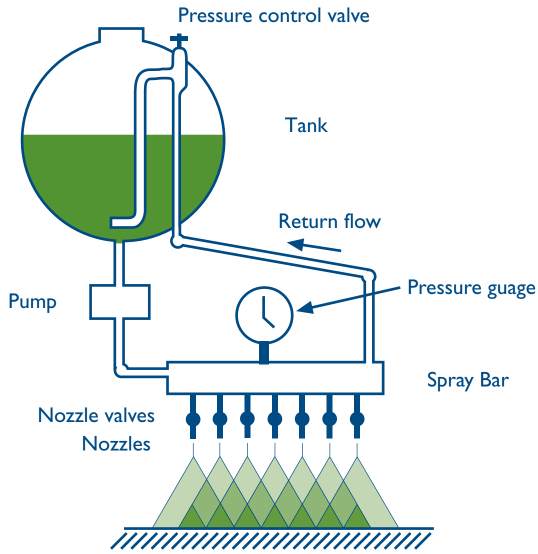


Figure 10-13 Simplified Type A system of binder pump.

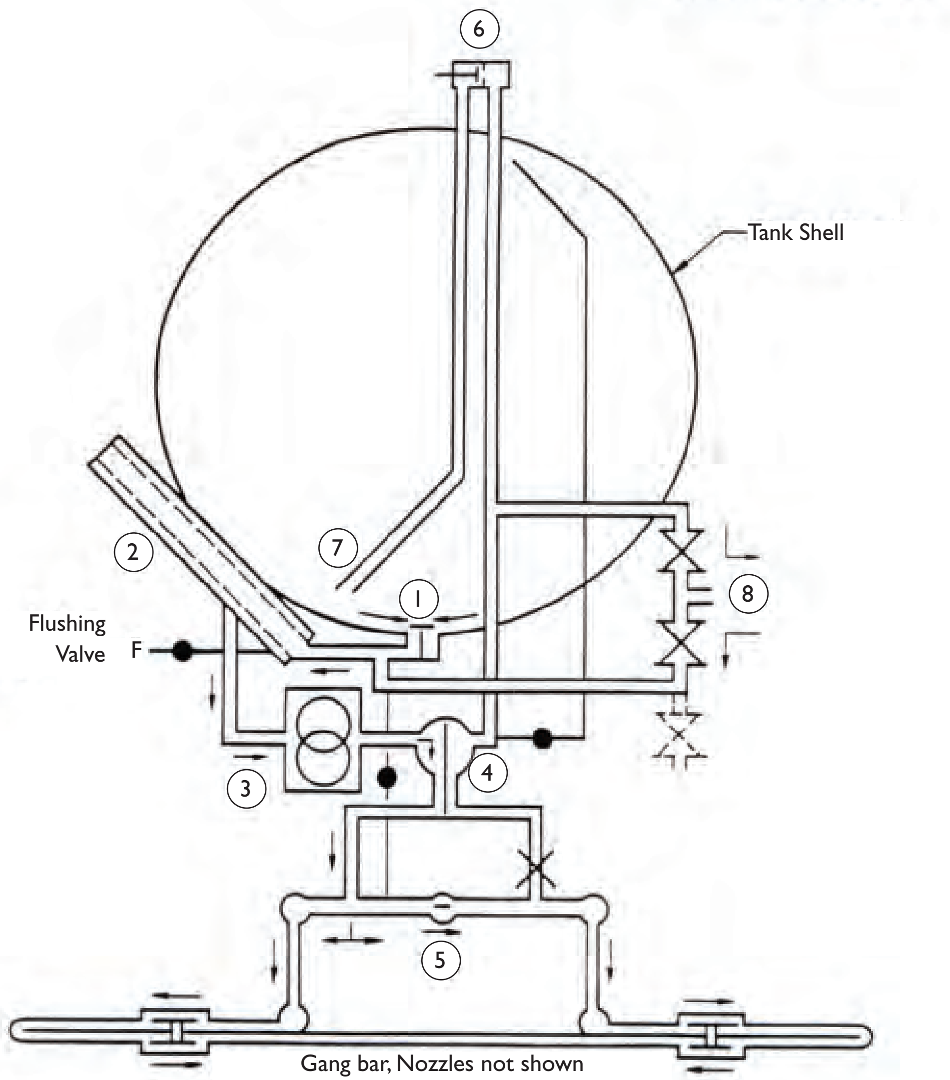
Pumps on type B and C systems should incorporate the following design aspects:

- Delivered binder application rate must have very little variation over the operating speed range, i.e. output is proportional to speed. The typical gear pumps that are in use work on the principle of a flow meter.
- Pumping action must be smooth as pulses could influence longitudinal spray pattern at high road speeds.
- Pumps should be designed for hot binder.
- Changing the number of operating spray nozzles while in use requires the pump output to be varied in proportion to the changes made.

Types A and B systems could be driven by an auxiliary diesel motor or an engine power take-off. Either way, the pump must be able to be controlled at a constant rate regardless of the truck speed.

Type C system pumps are always driven from a power take-off from the distributor's motor or transmission. The power take-off may therefore be mounted on the distributor vehicle's engine or transmission. Usually a hydrostatic transmission is used to transmit the power from the take-off to the pump because it allows the speed ratio between the take-off and pump shafts to be varied smoothly. Once it is set up for the number of nozzles to be used on the spray run, the ratio remains fixed.

Figure 10-14 illustrates the schematic layout of a typical spraybar and the associated pumping and circulating system when spraying.



1. Discharge Valve
2. Filter
3. Bitumen Pump
4. Control Valve (Bar Spray, Hand Spray, Circulate)
5. Spraybar Pressure Equilising Valve
6. Bypass Valve to Tank
7. Tank Return and Blend Pipe
8. Pump-in and Pump-out valves and attachment for hand spray

Figure 10-14 Passage of binder in spraybar and tank when spraying. Courtesy of DCS Penny Ltd

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Figure 10-15 shows a longitudinal section of a typical circulating system used in a binder tank. The functions of the system are to:

- Fill the tank.
- Circulate the binder in the tank.
- Circulate the binder through the bar and tank.
- Transfer binder from tank to tank.
- Spray binder through the hand-spray lance or spraybar.
- Suck binder back into the tank to clear the hand-spray lance or spraybar.
- Flush the system. Incorporated in the pipe work is a facility for flushing oil through the spraybar and pump after the system has been purged of binders, to ensure that no blockages are caused by congealing residual binder.

A number of transient and permanent faults can affect the pump's output per revolution and hence affect the accuracy of binder outputs calculated from the pump revolutions. Some of these are:

- Wear or damage to the pump.
- A faulty pressure relief valve: this could be caused by grit preventing the valve from seating completely, or by reduced pressure in the valve-closing mechanism.
- Blocked or partially blocked strainer: this is a fairly common fault.
- Air entrainment in the binder: when the pump is operating at full speed, i.e. when spraying to full width, air can be sucked in if the level of binder is too low over the main tank valve. This is more likely to occur if the last spray run is downhill.

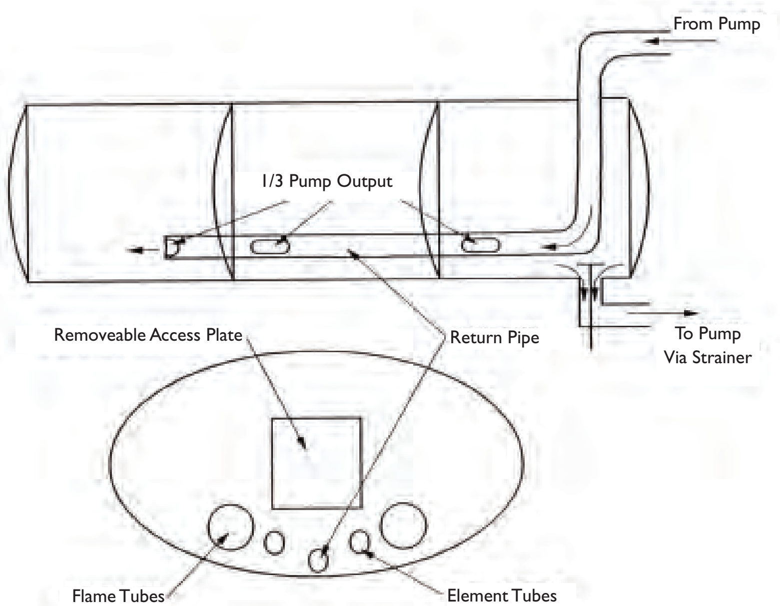

Figure 10-15 Typical circulating system used in a binder distributor tank. Top diagram is a longitudinal cross section. Bottom diagram is an end elevation. Courtesy of DCS Penny Ltd

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10.5 Instrumentation and Control

Many modern bitumen sprayers now monitor the performance of critical functions (i.e. of binder pressure, vehicle speed, temperature measurement, strainer maintenance) and give a warning (often audible) if these functions are outside the acceptable parameters.

10.5.1 The Dipstick

The dipstick is the main direct method of measuring the volume of material added to or sprayed from the tank. Modern systems may include direct electronic sensing of binder level.

Under the BCA E/2 procedure, dipsticks are calibrated to ±50 litres for tanks larger than 2000 litres and ±20 litres for smaller tanks. Since the reading error is not proportional to volume, readings over a full tank load are the most accurate. For this reason, as discussed below in Section 10.5.2, the dipstick is best used in conjunction with an accumulating pump tachometer.

For example, it is essential to take check dipstick measurements (at least 3 per distributor load are recommended) with a tachometer reading. Readings at approximately full, half full and before refilling are advised. If the two sets of measured quantities agree within the dipstick reading tolerance given in the bitumen distributor's QA Manual, the pump revolution reading may be taken as the more accurate. However if the disparity is greater than this, the system must be checked and the application rates for the affected spray runs reported.

10.5.2 Tachometer

Accumulating pump tachometers are counters that record the cumulative number of pump revolutions. They are fitted to many distributors.

The accuracy of the accumulating tachometers should be regularly checked against the dipstick.

Many distributors now have electronic pump governors, in which case the tachometer provides the means of checking and setting the pump governor for types A and B systems.

For type C systems, the tachometer provides an essential check of the setting of the hydrostatic pump drive. The rpm of the pump needs to be checked against the spray rate chart when the distributor is travelling at the speed indicated on the spray rate chart. This is to ensure that the actual pump rpm at a given speed matches the spray rate chart at that speed.

The number of revolutions recorded by an accumulating pump tachometer can be used to calculate the binder sprayed in the run. This method can be more accurate than the measured quantities by taking dipstick readings before and after the run, especially if the area that is sprayed is small. However, the tachometer readings should never be relied on as the sole measurement.

10.5.3 Binder Pressure Gauge

For a type A sprayer, the accuracy of the nozzle output depends on the accuracy with which the bar pressure is monitored and controlled. Output is proportional to the square root of pressure, and thus the maximum acceptable error in pressure gauge reading is twice the maximum allowable variation in total spray output.

For type A systems, BCA E/2 requires a 100-mm nominal diameter Industrial Gauge to NZS/BS 1780:1985 (SNZ 1985) standard, giving an accuracy of ±1%. For example, the bourdon tube-type gauge appears to be the most reliable and economical type capable of sufficient accuracy. For type B and C systems, a 50-mm nominal diameter gauge is recommended as a means of checking system performance.

10.5.4 Distributor Speed Control

BCA E/2 requires that the distributor's speed control system must be able to control the average speed over a 100m length to within ±3%.

The traditional method for speed control was to use an industrial tachometer driven from a fifth wheel. Because of the vulnerability of fifth wheels to damage, most modern distributors use either a high accuracy engine tachometer, or a tachometer with a sensor on the transmission or on a wheel. It is necessary to ensure that the accuracy is not affected because of changes to the rolling circumference of the vehicle tyres caused by tyre pressure variation, loading variation, build-up of dirt, bitumen and chip or wear.

A much more accurate approach is the use of an electronic vehicle speed governor. Accuracy of better than 0.5% over 100 m can be achieved. The driver is spared a difficult task and instead can concentrate on driving the vehicle and monitoring the spraying system.

10.5.5 Temperature Measurement

BCA E/2 requires distributors to be equipped with two thermometers, accurate to ±5°C over a temperature range of 20°C to 200°C for spraying cutback binders, or 0°C to 100°C for emulsion sprayers. The first thermometer must be mounted so that it gives an accurate reading of the binder passing to the pump. The second is mounted remote from the first and in a position to monitor the binder temperature when the tank heaters are operated.

Before spraying, the binder needs to be circulated until all material in the tank is properly mixed and at a uniform temperature. This is indicated by the two thermometers agreeing within their combined rated accuracy of ±10°C.

As the binder level falls during a spray operation, the second thermometer will eventually become exposed to the vapour space and this may result in a low reading. This cause should be obvious from dipstick readings.

10.5.6 Strainer Maintenance

The strainer provides essential protection for the whole spraying system, helping to prevent damage and blockages to every part of the system. The strainer should be checked for blockages regularly and cleaned as appropriate. At the same time it should be examined for wear or damage that may allow damaging particles to get through.

A strainer may go for months without being even partially blocked and then become hopelessly clogged from one load. The problem is that there is no way of knowing when debris, that might have been dislodged in any number of intermediate tanks and pipes on the binder's journey from refinery to the distributor pump, will build up in the strainer. Therefore the strainer needs to be checked at least daily to ensure ongoing good performance of the distributor.

The recommendation is to check strainers after every use of the pump, at the end of the day, and after every 15,000 litres sprayed, even if there is no obvious problem. If a heavy deposit is found on a strainer, clean it before every spray run until the source of contamination is known and no contamination is left in the system or upstream in the supply chain. Failure to clean strainers can lead to blocked nozzles or low application rates.

10.6 Controlling the Binder Application Rate

10.6.1 Total Binder Output Rate

Because the output per nozzle is fixed, the binder application rate is controlled by the distributor speed. The faster the distributor moves, the lower the rate. For all spray run widths and application rates:

$$R = \frac{O_n}{SV}$$

where: R = application rate (ℓ/m^2)

O_n = output per nozzle (ℓ/min)

S = spacing of nozzles (m) (generally 0.1 m)

V = speed of spraying vehicle (m/min)

Whatever the application rate, the total binder output rate is the total of the outputs of all nozzles operating.

$$P = O_n \times N$$

where: P = total binder output rate (ℓ/min)
N = number of nozzles operating

(This will have to be modified appropriately when end nozzles are in use if the end nozzle has a different size to the ordinary nozzles.)

Note that where a spraybar is fitted with electrically or pneumatically controlled nozzles, the switches must be inter-linked with the pumping system to ensure that the rate of binder delivery remains matched to the new spray width. Each distributor has a BCA E/2-approved spray chart applying to that particular distributor based on these principles.

10.6.2 Pump Output

Bituminous binders have relatively high viscosity even at spraying temperatures, and a positive-displacement type pump is required to deliver the binder to the spraybar. This is nearly always some type of gear pump. Provided it is operated at a relatively low back pressure and is not excessively worn, pump output from this positive-displacement pump is proportional to pump shaft rpm, i.e. each rotation of the pump always shifts exactly the same volume of binder (Figure 10-16).

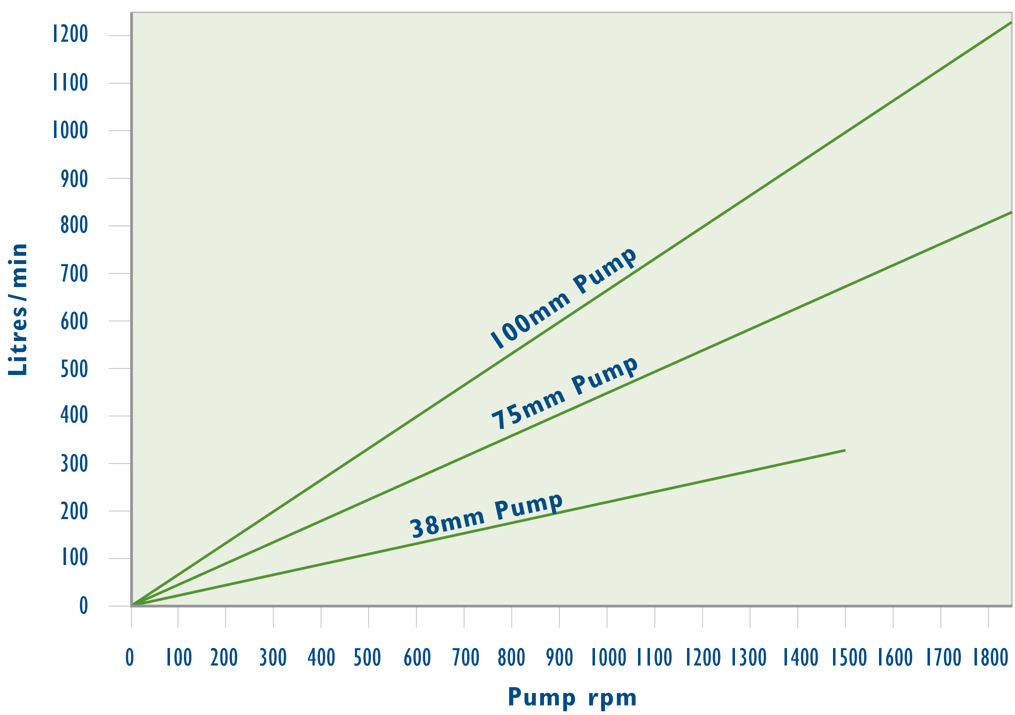

Figure 10-16 Relationship of pump output with pump rotation (rpm). Courtesy of DCS Penny Ltd

10.6.3 Spray Control Systems

The three types of spray control systems in use on distributors in New Zealand are described in Section 10.4.

Since the nozzle output depends on the pressure which is controlled by a simple valve in the type A system (Figure 10-13), theoretically the pressure control valve makes the bar output independent of pump speed. In practice, bar pressure depends also on viscous and turbulent drag in the pipes between bar and valve and in the valve itself. Hence, the binder viscosity and the rate of flow through the valve should be kept as constant as possible to ensure constant bar pressure:

$$\textbf{Pump Output} = O_n \times N + f_v$$

where:
- f_v = constant value of flow-through valve
- O_n = output per nozzle
- N = number of nozzles operating

Before spraying, the pump speed governor is set to a level that is determined by the spray width. This can be done directly by setting the pump rpm to a particular value as read on the pump tachometer, or indirectly by adjusting the rpm until the pressure gauge shows that the bar pressure is at a value that is appropriate for that width of spray. As spraying starts the bar pressure generally changes, so during spraying the pressure must be monitored to ensure that it is at the desired level to achieve the desired spray output.

Type B system pump speed is set to give exactly the correct output for the number of nozzles in use:

$$r = \text{pump rpm} = f(P)$$

where: P = pump output = $O_n \times N$

For an unworn positive displacement pump:

$$r = \frac{O_n \times N}{O_r}$$

where:
- O_r = pump output per revolution
- O_n = output per nozzle
- N = number of nozzles operating

The application rate is controlled by precise control of the distributor speed, as is the case for type A.

The above relationships are also true for the type C system which is hydraulically identical to the type B system.

Figure 10-17 A bitumen distributor in action. Photo courtesy of Fraser Ellis, Fulton Hogan Ltd

10.7 Heating Systems

10.7.1 Safety Requirements

All binder heating systems must comply with the latest BCA E/2 and COP BCA 9904 which contain requirements and tests for heating capacity and tank insulation performance.

Bitumen distributors (Figure 10-17) and bitumen tanker vehicles used to transport binder to the distributor in the field must comply with the heating safety requirement of the COP BCA 9904 (Chapter 6.7, NZ PBCA 2000). This is a requirement of the BCA E/2, audited at the annual and triennial inspections.

The heating of binder is potentially hazardous. It must always be carried out in accordance with BCA 9904.

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10.7.2 Insulation

The better insulated the distributor tank and the circulating pipework, the less re-heating will be required. This is desirable on safety and energy conservation grounds and will also reduce damage to the binder itself.

10.7.3 Types of Heating Equipment

10.7.3.1 Flame Tube Heaters

These heaters are used to rapidly heat binder to spraying temperature. They consist of a burner mounted at the end of the tank firing into a steel U- or Z-shaped tube (the flame tube) along the bottom inside the tank (Figure 10-15). The exhaust flue is outside the tank adjacent to the burner. These burners should only be run while the tanker is stationary, standing on level ground, and with the tank content above the level on the dipstick that ensures 200 mm of cover over the top surface of the heating tubes.

Control systems range from manual control to fully automatic with thermostatic control and flame-out protection devices.

If the tank temperature drops too low so that the product is no longer liquid, special action must be taken to avoid spot heating the product while trying to make it liquid again. Lighting the burner in short bursts may be necessary. Procedures must be developed for heating from solid to avoid excessive stress on the tank structure caused by expansion of the binder.

10.7.3.2 Electrical Heating

Thermostatically controlled electric elements fitted to spray tankers are normally used for maintaining temperature, or for overnight heating at a depot. They should only be used when the machine is standing on level ground and when the tank contents are above the safe heating level indicated on the dipstick. This ensures 200 mm of cover over the top surface of the heating tubes.

> The blending of binder is potentially hazardous. It must always be carried out in accordance with the Roading NZ Code of Practice, *Safe Handling of Bituminous Materials used in Roading* (NZ PBCA 2000, BCA 9904) and other manuals referred to in Chapter 2 of this book (e.g. NZ PBCA 2001).

10.8 Hazards of Plant Operations

10.8.1 Hazards of Blending Binder

Flammable additives should never be introduced through the tank hatch on to the surface of hot binder. They should always be introduced by carefully sucking them in through the distributor's pump-in valve or siphon.

The safest and most effective method of adding cutters, fluxes and other additives into a distributor is in-line blending. In this process, the additives are fed simultaneously and in the correct proportions to the suction line of the distributor pump. Drawing the additive into the suction line when transferring from the supply tanker into the distributor is one method. Some distributors are equipped to allow in-line blending directly by sucking in additive while the pump is circulating. Such activities should be completed at the mixing plant and not on-site.

For the system to be effective as a blending unit, the binder pump should be operating at maximum output. This ensures that the flow rate of binder provides adequate turbulence inside the tank.

Water contamination of the product to be blended presents an extremely dangerous situation. See Chapter 6.6 and Appendix 11 of BCA 9904, for precautions against the presence of water, operating and safety procedures to cope with water in hot bitumen.

10.8.2 Hazards of Transferring Binder

The loading of binder is potentially hazardous. It must always be carried out in accordance with Chapter 6 in BCA 9904, and BCA E/2.

When transferring binder, wherever possible, suck it through the transfer hose or, failing this, ensure that the pressure setting on the pumping unit is well below the pressure rating of the transfer hose. Start pumping slowly and allow the system to heat. The operator should be in a position, without endangering himself, to take remedial action at all times should an emergency arise.

Personal protective equipment (PPE) comprising overalls, boots, balaclava and face mask must be worn when transferring product. All pipework, equipment, and surfaces should be treated as being very hot.

Protective clothing and PPE must be worn by all those working around the machine. High visibility garments are essential for all sealing crew members.

An impact that ruptures the spraybar is very dangerous, so the bar should be kept in the parked position, i.e. telescoped together or folded up, depending on design, if it is not in use. Staff must be alert to the hazards of working amongst traffic, and understand how to control these hazards. COPTTM (Transit NZ 2004) explains how to work safely amongst traffic, and BCA 9904 gives details for safe transfer procedures.

10.9 Other Chipsealing Plant

10.9.1 Trucks for Chipsealing

Commercially available trucks (Figure 10-18) selected for use in chipsealing operations require appropriately powerful engine torque and low gear ratio specifications to suit the relatively low road speeds and the situations of working on hilly sloping roads while spraying. Some contractors fit left-hand drives to their vehicles which give the driver greater ease of control when operating along with the flow of the traffic.

Axle configurations vary depending on the gross laden weight. The most favoured combination consists of a tandem rear axle and single steering axle. Care is needed when turning this combination as the tandem axle tends to badly scuff a new seal.

10.9.2 Chip Spreaders

Spreaders used in New Zealand are devices either attached to a truck tailgate or self-propelled machines.

Traditionally, tailgate spreaders range from the simple fan-tail and box types to the more sophisticated hydraulically operated roller spreader. Only the latter type is capable of consistently providing the necessary control of evenness and application rate.

Self-propelled chip spreaders receive chip from trucks and apply it to the sprayed surface in a controlled way. These machines have the ability to spread chip in much wider passes than tailgate spreaders, and to match the width of the spraybars.

10.9.2.1 Truck-Mounted Roller Spreader

In the tailgate roller spreader illustrated in Figure 10-19, chips are gravity discharged from the truck tray through an adjustable gate and onto a rotating roller. The peripheral speed of the roller and degree of gate opening will determine the rate at which the chips will flow through to the roller and onto the ground.

Theoretically, if the gate opening is sufficient to produce an even single layer of chip on to the roller, and its peripheral speed matches the road speed of the truck, a single layer of chip would be spread on to the road surface.

In practice however, the peripheral speed of the roller is controlled at a lower road speed than that of the truck. This enables a wider gate opening to be used, resulting in a freer flow of chips onto the roller and better control of the application rate.

Some manufacturers may claim that roller spreaders will perform consistently, irrespective of truck speed, though many operators have found that this is only partially correct.

Figure 10-18 A truck supplying chip to a self-propelled chipspreader during a chipsealing operation.
Photo courtesy of Les McKenzie, Opus

Figure 10-19 Tailgate roller spreader. Photo courtesy of Philip Muir, Works Infrastructure Ltd

10

Width Variation
Modern spreaders are fitted with pneumatically operated cut-off plates. These can be activated from a control station on the side of the truck where the operator can be in full view of the driver. The older method of varying the width of spread by the operator physically inserting cut-off plates was very hazardous and is now not acceptable.

Control of Longitudinal Chip Spread
In some cases, the hydraulic drive for the roller-spreader drum is driven from a source that does not vary in proportion to the truck speed, e.g. off the truck hoist hydraulic system. In such cases the speed of the truck must be absolutely constant and correct for the entire spread run. If the roller is driven from a hydraulic system driven from engine or transmission, the chip spread rate is not so sensitive to a change in operating speed.

However it is still highly desirable to operate the truck at a reasonably constant speed. This is no easy task considering the driver is operating in reverse and has the added problems of poor vision, overhanging wires, trees, etc. A number of contractors have taken the practical step of fitting pre-set automatic truck speed controllers, which greatly improves the spreading operation.

An inconsistent flow rate of chips from the tray onto the roller is often caused by the spreader mismatching the type of tray fitted on the truck. Variations in the hoist angle can also cause inconsistent spreading.

Transverse Chip Distribution
The roller spreader is usually wider than the truck as this is essential for manoeuvrability. The hopper and the hopper tray connection must be designed so that the flow of chips from the tray out to the ends of the spreader is as good as that to the centre section immediately behind the tray. If this is not done, the spread rate at the edges of the spread will be too light.

On very tight corners, the end of the roller spreader on the inside of the bend has to cover less ground than the outside end. This means that it is moving more slowly than the truck, while the other end must move more quickly. The result is slightly too much chip on the inside of the bend and too little on the outside. It is much better to correct this by drag or hand brooming than to increase the chip spread rate.

10.9.2.2 Self-Propelled Chip Spreaders

These self-propelled motorised units are driven forward, allowing the operator to have a full view of the spreading operation (Figure 10-20). They have a receiving hopper at the rear for the chips from the supply trucks, and chips are transported to the spreading bin at the front. This bin is fitted with a feed gate and roller system which controls the spread of the chips relative to the speed of the machine. The gates are also used for varying the spread width.

Figure 10-20 Self-propelled chip spreader. Photo courtesy of Lindsay Roundhill, Opus

Some spreaders are designed to tow the feeder truck so the truck operator does not have to match speeds with the spreader during the spread run. A special hitch attachment allows for a change of trucks without having to stop during a chip-spreading run.

The disadvantages of a self-propelled chip spreader are cost, manoeuvrability is difficult in very tight areas, and transportation as they need to be trucked to the site.

The advantages of the self-propelled spreader are the quick turn-round of the chip trucks, considerably greater spreading width and speed, and better control, because only one machine has to be set-up and controlled.

10.9.3 Calibration of Chip Spreading Plant

Chapters 9 and 11 describe the importance of an accurate and even spread of sealing chip to achieve a top quality job. In New Zealand, a lack of control of chip application rates has been observed even though chip spreaders are available that are fully capable of being calibrated to produce a consistent application and uniform spread rate of chips. The wasteful and damaging variation and general over-application of chip is considered to be attributable to:

- Lack of operator training: many supervisors and foremen have different interpretations on what constitutes a correct application rate of chips;

- Spreaders are not being tested and calibrated; and
- Drag brooming is not commonly used.

Contractors' QA systems should have a regular programme of calibration, adjustment and operator training in accordance with the spreader manufacturer's instructions and operating manuals.

The spreaders have to be carefully adjusted to the correct settings for every change of chip ALD, chip stockpile, and design application rate.

Verification of chip application rates can be determined by carefully measuring the area covered by each truck load or by laying a section of cloth or building paper on the pavement, not less than 1m^2 in area, and passing the spreader over it (Figure 10-21). Aggregate collected can then be weighed and this will determine the weight per square metre of chips being spread using the equations given in Section 11.3.7.

Figure 10-21 Procedure for calibrating chip spreading on paper.
Photo courtesy of Bryan Pidwerbesky, Fulton Hogan Ltd

10.9.4 Rollers

The function of the roller is to ensure embedment of the chip into the binder and to provide a uniform mosaic of chip. Smooth steel-wheeled rollers are not often used on chipseal work because of the risks of breaking and crushing the chip, particularly when using softer aggregates and where uneven surfaces result in variable contact pressure.

10.9.4.1 Pneumatic-tyred Rollers

The most common roller is the self-propelled, multi-wheeled, pneumatic-tyred roller (Figure 10-22). It is capable of achieving the embedment and re-orientation of the chip into the binder by controlling its speed and number of passes. Typical characteristics are a minimum combined roller width of 2 m and an unballasted weight of 7 tonnes.

Ballasting is generally not necessary as chip orientation and embedment tends to be influenced more by the number of passes than by the applied force (Hudson et al. 1986). Unlike the smooth-tyred rollers used on asphalt and for general construction work, pneumatic-tyred rollers used on chipseal work may have a tyre-tread pattern which improves the operator's safety when travelling on public roads in wet weather.

Figure 10-22 Pneumatic-tyred roller. Photo courtesy of David Ashby, Opus

These rollers are operated at much higher speeds on sealing operations than would be normal for asphalt, pavement or subgrade compaction. The first pass is at 5-10 km/h to bed the chip in. Once the first full coverage of the area is complete, a higher speed of 15-29 km/h is more effective for re-orienting the chip and also increases the number of passes in a given time. Drive systems need to be capable of these speeds.

10.9.4.2 Rubber-coated Vibrating Drum Rollers

The rubber-coated vibrating drum roller is specifically designed for sealing operations. The rubber coating is provided to reduce the crushing associated with steel-wheeled rollers (Figure 10-23) but still provide the high contact pressure that assists with chip embedment. Overall width and speed is less than that for pneumatic-tyred rollers but this type of roller has been observed to be very effective in re-orienting chip (Sheppard & Petrie 1989, 1990).

If the pavement is rutted, the drum will tend to bridge the wheelpaths which will then not be well compacted. This can be allowed for, to some extent, if the roller has pneumatic rear wheels which are used to roll the wheelpaths. Note that the wheelpaths need some compaction but it is relatively less than for other areas as wheelpaths will be well compacted by traffic later.

Figure 10-23 A steel-wheeled roller. Photo courtesy of Julien van Dyk, The Isaac Construction Co. Ltd

10.9.4.3 Combination Rollers

The combination roller combines a rubber-coated steel vibrating drum on one axle with a single row of pneumatic tyres on the second (rear) axle (Figure 10-24). This is intended to provide the benefits of both the above forms of compaction in the embedment and re-orientation of chips.

Figure 10-24 The two axles of a combination roller showing the different rollers.

Photo courtesy of Fraser Ellis, Fulton Hogan Ltd

10.9.5 Brooms

Brooms used in chipsealing work have three separate functions:

- Removal of dust and loose foreign material before spraying operations (sweeping);
- Uniformly distributing inconsistently spread chips (drag brooming);
- Removal of loose chip from completed work (sweeping).

In dry conditions, sweeping may cause considerable dust nuisance. This is controlled with water applied by water trucks.

10.9.5.1 Rotary Brooms

The primary use of the rotary broom (Figure 10-25a) is for sweeping the prepared surface to remove loose and foreign materials before commencing sealing. Rotary brooms can also be used for removal of surplus chip from completed seals.

The most common form of rotary broom used in chipsealing work is a cylindrical broom that can range from 500 mm to 1000 mm in diameter and from 2 m to 3 m in length. The broom bristles may be plastic, wire, or a combination of these materials. For best performance, the bristles should be replaced before they wear down too far, to keep them of even length.

The broom may be either tractor-mounted or a towed unit, but front or rear tractor-mounted brooms are commonly used in sealing operations. Towed units lack manoeuvrability for many jobs. Brooms mounted on the front of trucks are also popular.

Broom Frame and Drive Mechanism
The angle of the broom shaft relative to the longitudinal direction of travel needs to be great enough to ensure the loose chips are swept sideways and not straight ahead. Otherwise, overloading of the broom will occur.

Front-mounted brooms ideally are designed so that the side to which the material is swept can be altered. This considerably increases the flexibility of operation, allowing the operator to adapt the sweeping operation to the wind direction or to traffic conditions.

Broom Speed
For efficient operation the rotating speed of the broom needs to be matched to the forward speed of the tractor. If the machine is travelling too fast relative to the broom rotation, the bristles will tend to scuff over the surface and leave loose chip behind. Excess speed will also promote excess wear and tear on the bristles.

Height Adjustment
The correct method of sweeping is to apply the minimum pressure of the bristles onto the pavement, so that the broom flicks just the dust and chips off the surface. Excessive pressure should be avoided. The broom must not be used as a grader or both the surface and the bristles will be damaged. Pressure settings may be manual or automatic.

Tractor-mounted sweepers normally do not have the facility for picking up the sweepings. Usually, the loose chips are swept to the side of the road and, if required, manually loaded on to a truck, or alternatively a suction-type sweeper is used.

10.9.5.2 Suction Sweeper

A particular form of rotary broom is the municipal-type suction sweeper. This type of unit uses a main rotary broom to direct swept material to a suction head that collects all swept material into a storage tank for disposal elsewhere. A second smaller rotary broom assists in removing loose materials from the kerb and channel.

Suction sweepers may also be utilised for removal of surplus chip from new seals, particularly in urban areas where total removal of surplus chip is required. This type of unit is not as efficient as the vacuum broom.

10.9.5.3 Vacuum Broom (suction cleaner)

The vacuum broom (Figure 10-25b) is designed specifically for sealing. It removes loose material from the surface by suction only. It consists of a suction unit positioned close to the road surface, a closed hopper to collect the material, a water sprayer and, where necessary, filter bags. The absence of contact with the surface minimises damage to new seals and is the preferred method of removal of loose chips from new seals.

(a) Rotary broom

(b) Vacuum broom

(c) Drag broom

Figure 10-25 Brooms used in chipsealing work may be (a) rotary, (b) vacuum, and (c) drag brooms.
Courtesy of Austroads Sprayed Sealing Guide (2004)

These may also be used in urban situations to remove dust nuisance and to clean kerbs and channels. Judgement needs to be exercised to avoid damage to surfaces and the vacuum broom must not be stopped over a sensitive surface, such as a very new seal, while the suction is still operating or the surface may be damaged.

These units are designed to handle the weight and high wear rate of significant volumes of chip, unlike standard municipal-type suction sweepers that are designed for handling lighter road litter and debris.

10.9.5.4 Drag Brooming

When the chip is applied at the correct rate, some areas will be chipped too lightly and others too heavily, even with good control. This can be rectified by drag brooming.

A drag broom is a soft bristle broom attached to a light timber or steel frame used after the aggregate spreading operation (Figure 10-25c). It is used to assist in correction of any spreading deficiencies. Dragging the broom across the surface, without any applied pressure, results in minor redistribution of loose chips and filling of open gaps between them. When the surfacing is warm, extra precautions are needed to avoid dislodging chips.

A low-cost but very effective alternative to the drag broom has been to tow a length of chain-link fencing (hurricane wire) called a wire drag (Sheppard & Petrie 1989, 1990).

It is important to closely control the speed of dragging as excessive speed will damage the seal, and may scatter chip resulting in broken windscreens and injuries.

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traffic

NZ TRANSPORT AGENCY
WAKA KOTAHI

ntroduction

Using traffic is the most effective way of achieving compaction of the total width of chipseal during the nitial set up period (typically up to 48 hours).

This is achieved by:

- progressively moving the traffic across the full width of the new seal
- reducing speeds to between 20km/h and 50km/h.

Compaction achieved through controlled traffic far exceeds the compaction achievable using rollers.

ackground

ccording to *Chipsealing in New Zealand,* section 11.4.1, affic can be used on site to assist with rolling. Rollers an be used for the initial passes to push the chip into lace and then be replaced by traffic.

he management of traffic flows across the width of e seal can continue to bed the chip resulting in a apid growth in seal strength.

hrough this technique early chip loss (as shown elow) can be minimised and it allows the use of a hipseal in higher stressed areas.

Moving the traffic across the full width f the new seal

he most effective means of moving traffic across the ll width of the new seal is to:

- narrow lane widths by the use of cones
- move these lanes progressively across the full width of the new seal (see diagram on next page)

The frequency at which the traffic is moved back and forward across the seal and the time period this is maintained depends on the traffic volume and the geometry of the site.

Traffic is typically controlled for up to 48 hours after sealing.

This method of compacting should also be used if it rains soon after sealing.

Reducing speeds

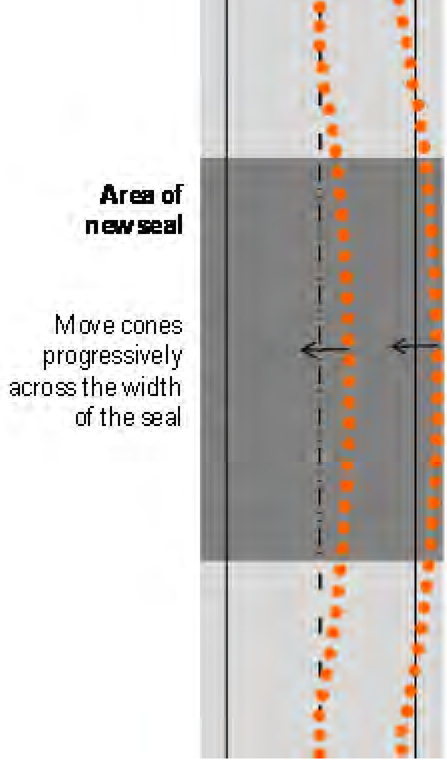
The most effective means of reducing speeds over the new seal is to:

- have workers on site
- increase driver awareness of the site by ensuring that there are vehicles with amber flashing lights at all times.

  Note: The lane management used to move traffic across the full width of the new seal also assists with lowering traffic speeds.

- more effective compaction of the seal
- longer expected seal life
- significant reduction in rework requirements
- significant reduction in customer complaints about flying chips, broken windscreens and bitumen splashes.

he benefits far outweigh the costs.

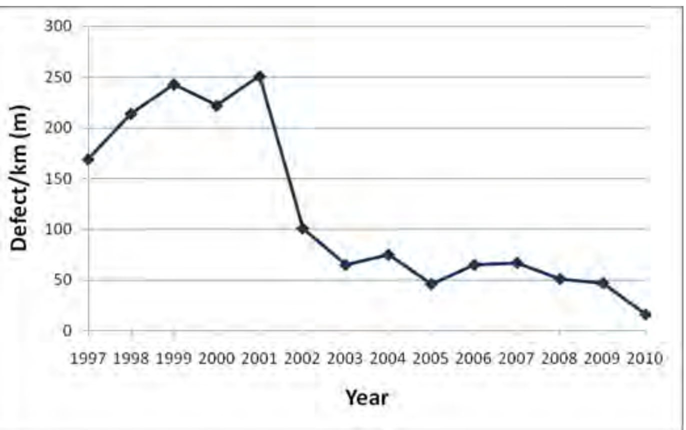


he Whanganui experience

ositive traffic management was introduced in West /hanganui in 2000. Subsequent years show significantly educed chip loss.

West Whanganui visual condition rating

Length of scabbing per km



sing traffic to compact the new seal for a period following hipsealing has been proven to reduce the chipseal defects of cabbing and stripping by approximately 65%.

his has had major financial benefits for contractors and the oad controlling authority.

or further information about the Whanganui experience refer the following research paper:

owler J. and McCoy R. (2009). Traffic management for esurfacing in the Wanganui region. *Proceedings NZ Transport gency & NZIHT 10th Annual Conference,* Rotorua, November 009.

during resealing

CHIPSEALING IN NEW ZEALAND

CHAPTER 11: PRACTICE NOTE 2

April 2011

NZ TRANSPORT AGENCY
WAKA KOTAHI

ntroduction

Research in 2008 has demonstrated that racked-in seals (if constructed properly) can be road marked and opened to unrestricted traffic flow within one working day.

n a racked-in seal, the binder is applied followed by a relatively light application of the big chip and then a smaller chip s applied that sits between the larger chips.

A racked-in seal (one application of binder, two of chip).

The smaller chip effectively locks the larger chip in place. As most of the traffic load is carried by the bigger chip the total effect is a stronger seal. A racked–in seal is not so dependent on traffic compaction to obtain strength.

enefits

e benefits of using racked-in seal are:

- reduction in traffic delays
- construction in an eight-hour working period including sweeping (if required) and road marking
- speed restrictions can be lifted at the completion of the road marking. This will reduce motorists' frustration at the traffic delays caused by chipsealing
- having no bitumen exposed to tyres reduces the chip pick up and flick and minimises the risk of bitumen tracking
- closely controlled chip application rates result in minimal:
  - loose chip on the completed chipseal surface
  - chip being flicked by vehicle tyres
  - sweeping before road marking.

ontrolling traffic

ffic must be controlled to ensure all parts of the lane are compacted and erlocked. Refer to practice note *Chipsealing in New Zealand, chapter 11: ctice note 1.*

pplying bitumen

rmal bitumen application processes apply.

en bitumen windows. The first application rate should be as low as you can get it without getting binder pickup. The chip
ed with a rubber tyred roller immediately after application.

Good spread

Section 9.11.5 suggests that the application rate for the first chip should be 1050/ALD m^2/m^3.

The trials that are the basis of this practice note used 1600/ALD m^2/m^3.

This is approximately double the coverage that would be used for a single coat chipseal as covered in *Chipsealing in New Zealand, section 11.3.7.*

Application of the second chip

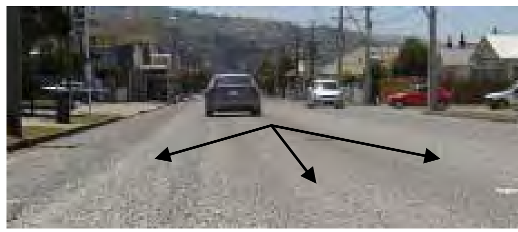
pplying small chip

ce the large chip has been rolled, the small chip is applied. Ensure there is an even spread of small chip over the surface. T
all chip should slot straight into the windows between the large chips. Ideally there should be no excess chip. The chip is
ed immediately by a rubber tyred roller.

Even spread

Too much small chip

Too much loose chip on seal surface and o
road shoulder

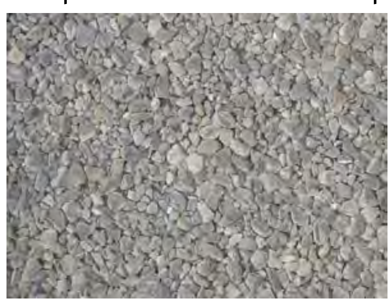


sing traffic to compress

ffic is directed over the new seal at 30km/h to compact and interlock the chip. Control the traffic to ensure all parts of th
l are compacted and interlocked. Once the seal has interlocked and settled, excess chip can be swept and road marking
npleted. Temporary speed limits can be removed or raised any time from the completion of road marking. All traffic
nagement equipment can be removed as soon as the temporary speed limit is lifted. This may be as early as the afternoo
nk.

Controlled traffic

Compacted and interlocked chip



ccess factors

e success of this methodology relies upon:

- planning
- the correct chip application rates (if excess chip is applied the technique will not succeed)
- well trained sealing crew

CHAPTER ELEVEN

Chipseal Construction Practices

Previous page: In the 1920s, hand spraying was the norm and application rates for bitumen and chip were less accurate than are expected and achieved today. Rules for no smoking and wearing protective clothing were unknown or not enforced, and so the job was more hazardous then.

Photo courtesy of John Matthews, Technix Group Ltd

Chapter 11 Chipseal Construction Practices

Chapter 11 Chipseal Construction Practices (continued)

Chapter 11 Chipseal Construction Practices

11.1 Preparation before Sealing Day

The preparation of the road in readiness for sealing is important to do properly and thoroughly as it is basic to the quality of the final chipseal. Before programming and organising the sealing work, many tasks must be carried out, and they may include:

- Specification and contract preparation;
- Site assessment;
- Treatment selection;
- Preliminary design;
- Pre-reseal repairs;
- Traffic management plan (not necessarily for each site but for a contract or series of sites), and associated safety equipment;
- Planning to reduce environmental impacts, to provide safe work sites and to prevent accidents by preparing for:
  - environmental emergencies such as spillages (provision of spillage kits),
  - run-off control (provision of bunds around stormwater drains),
  - fire (provision of fire extinguishers and other firefighting gear on site);
- Quality plan (not necessarily for each site but for a contract or series of sites);
- Binder selection;
- Chip stockpiling and testing;
- Notification to affected stakeholders and neighbours (short-term), and community liaison (long-term);
- Plan to reinstate road marking (possibly including recording of existing roadmarking);
- Confirmation of application rate with actual chip sizes determined from testing.

These tasks have been discussed in detail in previous chapters.

11.2 Programming and Organising for Sealing

With these tasks completed or at least in progress, planning the actual seal construction process can begin in detail. To organise for the sealing day the following aspects must be considered.

11.2.1 Specification or Contract Requirements

It is important to be aware of and understand the requirements of the contract. The contract specification will detail who is responsible for different parts of the sealing process and the end result required, though it is often left to the constructor to determine whether the proposed seal will actually meet specified performance criteria.

It is therefore crucial that the person responsible for sealing on the day clearly understands the 'defects liability' and 'performance' requirements that apply under the contract.

In many circumstances the most practical treatment giving best value will in fact not meet the specification and the constructor can be left with the task of meeting requirements which cannot be achieved. This situation can often show up after the seal has been constructed and after the end of the 'defects liability' period, e.g. after the 12-month defects liability period in a TNZ P/17 Performance-based Contract has passed, and the texture is found to not meet the minimum performance criteria.

While these issues should have been considered and resolved during treatment selection stages, it is important for seal constructors to be aware of these requirements. If necessary, they should discuss any areas of uncertainty they may have with the engineer, consultant or client, in order to reach agreement before starting the sealing operations.

11.2.2 Site Assessment

Safety and environmental issues concerning the site need to considered in the planning process. For example, traffic safety (e.g. narrow shoulders, banks, limited passing), fire hazards (e.g. flammable vegetation on the berms), noise impacts (e.g. houses very close to road), possible pollution of stormwater and air (e.g. lack of catchpits in drains, open streams, spray drift into gardens), spillages of bitumen, diesel, and other chemicals.

The plan should therefore ensure that the following will be on site: firefighting equipment, fire extinguishers in easily accessible places, adequate first aid kits, bitumen burns cards, spillage kits containing sand to cover the spill, portable textile dams to block off drains, a suitably enclosed catch tank to carry away any bitumen or oily residues and a solids waste bin.

While many of the following items should have been addressed in the site assessment, treatment selection and design stages, circumstances can change and checking these items before sealing is sound practice and helps to avoid costly mistakes.

11.2.2.1 Location and Size

It is important to make sure the site is located correctly and well marked. Also make sure the sealing crew can find the site and that they do seal the correct section of road.

The site size needs to be known accurately to make sure that the volumes of materials are correct and adequate. Make sure that the limits of the site have been established with regard to entranceways, intersections, extra widening, parking bays, etc. Discuss with the client or engineer to check the location of the limits and that the treatment selection and design have considered all the site and not just the carriageway.

11.2.2.2 Community Liaison

Close and early consultation with the contractor, Road Controlling Authorities (RCAs), road user groups, directly affected neighbours and the wider community is important to minimise and manage the impacts, especially disruption, that chipsealing has on the local community and the general public.

Sealing activities have the potential to create a range of positive and negative effects for the natural environment and neighbouring communities. However, costly remedial work and unwanted negative publicity can be avoided by considering environmental and community effects early when planning sealing works.

Noise effects associated with maintenance activities and operation of road works, as well as the possibly increased traffic noise following an improvement to a road, warrant consideration when scheduling, planning and designing sealing works. The noise guidelines of the local RCA, and the input from community groups, will give guidance to mitigating the noise caused by sealing construction. Sealing at night to avoid peak traffic on motorways is common practice which, if near residential areas, may need to be restricted to certain hours.

New seals are 'tender' and can be damaged easily while they are curing and loose chip is present. The timing of sealing on a particular site is therefore important as there are occasions when the construction process can be hindered, quality affected, unnecessary nuisance caused and safety compromised because of other circumstances.

Examples could be:

- *Special events*
  The engineer and the client should be able to help sealing crews to establish if any special events will coincide with the programmed sealing. These can be events which will damage the new seal during use (such as cycle races, motor races, and marathons). Other events in the vicinity of the new chipseal can also affect the traffic flow over the new seal such as show days, concerts, parades, etc.
- *Site location and surrounding land use*
  The location and surrounding land use must be considered in treatment selection and design but also must be taken into consideration when planning to seal. Examples of locations and surrounding uses which can effect the planning and timing of sealing are:
  - *Schools:* It can be unsafe and create unnecessary nuisance to seal near schools during class times and especially at school start and finish times.
  - *Shops and businesses:* The effect on business customers should be considered, businesses can be affected by the construction and, conversely, seal construction can be hindered by business movements.
  - *Stock:* Stock crossing or using the road will seriously disrupt construction and affect quality. Sealing in the vicinity of stock saleyards and near sale days not only affects the new seal through increased traffic movements but also through effluent contamination.
  - *Forest operations and Crop harvesting:* Short-term events, sometimes one-off or annual such as the harvest of crops (maize or tomatoes for example) and of small forest lots, can cause substantial damage to new seal coats. Not only are the seals subjected to traffic stresses and heavy equipment, but often the surface is contaminated with debris from the harvest site. In these cases it is wise to complete the work far enough in advance to allow the new seal to cure, or to wait until after the harvest, if this timing will not compromise the seal construction and performance.

11.2.3 Design Assessment

Check that the supplied chipseal design does take all the site into consideration and that nothing has changed since the original assessment.

11.2.4 Plant and Equipment

11.2.4.1 Construction Plant

Plan the number of rollers required, the number of chip trucks and spreading equipment, sprayer size, supply tankers and sweeping requirements (Figure 11-1).

Figure 11-1 A 1920s road sealing team ready for work, with their steam roller, the tar kettle stoked up with the distributor nearby, rotary broom, and chip spreading trucks, in Cook County, Gisborne.

Photo courtesy of John Matthews, Technix Group Ltd

11.2.4.2 Traffic Management

Ensure the correct type and number of traffic management materials are available, e.g. the correct signs and enough of them to do the job. Check with Transit's COPTTM (2004 and amendments) for information, and that everything is available to comply with the site traffic management plan.

11.2.5 Consumables

Consumables include items and materials to be used during construction which can include the obvious hand tools and cans of spray paint etc. However consideration should also be given to include: Raised Pavement Marker covers (if appropriate), tags to assist with line marking reinstatement, and masking paper used to protect road-side furniture and for spray run starts and stops.

11.2.6 Materials

11.2.6.1 Chip

The volume of chip ordered and stockpiled should be checked against the site area to ensure enough is available to complete the project. Volumes stockpiled must allow for some 'wastage'. The amount of waste will depend on factors such as stockpile location, overall volume and the surface the stockpile sits on. Test results should be available to confirm compliance with specifications and enable final design application rate calculations.

11.2.6.2 Precoated Chip

When handling hot precoated chips, they must be covered during transport and spreading to minimise heat loss and prevent contamination.

If precoated chips are to be stockpiled before use, great care must be taken to avoid contamination with dust or other contaminants. Dust will adhere all too readily, counteracting some of the advantages gained by precoating.

Safety procedures: These must be followed, as always, because precoating materials can contain a high proportion of distillate oil and/or volatile cutter, which increases flammability risk during blending and use. The advice for the use of bitumen cutbacks contained in RNZ's COP BCA 9904 (2000) should be followed as well as the additional precautions listed below.

- If heating is required to reach the desired viscosity, this should be carried out under carefully controlled conditions at a blending plant before the precoat is transferred to a job site.
- Flame-tube heaters should not be used.
- On-site blending should not be used.
- If precoating on site, use materials only below 60°C.
- A special safety plan must be developed and put in place covering blending, storage, transport, and use of precoating materials.

Environmental issues: Although much of the volatile cutter evaporates into the atmosphere during and soon after the precoating process, the actual quantities involved are very small.

11

If rain occurs before full coating and absorption has taken place, a significant risk is that the precoat will wash off the surface and contaminate the environment. Once coating and absorption is complete however, a well-designed precoat is remarkably water-resistant.

Traffic issues: Traffic can pick up precoated chip that has too thick an adhesive coating and spread it far and wide.

11.2.6.3 Binder

The volume of binder needs to be checked and matched to tanker requirements. Adhesion agent and cutback volumes should be assessed and planned for. Spray temperatures should be estimated.

11.2.7 Construction Checklist

With the above items actioned, the actual construction methodology should be finalised. In this process an experienced practitioner will consider:

- Safety measures and any safety issues specific to the site.
- Notification of affected parties.
- Site size.
- Traffic volumes and traffic management requirements.
- Site characteristics and physical features and hazards which will affect the construction process such as: steep gradients, narrow carriageways, parked vehicles, overhead services, over-hanging trees and obstructions.
- Seal design type.
- Chip spread rates and how they match spreading equipment capacity, e.g. the area that a truck load of chip will cover, and if two chip sizes are being used, the order and timing of delivery onto site that will be required.
- Spray sequence and spray run size.
- Binder volumes, tankers and safe heating levels need to be considered: e.g. at the design application rate the length and width that a spray run will cover and best suit traffic use of the carriageway, chip spread rate, tanker capacity, safe heating levels, transfer times and rolling requirements.
- Spray runs and volumes must be planned to avoid the situation where tankers are left with binder below allowable spray temperatures, and cannot be re-heated because the quantity of binder is below the safe heating level for the tank.
- Longitudinal laps should be planned to ensure they do not coincide with traffic wheelpaths.
- Rolling method: e.g. type of rollers and number that are necessary, along with the pattern of rolling to suit traffic conditions: e.g. in the case of a two coat seal, one of the techniques can involve the use of a light steel-wheeled roller.
- More rolling is required on low traffic volume roads because on high traffic volume roads traffic can be diverted, if managed correctly, to roll the new seal.

- Sweeping requirements both before- and after-sealing: e.g. check if materials need to be removed from site; and from kerb and channel (K&C).
- Plant and people/staff required.

11.3 Preparation for Chipseal Construction

11.3.1 Chipsealing Techniques

The performance of all seal types is directly affected by the techniques used during chipseal construction. Quite different seal performance characteristics can be achieved with the same seal type but different sealing technique. This is not to say there is a right or wrong way to construct a seal, but merely that different results can be achieved depending on the construction methods used.

For example two coat seals are very dependent on the chip size compatibility, the chip spread rate achieved, and the rolling technique used, as outlined here (Figure 11-2):

- A two coat with very high spread rates used for the bottom coat will result in large 'windows' which allow the small chip to fall in beside the large chip and be in contact with the bottom layer of binder. This will result in a two coat which looks a little like a racked-in seal. This can reduce the overall binder volumes required, and achieve high texture but may not be as stress-resistant as a two coat with more chip interlock.
- A two coat constructed with less space between the larger chips than described above, with the small chip locking into the large chip with little contact with the underlying surface, will look quite different to the above seal.
- If the bottom coat of chip is rolled before the second spray of bitumen is applied, this will produce a different looking seal to a two coat which is not rolled between coats.
- In some situations the bottom coat is rolled with one pass of a light steel-wheeled roller. This has the effect of pushing the large stone flat onto its AGD, and the resultant seal can be more smooth, very tough, and quieter, but with less overall texture.

Construction techniques therefore must be considered and discussed with the engineer or client to make sure the end result is what is expected and needed, and is the best engineering solution for each site.

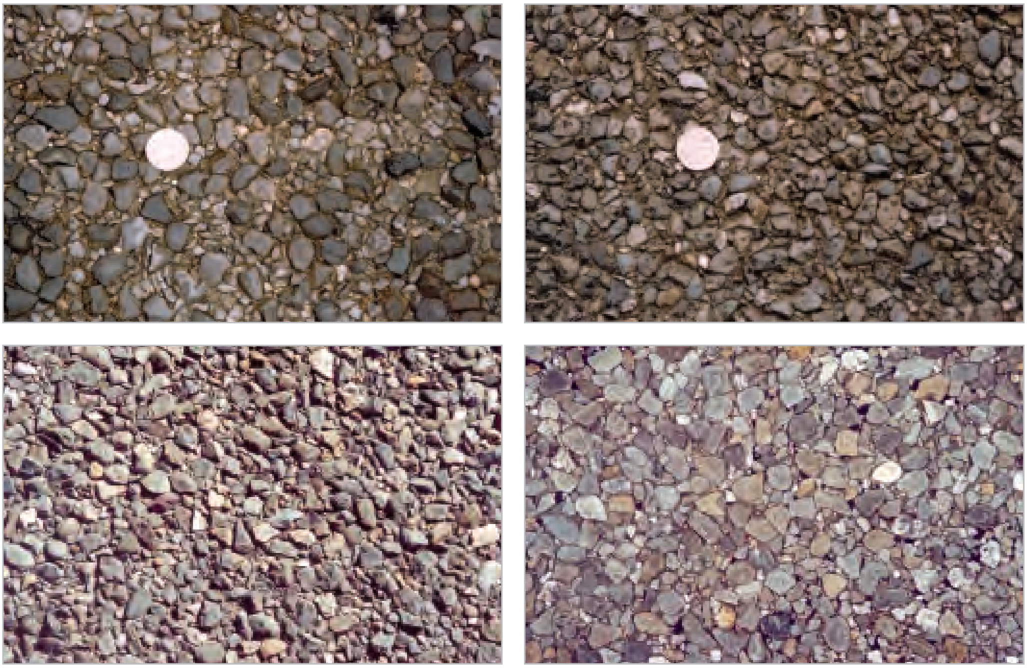


Figure 11-2 As with two coat seals, a wide variety of finishes can be achieved with racked-in seals. (The coin is about 3cm diameter.) Photos courtesy of Les McKenzie, Opus

11.3.2 Cutter

Binders are cut back to increase their wetting ability and adhesion to chip (Section 4.2.1). The choice of cutter type and amount of cutter by volume depends on the local climatic conditions and, in particular, on the temperatures of sealing day (Table 11-1) and the following few days and nights (as explained in Section 4.7.4.1, Figure 4-17).

Not enough cutter can result in a binder which is too stiff and, in cold conditions, this can cause stripping. But too much cutter can result in a binder which is too soft and will not hold chip in place, or will become soft in hot weather and cause stripping, bleeding or flushing.

The volume of cutter to be blended with the bitumen is part of chipseal design (Chapter 9) and should be decided before arriving on site because cutter needs to be blended at a central blending plant. Adding cutter to a binder is an extremely dangerous operation, and is not recommended to be carried out on-site (Chapter 2). Whether on-site or in a blending plant, cutter must never be added through the bitumen-tank top onto a hot load of bitumen. RNZ's COP BCA 9904 lists the procedures for bleeding and cutting.

Table 11-1 A guide to the recommended diluent content in relation to bitumen grade and average shade air temperature.

Average Shade Air Temperature (°C) for sealing period	Recommended Diluent Content			
	Bitumen: 180/200		130/150	80/100
	First Coat	Reseals	Reseals	Reseals
	Diluent (pph)		Diluent (pph)	Diluent (pph)
12.5	11	8	10	12
15.0	10	6	8	10
17.5	9	4	6	8
20.0	7	2	4	6
22.5	5	0	2	4
25.0	3	0	0	2
27.5	2	0	0	0
30.0	2	0	0	0
32.5 & over	2	0	0	0

Note: Up to 4 parts extra may be added for late season sealing or for other anticipated adhesion difficulties.

11.3.3 Flux

As explained in Sections 4.2.1 and 8.2.1, fluxing is usually achieved by the addition of AGO to permanently soften a binder. The amount of flux will be determined in the binder determination and design. The addition of the flux and calculating the volume to be added is part of the preparation and construction process.

11.3.4 Adhesion Agent

Adhesion agents are added to assist with chip–binder adhesion and to prevent stripping in wet weather. This does not mean that adding an adhesion agent allows sealing to be carried out in wet weather but it does help prevent failure if wet conditions are experienced shortly after sealing.

In some situations, even in dry conditions, a particular aggregate type may require the addition of an adhesion agent to promote good adhesion.

11.3.5 Calculating Binder Constituents

To calculate the constituents (bitumen, cutter, flux, adhesion agent) of a binder we consider them in terms of parts per hundred (pph). A worked example showing how to calculate volumes is on pages 429-431.

Note: calculating by ‘parts per hundred’ is not the same as calculating by ‘percentages’.

Worked Example

To Calculate the 'Parts' of a Bitumen Binder

Volume of kerosene in the binder	=	'one part' multiplied by the number of parts of kerosene
Volume of adhesion agent in the binder	=	'one part' multiplied by the number of parts of adhesion agent
Volume of AGO in the binder	=	'one part' multiplied by the number of parts of AGO
Volume of bitumen in the binder	=	'one part' multiplied by 100 (number of parts of bitumen)
Volume of 'one part'	=	Total binder divided by total number of parts

Example 1: To convert pph to ℓ

Binder at 15°C	6450 ℓ	=	100 pph
Kerosene		=	5 pph
AGO		=	2 pph
Adhesion agent		=	0.7 pph
	total parts	=	**107.7 pph**

Volume of 'one part' $= \dfrac{\textit{Total binder}}{\textit{Total number of parts}}$

'one part' $= \dfrac{6450\ \ell}{107.7}$

$=$ **59.89 ℓ**

Volume of kerosene in binder = *'one part' multiplied by number of parts kerosene*

Kerosene = $5 \times 59.89\ \ell$ = $299\ \ell$

Volume of AGO in binder = *'one part' multiplied by number of parts AGO*

AGO = $2 \times 59.89\ \ell$ = $120\ \ell$

Volume of adhesion agent in binder = *'one part' multiplied by number of parts adhesion agent*

Adhesion agent = $0.7 \times 59.89\ \ell$ = $42\ \ell$

Volume of bitumen in binder	=	*'one part' multiplied by 100 (number of parts bitumen)*		
Bitumen	=	100 × 59.89 ℓ	=	5,989 ℓ
Total volume	=	**6,450 ℓ**		

Example 2: To convert ℓ to pph

Binder at 15°C	=	7600 ℓ
Kerosene	=	220 ℓ
Adhesion agent	=	4 bags (40 kg)

To calculate parts of adhesion agent and kerosene in the binder

Volume of bitumen / 100	=	Volume of 'one part'		
Total binder	=	7600 ℓ		
– less kerosene	=	220 ℓ		
Binder less kerosene	=	7380 ℓ		
– less adhesion agent	=	40 ℓ		
Volume of bitumen	=	7,340 ℓ		
Volume of bitumen in binder	=	*'one part' multiplied by 100 (number of parts bitumen)*		
Volume of 'one part'	=	7340 ℓ/ 100		
therefore Volume of 'one part'	=	**73.4 ℓ**		
Volume of kerosene	=	**220 ℓ/ 73.4**	=	**3.0 pph**
Volume of adhesion agent	=	**40 ℓ/ 73.4**	=	**0.5 pp**

The formulae are expressed in words rather than symbols, ready for use while on the job

To calculate the changes required to make one binder into another binder (e.g. 'left over')

Step 1	Calculate the components of the final binder
Step 2	Calculate the components of the existing binder
Step 3	Subtract 'step 2' from 'step 1' to give the components to make up the new binder

Example 3: To convert one binder to another

We have 5,000 ℓ of 180/200, with 2pph AGO and 3pph kerosene, i.e. 105 total parts

We want 12,000 ℓ of 180/200, with 2pph AGO and 5pph kerosene, i.e. 107 total parts

Step 1 Calculate the components of the final binder

Final Binder

Volume of one part	= 12000 ℓ/107		
	= 112.15 ℓ		
Kerosene	= 112.15 ℓ × 5	=	560.8 ℓ
AGO	= 112.15 ℓ × 2	=	224.3 ℓ
Bitumen	= 112.15 ℓ × 100	=	11,215.0 ℓ
	Total	=	**12,000.0 ℓ**

Step 2 Calculate the components of the existing binder

Existing binder

Volume of one part	= 5000 ℓ/105		
	= 47.62 ℓ		
Kerosene	= 47.62 ℓ × 3	=	142.9 ℓ
AGO	= 47.62 ℓ × 2	=	95.2 ℓ
Bitumen	= 47.62 ℓ × 100	=	4,762.0 ℓ
	Total	=	**5,000.0 ℓ**

Step 3 To convert the existing binder to the final binder, you need to add:

Kerosene	= 560.8 – 142.9 ℓ	=	417.9 ℓ
AGO	= 224.3 – 95.2 ℓ	=	129.1 ℓ
Bitumen	= 11215 – 4762 ℓ	=	6,453.0 ℓ
	Total	=	**7,000.0 ℓ**

11.3.6 Binder Spray Temperature

To ensure even distribution, binders must be sprayed within a specific temperature range. Once the final make up of the binder has been decided, the spray temperature is then calculated. The seal design process will calculate a residual spray rate (litres/m^2) which is 'cold' and without cutter, flux or adhesion agent. It is the task of the sealing constructor or sealing crew to calculate the final binder constituents and the final hot spray rate including or excluding cutter, flux and adhesion agent (in litres/m^2).

Spraying cold binder (i.e. binder not heated to within the recommended spray temperature range) can result in poor distribution, streaking and chip loss.

The process to calculate the final spray rate from the residual spray rate is as follows:

1. Spray temperatures are established (from Table 11-2 which indicates the recommended spray temperatures for binders based on the three most commonly used penetration grades of bitumen: 180/200, 130/150 and 80/100);
2. Then a conversion heating factor from cold to hot binder is used (from Table 11-3).

11.3.7 Sealing Chip Spread Rates

In an effort to continually improve the performance and cost-effectiveness of our chipsealing operations chip coverage rates are reviewed as follows.

Earlier designs were based on this basic formula:

$$\text{Spread Rate} = \frac{630}{\text{ALD}} \ \text{m}^2/\text{m}^3 \qquad \text{Equation 11-1}$$

For average chip sizes this provided target rates[1] of 58, 72, 93 and 126 m^2/m^3 (assuming an ALD of 5 mm for Grade 5 chip) for Grades 2, 3, 4 and 5 chips respectively (Figure 11-3).

The revised target spread rates are based on a change in the formula to:

$$\text{Rate} = \frac{750}{\text{ALD}} \ \text{m}^2/\text{m}^3 \qquad \text{Equation 11-2}$$

This represents a considerable increase in spread rates,[1] i.e. 92, 114, 147 and 200 m^2/m^3 for Grades 2, 3, 4 and 5 (Figure 11-4). Because of the size of the increase, the suggestion is that sealing crews move cautiously towards these new target rates, while considering the following points:

[1] Assumes average ALD from TNZ M/6:2004 tables.

Table 11-2 Recommended spraying temperatures for hot bitumen binders, based on the 3 most commonly used penetration grade bitumens.

(i) For Binders Based on 180/200 grade Bitumen

Total Diluent	Temp. °C	Total Diluent	Temp. °C
0	160-180	8	141-161
1	157-177	9	139-159
2	155-175	10	136-156
3	153-173	11	134-154
4	150-170	12	132-152
5	148-168	13	129-149
6	146-166	14	127-147
7	143-163	15	125-145

(ii) For Binders Based on 130/150 grade Bitumen

Total Diluent	Temp. °C	Total Diluent	Temp. °C
0	167-187	8	147-167
1	164-184	9	145-165
2	162-182	10	142-162
3	160-180	11	140-160
4	157-177	12	138-158
5	155-175	13	135-155
6	153-173	14	132-152
7	150-170	15	130-150

(iii) For Binders Based on 80/100 grade Bitumen

Total Diluent	Temp. °C	Total Diluent	Temp. °C
0	175-195	8	154-174
1	172-192	9	152-172
2	170-190	10	149-169
3	167-187	11	147-167
4	165-185	12	144-164
5	162-182	13	141-161
6	160-180	14	138-158
7	157-177	15	136-158

Table 11-3 Heating factor (H_{fh}) for hot bitumen binders.

Temp °C	Multiplier	Temp °C	Multiplier	Temp °C	Multiplier
15	1.0000	76	1.0393	138	1.0813
16	1.0006	78	1.0407	140	1.0827
18	1.0019	80	1.0420	142	1.0841
20	1.0031	82	1.0433	144	1.0854
22	1.0044	84	1.0446	146	1.0868
24	1.0057	86	1.0459	148	1.0883
26	1.0066	88	1.0473	150	1.0897
28	1.0083	90	1.0487	152	1.0911
30	1.0095	92	1.0500	154	1.0924
32	1.0107	94	1.0513	156	1.0939
34	1.0120	96	1.0526	158	1.0953
36	1.0133	98	1.0540	160	1.0967
38	1.0146	100	1.0553	162	1.0982
40	1.0158	102	1.0566	164	1.0995
42	1.0171	104	1.0580	166	1.1010
44	1.0184	106	1.0593	168	1.1023
46	1.0197	108	1.0607	170	1.1038
48	1.0210	110	1.0620	172	1.1052
50	1.0223	112	1.0634	174	1.1066
52	1.0235	114	1.0648	176	1.1080
54	1.0249	116	1.0662	178	1.1094
56	1.0262	118	1.0675	180	1.1109
58	1.0275	120	1.0688	182	1.1123
60	1.0288	122	1.0702	184	1.1137
62	1.0301	124	1.0716	186	1.1152
64	1.0315	126	1.0730	188	1.1166
66	1.0327	128	1.0743	190	1.1181
68	1.0341	130	1.0757	192	1.1196
70	1.0452	132	1.0771	194	1.1210
72	1.0367	134	1.0785	196	1.1225
74	1.0380	136	1.0800	198	1.1238
				200	1.1254

Source: ASTM D4311-83, Table 2

1. **No changes** in current spread rates should be attempted until they have been confirmed, i.e. find out what the present spread rate is before making any changes.
2. Increase the rates slowly. If the previous rate for a grade 4 chip was 90 m^2/m^3, the next target should be 100 to 105 m^2/m^3.
3. When assessing spread rates, the volume (m^3) of chip on the truck must be known to a reasonable degree of accuracy, e.g. if the truck's expected load is 10 m^3, then the actual volume of chip must be calculated to within 0.5 m^3 or so.

Note: Weight to volume conversions (i.e. weight per 1 m^3 of chip) for each grade of chip to use will be available from the supplier. Calculating the volume of the truck load from the weighbridge docket then becomes a simple calculation, i.e.:

$$\text{Volume of load} = \frac{\text{Weighbridge docket}}{\text{Weight of } 1\text{m}^3 \text{ of Grade 4 chip}}$$

Weight of 1 m^3 of grade 4 chip = 1.52 tonnes

Weighbridge docket = 11.24 tonnes

$$\text{Volume of Load} \quad \frac{11.24}{1.52} = 7.40 \text{ m}^3$$

If the target spread rate is 110m^2/m^3 then:

Area the load will cover = Volume of load × Spread rate

= 7.4 × 110

= **814 m^2**

When working from stockpiles, assessing the volume of the load will obviously be more difficult but may be achieved with reasonable accuracy if the volume of the loader bucket is known. Another method would be to check the application rate of the first truck by measuring the volume of the tray and striking the load off flat with the top of the tray. Calculate the spread rate using the formula shown above, re-arranged as shown:

$$\textbf{spread rate} = \frac{\textbf{area the load covers (m}^2\textbf{)}}{\textbf{volume of load (m}^3\textbf{)}}$$

11

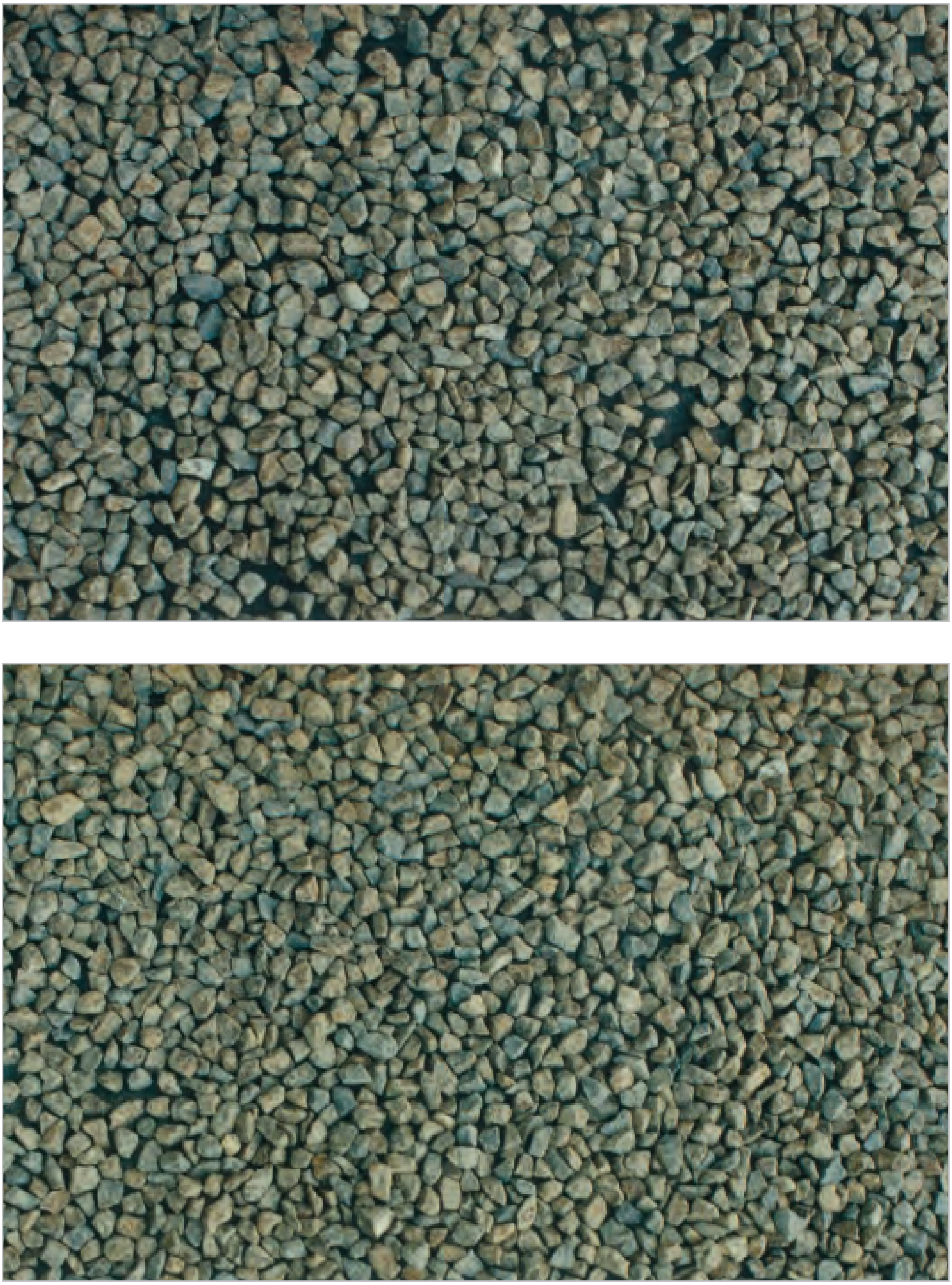


Figure 11-3 Previously advice was to aim for a chip spread-target rate as shown at the top of this page. This is now considered as over-chipping. The image at the bottom of the page shows a very over-chipped seal. Photos courtesy of Shirley Potter, Opus

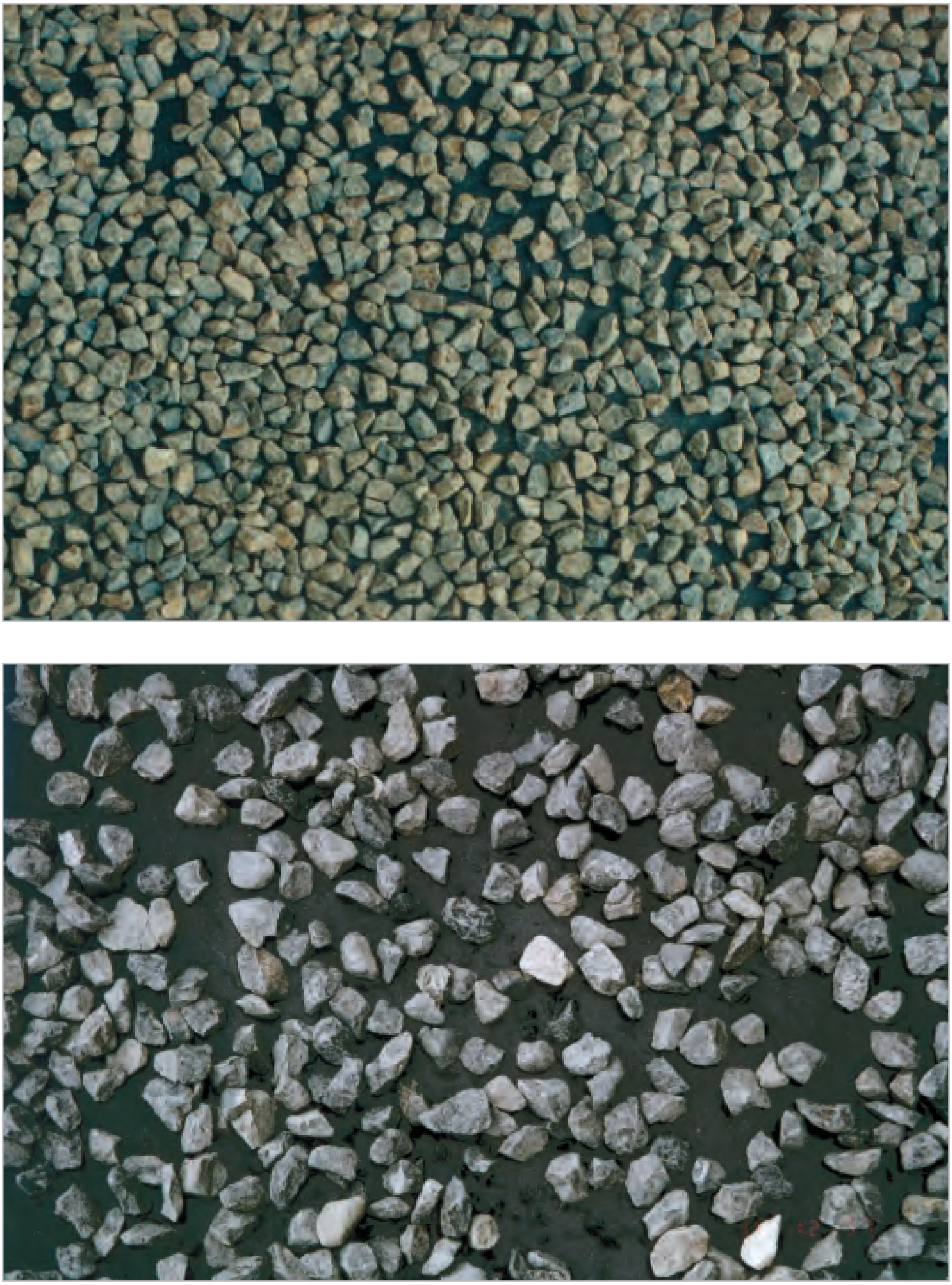


Figure 11-4 Now advice is to aim for a chip spread-target rate as shown at the top of this page. This was previously considered as under-chipped. The image at the bottom of this page shows a chip spread rate suitable for use in the first layer of a racked-in chipseal. Note the large 'windows' where smaller chip in the second layer can adhere to the binder. Photos courtesy of Shirley Potter and Les McKenzie, Opus

4. The ability to achieve the new target rates will depend greatly on the type of sealing that is required. For example, when sealing a long straight section of State Highway 1, the chances of achieving target rates of sealing chip application will be far better than if the job is on a busy street in Auckland City with many intersections and roundabouts, etc.
5. However, irrespective of the actual rates achieved, significant savings can be made in all sealing situations if the process is properly controlled.
6. Ways in which savings can be made on volume of chip used include:
   i. Consider hand spreading of chip around the 'wings' of intersections rather than using the spreader.
   ii. As chip is usually spread to a 2.4 m width, and the bitumen sprayer sprays at 3 m width, usually a second pass of the chip spreader is made with some of its tail gates closed. Despite the best care, this often ends up with double-applied chip in some areas. Where weather conditions and seal type allow, it can be acceptable to leave a narrow length of unchipped seal for short periods, until the next spray run has been completed, and then complete the chip spreading.
   iii. Consider reducing the number of runs to reduce the number of overlaps (i.e. use the spraybar at its widest practical setting).

The aim is to apply the same level of control into the spreading of chip that is put into the spraying of binder.

> Ultimately the 'best' spread rate will be that which provides the most economic use of sealing chip while providing the required interlock of the individual chips.

11.4 Seal Construction on the Day

11.4.1 Rolling

Rolling can begin as soon as the chip has been applied and has been satisfactorily spread on the binder (Figure 11-5). Current rolling practice varies from seal type to seal type but is usually carried out by bedding in the chip with a pneumatic-tyred roller (PTR) travelling at around 8 km/h for about five roller passes. See discussion on the effects of rolling in Section 4.2.2.

The number of passes, the speed of the rollers, the number and type of rollers required will depend on site conditions, seal type and traffic count. They should be considered as part of the site planning in conjunction with the site traffic management plans (see TNZ COPTTM, 2004 and amendments).

Figure 11-5 Once the planning has been done, seal construction can begin.
Clockwise from top left: Spraying the binder. Top right: Spreading the chip. Bottom right: Rolling underway while waiting for the chip-spreading operation to complete the second run. Bottom left: Rolling underway on the almost completed seal. Photos courtesy of David Ashby, Opus

Because rolling plant can create significant traffic hazards and add to the dangers of sealing very busy sections, traffic can be used on site to assist with rolling. In these cases, the rollers can be used for the initial passes to push the chip into place and then be replaced by traffic. If managed correctly and moved across the sealing site, traffic can continue to bed the chip into the binder.

The construction crew should set up rolling patterns that concentrate on the areas which only receive intermittent traffic, e.g. parking bays, shoulders and centrelines.

Special attention should also be paid to the site if a cold front is predicted or arrives during seal construction. The arrival of a cold front causes a rapid drop in pavement temperature which will interfere with the formation of the bond between binder and chip (Pollard 1967). Shaded areas can also cause bitumen to cool too rapidly for good adhesion to occur. See discussion in Section 11.4.5.

If temperatures drop suddenly or a chipseal is to be constructed in a shaded area, extra rolling and low-speed trafficking can help prevent chip loss. These measures work because the effect of rolling and traffic on the development of a good bond can be considered to be similar to a pressure-sensitive adhesive. As the viscosity of bitumen is stress-dependent, the stress from vehicle tyres causes the binder to have lower viscosity and also increases the rate of wetting. The rate of wetting will be directly proportional to the stress imposed (Forbes et al. 2000).

11.4.2 Drum Rollers

Drum rollers, also called flat drum rollers because they have no tread, are either steel or rubber coated. The use of a flat drum roller can produce a very flat seal coat as the drum has the effect of pushing the chip onto its flat (i.e. its AGD is embedded in the binder, and its ALD is the vertical dimension).

This technique can be used on most seal types and especially for single coats, two coats and racked-in seals. In constructing racked-in or two coat seals, if the first layer of chip is rolled with this kind of roller, the finished result will be a smoother flatter seal with less macrotexture than a seal which has been rolled with only a PTR.

Care is required however to prevent chip crushing, especially with steel drum rollers. Usually only one pass is required to make the chip lie flat.

Road shape should also be considered when using flat drum rollers as many pavements have some rutting (often shallow, and generally in the wheelpaths) and this will result in the drum bridging the ruts and not making contact with the chip in them. If traffic is not well managed during the initial compaction period, the seal in the ruts in the wheelpaths does not get rolled enough, and is at risk of early stripping.

11.4.3 Heating Binder

Binders must be heated to reach the appropriate viscosity to ensure even spraying and distribution. This procedure requires care when heating to carry it out safely and to avoid binder degradation. BCA 9904 must be followed when heating and only experienced trained staff should be involved.

When tankers are heating bitumen on site:

- Binder levels must be checked to make sure they are above safe heating levels.
- The tanker must be on level ground.
- The tanker must be attended at all times unless the unit is specifically designed to be heated while unattended.
- Rise in temperature must be controlled (this varies for different binder types).
- Certain binders, e.g. PMBs, are particularly sensitive to heating rate.
- The tanker must not be moved for 15 minutes after heating has been stopped.

11.4.4 Spraying

11.4.4.1 Spraybar Height

Correct spraybar height is crucial to achieving accurate spray rates and correct distribution across the spray area. As part of the E/2 certification (NZ BCA 1992) of a sprayer, the spray bar height will be noted and this should be checked regularly and corrected on site. Spraybars at an incorrect height can be a leading cause of streaking of binder (or stripes) on the road surface. When operating at the wrong height binder streaking will occur with corresponding chip loss.

11.4.4.2 Spraybar End Nozzles

A spraybar end nozzle is designed to prevent the last spray nozzle from 'fanning' at the outer edge, and to allow the full application rate right up to the outer edge of the spray run. It can provide a defined line at the outer edge of the sprayed area. Because the correct binder application rate is only achieved with a triple overlap of nozzles, the outside edges of the spray area will not receive the full design spray rate if an end nozzle is not used.

Some clients however prefer not to apply the full rate at the outer edge as this can cause run-off where the road surface drops off into the kerb and channel, or onto an unsealed shoulder. Instead they prefer to allow the last nozzle to fan at the outer edge. Often the reason for this is that usually traffic does not use the edge, and chip loss caused by a lighter application over the last few millimetres of the road edge may not be a problem.

The use of end nozzles is not always specified. Therefore if it is not clearly defined in the specification, it is wise to discuss the issue with the client to decide which method is best for their road.

11.4.4.3 Variable Rate Spraybars

In more recent years variable rate spraybars have made it possible to spray more than one application rate over a single spray run. This can be useful for applying more binder to shoulders or coarse textured areas while applying a different rate to wheelpaths in the same pass.

As technology develops, spray systems will become more sophisticated. To assist with their development, practitioners, engineers, consultants and clients should all be open to new improvements and allow trials to be carried out during their particular works.

11.4.4.4 Spray Runs

As discussed above, spray runs should be carefully planned to match the site conditions, the seal type, the design, chip and the plant on site.

When planning the spray run an approximate layout is developed, based on initial test results gathered during the programming and pavement check phase. Road geometry, variations and gradients, etc., are taken into account on a visual examination of the road.

Run start / stops
The start and end positions, widths and tapers need to be planned and documented in advance in all but the very simplest situations. It is essential that the appropriate application rates are designed in advance for different parts of the pavement to be sealed, and that the field construction personnel are absolutely in no doubt where each change in rate is to occur.

Strong paper should be used at spray run starts and stops to ensure that clean straight lines are achieved (Figure 11-6).

Figure 11-6 A spray run about to start. Note the paper spread in place so that an accurate start line can be achieved.
Photo courtesy of Les McKenzie, Opus

Laps
To achieve full application rates, longitudinal joints need to overlap (distance of which is specified in the distributor's BCA E/2 certificate) to achieve the triple overlap of spray nozzles. Longitudinal laps between spray runs should, as far as is possible, be planned to be on lane boundaries, and not in the wheelpaths.

Tapping on and off
The width of seals will often vary along the length of a spray run. To cater for the variation in width, spraybars usually have the ability to traverse sideways a short distance and extra taps are turned on or off while spraying.

In the past the practice of 'tapping on or off' was frowned on by some, because adding or reducing taps during a spray run can have the effect of changing the spray application rate. Usually though, an experienced sprayer operator adjusted the spray pump output to compensate for the changing number of nozzles during the spray run.

More modern sprayers have the ability to automatically adjust and maintain a constant application rate when spray nozzles are turned on or off during a spray run. Telescopic spray bars allow the overall bar width to vary without altering the application rate across the bar.

11.4.4.5 Spraying on Difficult Areas

On sharp bends

> While often very little can be done to avoid them, sharp bends will have an effect on application rate across the road. Because the end of the spraybar on the inside of the bend travels slower than the outer end, the application rate will be lighter at the outside than the inside of the bend.

Experienced practitioners will be aware of this and will attempt to minimise the effect as best they can by reducing the spray width. However reducing the spray width down to narrow strips is not always practical. It also introduces more possibility for error by increasing the number of joints, in a position where a quality joint is difficult to construct. In extreme cases a chipseal may not be the best treatment anyway, and a realistic practical approach is required and alternatives should be discussed with the client.

On excessive cambers
As with sharp bends, excessive camber (where the road crossfall is steep) can affect application rates across the road. The effect is that the spraybar can come very close to the road on the low side and can be higher off the road on the high side. This alters the overlap of the spray nozzles at the point of contact with the road so that heavy rates are applied close to the road while light rates are applied when the bar is high.

In some cases the effects can be minimised by altering the bar height and/or the spray width. However not all circumstances will allow this to be completely successful. Unfortunately sharp bends are often associated with excessive camber and, when combined, these can make achieving the required residual application rate over the full spray width very difficult. As with sharp bends a chipseal may not be the best treatment and a realistic approach toward alternatives is required.

On intersections

At intersections in particular, and generally wherever the road has a complex shape, it is an important task to ensure that hand-sprayed areas are kept out of major traffic wheelpaths. Failure to do so risks flushing and tracking of excess binder over wide areas. Therefore the most desirable procedure is to prepare a plan of the intersection, showing the areas and spray rates of each run.

11.4.4.6 Hand Spraying

Hand spraying should be kept to a minimum because it is operator-dependent, and experienced persons are now rare (Figure 11-7).

Figure 11-7 In the 1920s, hand spraying was the only way to get the binder onto the road. It required highly developed skills to apply the binder evenly over the surface.

Photo courtesy of John Matthews, Technix Group Ltd

Hand spraying is carried out in difficult areas which cannot be sprayed with the spraybar because of their shape or restricted access. Usually areas such as triangles at road intersections, odd shapes, around posts and guard rails, and areas very close to buildings, are hand sprayed.

Control of application rate is very difficult and completely operator-dependent. An experienced operator is required, and even then the actual rate applied can be very difficult to determine because the small volumes sprayed are not easy to measure accurately. In many cases the inaccuracy does not affect the end result, e.g. hand spraying around the posts of guardrails.

However in important areas, such as the 'wings' of intersections and odd-shaped areas of entrance ways where traffic stress is high but space for a mechanical sprayer is limited, hand spraying has to be used despite the disadvantage of controlling the application. In many cases these problems cannot be avoided and, until more innovative construction methods are developed, operator experience and increased care are the only factors that can reduce risk.

Practitioners should rely on experience and care while clients and specification writers should be aware of the constraints and take a practical approach.

11.4.5 Weather Conditions

As touched on in Section 11.4.1, the arrival of a cold front or presence of shaded areas on the road can cause the binder to cool too rapidly for adequate binder–chip adhesion to occur. The reason behind this is that the rate of wetting of a binder on a stone is an inverse function of the binder viscosity (Forbes et al. 2000).

Forbes' research showed that the change in viscosity with temperature is exponential, i.e. viscosity increases rapidly with decrease in temperature and this increasing binder hardness has a very significant effect on the time for wetting, and therefore adhesion, to take place. (See Figures 4-4 and 4-6, and discussion in Section 4.2.3.)

This work also illustrates in part why initial adhesion problems can occur where a pavement is in the shade. The pavement in the sun could be at 35°C but in the shade below 20°C. Thus the chip in the sun-lit areas may have adhered when the construction crew leaves the site, but in the shaded area it may not have adhered and chip loss may occur overnight and over subsequent days. Seals constructed earlier in the day generally adhere and perform well.

11.4.6 Remedial Work

Remedial work is covered in Chapter 12.

11.5 Preparation for Sealing with Emulsions

11.5.1 Introduction

This section discusses issues relating to the use of and preparation required for sealing with emulsified binders (see also NZ BCA 1996).

Chipsealing emulsions are described in Section 8.3, and are simply another means of placing a bituminous binder into a chipseal surfacing. Advantages of emulsion are listed in Section 8.3.6.

11.5.2 Material Selection

Bitumen grades used for emulsion sealing should be the same as those used for cutback sealing, although harder grades can be considered.

The base bitumen may contain small volumes of diluent, e.g. kerosene, to:

- reduce settlement or upcreaming by matching density of dispersed phase to that of the continuous phase;
- improve green-strength of seals constructed under cool conditions by increasing the rate of droplet coalescence, and hence formation of a continuous binder film.

> The composition of the binder in the emulsion should be discussed with the manufacturer, taking into consideration the required break rate, site stresses, seal type, road geometry, site climatic conditions, and expected pavement temperatures during construction.

The type and quantity of emulsifier used in the emulsion is generally proprietary information. Therefore the contractor should inform the manufacturer if long distance transportation of the emulsion is required, for which adjustments to the formulation may be needed.

The type and grade of emulsion that is used for chipsealing depends on the nature of the seal coat as listed in Table 11-4. It is expected that cationic emulsions will be selected because of their active breaking characteristics and good adhesion to most aggrgeates used in New Zealand. This list is only a general guideline.

Table 11-4 Emulsion grades used for various seal types.

Seal Type	Emulsion Grades
Voidfill	CQ55, CQ60
First coat seals	CQ65, CQ70
Reseals	CQ65, CQ70
Two coat seals	CQ65, CQ70
Wet lock seals	CQ55, CQ60, CQ70

Lower viscosity emulsions, hence with lower binder content, are recommended for seals where the binder is required to collect in the surface voids of the substrate, e.g. voidfills, wet lock seals. Higher binder content emulsions with higher viscosities are recommended for reseals where there is risk of run-off, and for higher application rates for coarser seals.

Advanced emulsions that contain polymer modifiers have become available in recent years. These emulsions may be manufactured using PMBs, or have the polymer added in a latex form during manufacture. These polymer modified emulsions (PME) are proprietary materials so careful assessment should be made of the claimed material properties to allow comparisons to be made with similar or conventional emulsions. Experience has shown that these PMEs allow the use of highly modified binders but with a reduced risk of failure compared with hot-sprayed modified binders.

11.5.3 Spray Rate Calculations

The design principles of chipseals constructed using emulsified binders are the same as those using cutback bitumen and have been described previously in this book. Specific matters for consideration that relate to emulsions follow.

Calculate the normal residual binder application rates using the formula for chipseal (Equation 9-13) in Chapter 9. As emulsions comprise binder dispersed in water, spray rates must be factored upwards to allow for the water in the emulsion, using the formula below. If emulsions are sprayed at elevated temperatures, e.g. for viscous grades such as CQ70, the expansion of the emulsion caused by heating must also be accommodated by multiplying the emulsion spray rate with the Heating Factor from Table 11-5.

$$ESR = R \times \frac{100}{EBC} \times H_{fe}$$

where:
- ESR = Emulsion Spray Rate (ℓ/m^2 at 15°C)
- R = Residual Binder Application Rate (ℓ/m^2) at 15°C, from Equation 9-13
- EBC = Emulsion Binder Content (%)
- H_{fe} = Heating factor to compensate for volume changes due to elevated spraying temperatures (see Table 11-5).

Additional care must be taken for emulsion spray rates greater than approximately 1.8 ℓ/m² due to the risk of run-off. This also depends on substrate texture, road geometry and seal type. Some emulsions with binder content greater than 72% and hence higher viscosity may be sprayed at higher application rates. However, as these are generally proprietary materials they should only be used in accordance with the manufacturer's instructions.

Table 11-5 Heating factors (H_{fe}) for use with emulsions.

Temperature (°C)	Multiplier H_{fe}	Temperature (°C)	Multiplier H_{fe}	Temperature (°C)	Multiplier H_{fe}	Temperature (°C)	Multiplier H_{fe}
15	1.0000	35	1.0094	55	1.0189	75	1.0286
16	1.0005	36	1.0098	56	1.0194	76	1.0291
17	1.0009	37	1.0103	57	1.0199	77	1.0296
18	1.0014	38	1.0108	58	1.0204	78	1.0301
19	1.0019	39	1.0113	59	1.0208	79	1.0306
20	1.0023	40	1.0117	60	1.0213	80	1.0311
21	1.0028	41	1.0122	61	1.0218	81	1.0316
22	1.0033	42	1.0127	62	1.0223	82	1.0321
23	1.0037	43	1.0132	63	1.0228	83	1.0326
24	1.0042	44	1.0136	64	1.0233	84	1.0331
25	1.0047	45	1.0141	65	1.0237	85	1.0336
26	1.0051	46	1.0146	66	1.0242	86	1.0341
27	1.0056	47	1.0151	67	1.0247	87	1.0346
28	1.0061	48	1.0155	68	1.0252	88	1.0350
29	1.0065	49	1.0160	69	1.0257	89	1.0355
30	1.0070	50	1.0165	70	1.0262	90	1.0360
31	1.0075	51	1.0170	71	1.0267	91	1.0365
32	1.0079	52	1.0175	72	1.0272	92	1.0370
33	1.0084	53	1.0179	73	1.0276	93	1.0375
34	1.0089	54	1.0184	74	1.0281	94	1.0380
–	–	–	–	–	–	95	1.0385

11.5.4 Emulsion Binder Spray Temperature

The recommendation is that emulsions with binder contents greater than about 65% should be sprayed hot, usually in the range of 80°– 95°C. Two reasons are given for this recommendation.

- The elevated temperature reduces the emulsion viscosity, thus aiding pumping and distribution through the spray nozzle.

- The heat of the emulsion accelerates evaporation of the water during spraying.

Emulsions with lower binder contents may be sprayed from ambient temperatures up to 95°C.

While some chipsealing emulsions may contain small volumes (≤5 pph) of diluents such as kerosene in the binder, the suggestion is that adjustment of the application rate to compensate for the evaporation of the diluent may be neglected because volume changes are gradual and negligible. As emulsions are sprayed at relatively cool temperatures, diluents will evaporate slowly after the emulsion has broken and the seal has been constructed. Consideration should be given to the upward adjustment of application rates to compensate for diluent loss if more than (say) 5 pph of diluent is present in the emulsified binder.

11.5.5 Plant and Handling

Emulsions are sprayed using bitumen distributors complying with the BCA E/2 specification. Consideration must be given to the following:

- Tanks should be cool before loading with emulsions.
- As emulsions are water-based, they will boil if heated to 100°C. Therefore the recommendation is that temperatures do not exceed 95°C.
- When heating emulsions it is preferable to use electric elements that have lower and evenly distributed surface temperatures compared with flame tubes. If flame tubes are used, the heating rate should be reduced enough to prevent high flame-tube surface temperatures that could cause localised boiling.
- Excessive circulation through the pump will cause coalescence of the binder droplets in the emulsion, and eventually the emulsion can break. It is recommended that circulation is minimised.
- Emulsions will not remove binder residues in pipework. If pipework is partly or fully blocked, flushing and cleaning with hot bitumen is necessary before introducing emulsions.
- Spraybar height, or nozzle type or nozzle angle, may need to be changed because emulsion spray characteristics are different to cutback bitumen. This is shown by streaking, visible in sprayed surfaces.

Sprayers that have previously contained emulsion often have small volumes of emulsion or water remaining, either trapped under a skin of binder, or in pipework. This is a significant hazard if hot binders with temperatures over 100°C are introduced. The water will boil on contact with the hot binder, flash into steam, and the consequent expansion will cause the binder to foam. If the volume in the tank is sufficient, it will be violently ejected. Tanks must be carefully de-watered by adding small volumes of hot binder and allowing the water to boil off under controlled conditions. Refer to the Bitumen Safety Book (NZ PBCA 2001), and the Code of Practice BCA 9904 (2000) available from Roading NZ for more information and advice.

11.5.6 Construction

There are some specific differences in practice when constructing chipseals using emulsified binders:

- The sealing chip must be clean. Emulsions will break and adhere to any dust on the surface of sealing chip but not penetrate the dust layer and bond with the chip surface. The use of dirty chip increases the risk of early chip loss.
- Sealing chip must not be excessively wet, as the excess moisture will dilute the sprayed emulsion causing delayed seal curing times and possible run-off. However damp chip assists the emulsion to wet and flow over the chip surface.
- Chip must be applied as soon as possible after the emulsion has been sprayed and before the sprayed film changes colour from brown (unbroken emulsion) to black (binder from the broken emulsion). The emulsion should break after the sealing chip has been applied, thus ensuring a good bond to the chip aggregates and effectively 'casting' them in place.
- Cold ambient temperatures, high humidity and light wind conditions or combinations of these three can significantly extend breaking times and lengthen curing, by slowing evaporation of the water from the emulsion. Sealing should be programmed to avoid these conditions. However specific formulations and care in construction may allow work to proceed.
- High ambient temperatures, low humidity, light wind conditions, moderate to steep road gradients, high traffic flows, or a combination of these factors can cause chip aggregates to adhere to tyres and be dislodged. Application of a light mist of water to the completed seal can prevent the chips from adhering to tyres and being lost.

11.5.7 Breaking and Curing

The two distinct processes that must take place before an emulsion seal attains full strength are breaking and curing.

Breaking is the process in which the binder droplets in an emulsion separate from the emulsion and coalesce to form a continuous binder film.

Curing is the development of strength in an emulsion seal as the water from the broken emulsion evaporates. The seal does not achieve full strength until all the water has evaporated.

New emulsion seals where the emulsion has broken but curing is not fully complete may be trafficked provided traffic speed is kept below 30 km/hour. The kneading action of the vehicle tyres will assist the loss of water, and hence develop strength in the seal.

First coat seals may be constructed using emulsions, but suitable basecourse preparation is essential for success. As emulsions break on contact with dust or fines, newly constructed basecourse layers must have a visible clean mosaic of coarse aggregate particles and be slightly damp for good adhesion to be achieved. The water in the emulsion will also swell any fines on the surface of the basecourse, preventing penetration of the emulsion.

Early rain, particularly if sprayed emulsions have not broken, can cause catastrophic failure of the seal by washing the emulsion away. Spill kits should be carried and used to prevent possible pollution of waterways should such an event occur.

High ambient temperatures can cause skinning of the sprayed emulsion, trapping the water and slowing rates of cure. Slow traffic and rolling will help release the trapped water and accelerate the curing process.

11.6 Preparation for Sealing with PMBs

11.6.1 Introduction

Sealing using polymer modified binders (PMBs) requires that all the normal good practices relating to conventional sealing are to be followed and, as well, a number of extra precautions are to be undertaken to ensure a good PMB seal.

PMBs are used in chipsealing to provide enhanced properties to the final seal. These improved properties can include:

- The ability to withstand increased levels of shear stress;
- Improved performance over wider temperature range;
- Improved resistance to crack propagation.

To obtain these improved properties requires increased care and skill during the sealing operation because polymer sealing uses materials which are more susceptible to many influences such as weather, pavement temperature, shade from trees, air and binder temperature, kind of aggregate, and sealing technique. To ensure high levels of success with hot-applied PMB, it is preferable to spray during the ideal sealing period of December through to March (summer months).

11.6.2 Material Selection

As described in Section 8.4, the range of polymers available today for use in polymer sealing is extensive and they vary greatly in their performance characteristics and more importantly in their application techniques. Because of this extensive range, only an outline can be provided here to the character of this extensive range of products. Thus in all cases, direct advice should be obtained from the polymer manufacturer before undertaking any polymer sealing to ensure that any specific properties or application techniques are thoroughly understood. As well, the reason for using a PMB should be clear before commencing sealing so that the additional cost inherent in using a PMB can be fully justified.

Unless special techniques such as SAMs or SAMIs (see Section 8.4.7) are being applied, most polymers used in sealing are used at polymer concentrations of less than 5% (by weight) in bitumen.

Because of the many additives used in producing PMBs, the grade of bitumen used in their manufacture does not have as significant an effect as the grade of bitumen has in straight bitumen sealing. Viscosity, which with straight bitumen is normally closely related to the respective grade of bitumen, can be changed by the large number of additives that are incorporated into a PMB. Once again, advice should be taken from the PMB manufacturer.

11.6.3 Spray Rate Calculations

> The design principles of chipseals are the same whether straight bitumen or PMB is used as the binder. If 3% polymer concentration (or less) is used in a seal design, no adjustment should be made to the application rate over that of conventional bitumen.

Most 3% PMBs made in New Zealand do not have greatly increased viscosity over that of conventional bitumen, hence neither the spray fan shape nor the chip orientation is greatly affected.

> The greater difficulty occurs when polymer concentrations greater than 3% are used. Research work has shown that, for hot application (but not emulsion) of a number of polymer types, the spray fan shape is greatly affected, leading to possible 'tramlining'.

Also the viscosity can be increased to a level where it begins to affect the ability of aggregate to be able to orient down on to its AGD. This has major implications in terms of seal voids and affects the chipseal's ability to obtain sufficient binder rise before the onset of cooler temperatures at the end of a sealing season. As a consequence, early autumn stripping of aggregate can be a possibility. Once again, the advice of the polymer manufacturer should be taken on the specific character of the particular polymer product.

11.6.4 Spray Temperature

The objective of selecting a spray temperature for a PMB is to obtain the same viscosity of the particular product being sprayed as the bitumen for which the distributor obtained its BCA E/2 certificate. This will ensure very similar spray distribution and a similar application rate as when straight bitumen is applied.

As most PMBs have a higher viscosity than bitumen for a given temperature, this means that most PMBs need to be sprayed at higher temperatures than conventional bitumen. For example, 3% SBS-polymer sealing binders are typically sprayed at temperatures between 160 and 180°C. As not all polymers follow this trend of requiring higher temperatures than bitumen, spray temperature recommendations should be obtained from the polymer manufacturer.

Some polymer manufacturers also endorse the use of cutters to reduce the viscosity of their PMB thereby assisting in obtaining a suitable spray fan shape, improving aggregate wetting and allowing the chip to orient into its correct position. Consultation with the PMB supplier is essential before adding any cutter to a PMB.

Another highly effective way of reducing the application viscosity of a PMB without having to increase the temperature or add cutters is to emulsify the PMB and apply it as a PME.

11.6.5 Handling

Conventional bitumen distributors can be used in polymer sealing. The differences in the spraying character of the PMBs over conventional bitumen usually relate to any increase in viscosity. Normally, a satisfactory spray fan shape can be obtained with PMBs by increasing the spraying temperature, by the addition of cutter, or by using PMEs.

Some important handling characteristics specific to hot PMBs are:

- Most PMBs can be rapidly degraded by excessive heat. This means that no PMB should ever be heated above 190°C. If heating the PMB in the bitumen distributor is necessary, the heating rate should not exceed 12°C per hour.

- The high viscosity of most PMBs (especially at low temperatures) means that circulation while heating is a necessity. Circulation will enable fresh PMB to be run past the heating tubes constantly, and this will minimise any localised degradation of the PMB.

> - The highly viscous nature of most PMBs means that they will adhere to fabric or skin. Burns from PMBs can be severe and extreme care should be taken at all times when handling the hot product. It is essential that full personal protection equipment is worn at all times when working with hot PMBs.

- The presence of any water in tanks (e.g. from condensation), pipework or hoses can cause localised boiling and extreme foam-over. Ensure that all tank lids are waterproof and that no emulsion residues are present before pumping hot PMB.
- Separation (or layering) of a PMB can occur if the product is left for a prolonged time at elevated temperatures without stirring. The PMB should be circulated for a number of hours before use. Contact the polymer supplier if extended elevated storage has occurred, as they will be able to give guidance on possible remedial actions.

11.6.6 Construction

The most critical aspect in constructing a polymer seal is to ensure that satisfactory chip adhesion is obtained. Therefore a number of specific actions need to be undertaken to ensure a good bond between the PMB and the aggregate:

- If hot PMB is used, then the aggregate should be precoated to maximise the bond between the PMB and the chip. Precoating is not required if PME is used.
- The aggregate should be spread immediately after the PMB is sprayed and multi-tyred rolling undertaken to maximise the contact area between the binder and the chip.
- If PME is used, good traffic control is essential to minimise chip rollover and pick-up. All normal emulsion construction practices should be followed (see Section 11.5).
- In two coat polymer seals, a conventional bitumen may be used as the binder for the second locking coat. The freshly sprayed conventional bitumen with a lower viscosity than the PMB can flow into the voids of both layers, providing an improved bond.
- Because hot-applied polymer seals have increased susceptibility to early damage from chip loss if moisture is present, increased vigilance must be taken with regard to the weather before sealing. A window of 1 to 2 days fine weather following spraying is needed to allow the seal time to build chip adhesion. This requirement is lessened if PME is used because, once it has broken and is fully set-up (in about 2 to 4 hours), the PME seal is much less sensitive to water damage.

11.7 Environmental and Community Issues

Today the public and RCAs are more conscious of environmental and social issues than ever before. The following sections list matters to consider when planning chipsealing work to help enable the chipsealing practitioners to better deliver RCA goals of environmental sustainability. See also discussion on environmental and community issues in Section 6.10.

11.7.1 Waste Minimisation

Waste minimisation includes consideration of the way waste is disposed of, reducing the amount of waste to be disposed of, e.g. at the landfill, and reducing the demand on primary sources of materials, e.g. of sealing chip.

Waste minimisation and substitution of materials are aspects to consider in the planning and selection process, and in activities such as:

- Re-using milled sealing material;
- Evaluating chip application rates to use less chip and binder;
- Substituting materials from other waste streams, such as clean fill or construction and demolition waste, for use in basecourse or subsurface pavement layers.

11.7.2 Energy Efficiency

Taking simple steps to reduce energy consumption can result in cost savings, and make a positive contribution to national energy reduction targets.

Including energy conservation practices and products, and improving vehicle fuel efficiency, e.g. by smoothing the road texture and surface, in the planning and selection process can achieve the best value of energy use.

These conservation principles can be put into practice in the following examples:

- Examining ways to maximise energy efficiency, e.g. avoiding unnecessary heating of binder before its application;
- Using products which enhance energy efficiency, e.g. insulation in binder heater tanks;
- Calculating the fuel efficiency benefits (and benefits of reduced road–tyre noise) of using smaller chip sizes;
- Using locally sourced material, to reduce haulage distance, and therefore reducing overall fuel consumption, transport costs and vehicle emissions;
- Cost-effective options to recycle loose chip should also be investigated. For example, using rotary brooms to sweep up excess chip and stockpiling it for other uses.

11.7.3 Water Management

The effects of sealing activities on the volumes of water used and impacts of water run-off on stormwater can be reduced through careful water use and sensible management practices.

Key water management objectives include:

- Reducing the volume of potable (drinking quality) water used in sealing and maintenance activities, e.g. for washing down;
- Ensuring pollutants from sealing activities do not enter waterways[2].

Good management practices include:

- Filtering and re-using water collected from high pressure water treatments;
- Avoiding spillage of binders;
- Ensuring containment devices are in place and spillage kits (of fine aggregate to cover oily spills, portable textile dams to block run-off) are available;
- Ensuring that contact with the local Fire Brigade has been made.

See Roading NZ's BCA 9904 (2000), Chapter 3.12 Emergency Precautions for Fire Control and Spillage, and Chapter 5.11, Spillage Hazards, for details.

Check list of Environmental and Community Principles relevant to chipsealing.

	Have the following environmental and community principles been considered in planning for and completing pavement sealing works?
	Have waste management and energy efficiency principles been considered? e.g. heating the bitumen tanker?
	Have all opportunities to conserve water been considered?
	Have methods to avoid discharges of sediment and other pollutants into waterways been considered and actioned?
	Have spillage kits and fire extinguishing kits been prepared?
	Have affected stakeholders (and neighbours) been consulted and advised of sealing activities?
	Have other key environmental & community considerations been identified & actioned? Noise Air quality Site safety Fire prevention Other?

2 Waterways are water bodies such as streams, rivers, coastal areas, ground water, wetlands.

11.8 References

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constructed seals

CHIPSEALING IN NEW ZEALAND

CHAPTER 12: PRACTICE NOTE 1

NZ TRANSPORT AGENCY
WAKA KOTAHI

April 2011

ntroduction

his practice note provides suggestions for seal repairs. It identifies immediate responses and mitigating repair ptions. It also identifies permanent repair options that will enable the design life of a particular seal coat type to be chieved.

his practice note reinforces the information in chapter 12. It is considered that many failures to chipsealing could be atisfactorily repaired if immediate responses are implemented as per the instructions in chapter 12. Please also refer o seal performance and seal life issues which are covered in chapter 4 or pre-reseal repairs which are covered in hapter 7.

ey points

e aim is that repairs are designed and executed so at the expected life of the seal is not compromised.

is important to figure out what has gone wrong before ciding on a possible solution.

e most successful repairs are those that:

- are completed promptly and competently, and
- minimise the addition of binder to the seal.

me repair methods will lead to a shorter seal life and ntract negotiations may be necessary. In some cases e only effective treatment to return the seal to its pected life is to remove the seal or to cover it with an propriate bituminous mix.

is could be achieved by carrying out pavement type eatments such as recycling, applying a granular erlay, removing the seal and re-sealing, or applying a t mix asphalt overlay.

Overall message for all treatments

o not apply more bitumen in higher traffic areas (unless the problem is caused by low binder).

owever, in some low traffic areas, a small amount of tra binder may be acceptable.

able of treatment options

e table on the next page gives an indication of the eatments that may be appropriate to address specific lures of the seal.

e table addresses three common symptoms of seal lure (chip loss, flushing and chip roll-over).

ote: Some of these symptoms may not become

The table lists possible causes for each symptom.

In some cases an immediate response is stated. This is the best immediate response for the situation but may not be the only one.

Where it says 'repair small areas...' apply dry chip to the areas of chip loss then use one of the recommended treatments.

The recommended treatment options for each cause are indicated by one of the following symbols:

P	Permanent treatment option which is likely to result in the seal achieving its expected life.
M	Mitigating treatment option which may not result in the seal achieving its expected life.
M/P	Could be a permanent treatment option but, if the expected seal life will be reduced (eg if the target texture is compromised) it is a mitigating treatment option.

There are many variables when dealing with a seal failure. The table provides a good starting point to help identify the best options for treatment.

Talk to your local experts if you are uncertain about the cause of the seal failure or which treatment option is best for the situation.

In some cases the best treatment option is to leave the seal as it is and negotiate reduced contract payment. For example, if the wrong binder has been applied or if dirty chip has been used the life of the seal will be shortened. It may, however, be more economical to renegotiate contract payments rather than replace the seal.

ptom	Cause	Immediate response	Compact usi controlled tr (refer to Practic	Apply cold w	Apply small sweep	Apply wet lo coat	Apply dry lo coat	Add fog coat bitumen	Hot or pre-c chip	Reliven bind	Water cuttin	Sandwich se	Slury seal	Remove sea	Recycle	Granular ove	Hot mix asp
loss	Rain	Reduce traffic speed possibly as low as 20km/h				M/P			P	P		P		P	P	P	I
	Stress	Repair small areas before widespread chip loss occurs					P		P			P		P	P	P	I
	Dirty chip	Reduce traffic speed possibly as low as 30km/h	P			M/P				P				P	P	P	I
	Inadequate rolling	Repair small areas before widespread chip loss occurs	P					P	P	M				P	P	P	I
	Too little binder application	Repair small areas before widespread chip loss occurs				M		P				P	P	P	P	P	I
	Wrong binder too hard	Repair small areas before widespread chip loss occurs	M			M		M	M	M		P	P	P	P	P	I
	Wrong binder too soft	Repair small areas before widespread chip loss occurs	M				M		M			M	P	P	P	P	I
	Over application of chip	Keep sweeping to remove excess chip					M		M								
	Shaded or damp areas	Repair small areas before widespread chip loss occurs				M			M			P	P	P	P	P	I
	Wrong time of year for sealing	Control traffic immediately and repair small areas	M			M			M				P	P	P	P	I
	Absorption of binder into substrate					M		M				P	P	P	P	P	I
ing	Too much binder applied				M						M	M/P	P	P	P	P	I
	Inadequate preparation of substrate										M	P	P	P	P	P	I
roll-	Stress						P		P			P		P	P	P	I
	Incorrect binder choice		M				M		M			M	P	P	P	P	I

CHAPTER TWELVE

Chipseal Failures and Repairs

Chapter 12 Chipseal Failures and Repairs

Previous page: Chipsealing in progress on State Highway 73, west of Arthur's Pass. One of the reasons for the chipseal was to repair the lightly flushed existing surface seen on the left of the road. This photo was taken in high summer, as indicated by the flowering rata trees. It is also the best time for sealing.

Photo courtesy of Les McKenzie, Opus

Chapter 12 Chipseal Failures and Repairs

12.1 Background

The intent of this chapter is to describe those seal failures that occur soon after the construction of new reseals, and to identify their causes. As well it includes suggestions for their repairs that will give satisfactory results and, where appropriate, will enable the design life of a particular seal coat type to be achieved. It does not include seal performance and seal life which are covered in Chapter 4, or pre-reseal repairs which are covered in Chapter 7.

Even though the design and construction principles outlined in the preceding chapters may have been followed, post-sealing failures do occur and faults do develop. The type or cause of a failure must be identified, and an appropriately timed treatment decided on and applied. Otherwise a failed seal can develop which will require significant and expensive repairs. This chapter does not deal with all the symptoms that appear during the life of a chipseal as it deteriorates. For example, this discussion does not include cracking or layer instability (covered in Chapters 6 and 7).

This chapter only deals with failures that can be corrected through a treatment that is designed to correct the deficiency, instead of renewing the seal. Apart from unscheduled reseals required at short notice (Section 12.8), reseals are not covered in this chapter.

12.2 Texture Loss

Texture loss and cracking, as discussed in Chapter 4, are the main causes of seal failure. Seal failures by texture loss can include:

- premature binder rise;
- flushing;
- bleeding;
- chip loss;
- chip rollover; and
- pavement structural failures.

If these are treated appropriately and promptly, the surface often can continue to function as intended.

Some of the factors that contribute to loss of texture include:

- chip re-orientation so that the height of the chip decreases;
- overspraying, which results in too much bitumen;

- chip embedment as chip is pushed down into the substrate;
- binder rise around the chip;
- chip crushing and breakdown during construction, thus reducing effective chip ALD (over-chipping can also cause this) (see Figure 11-3);
- long-term consolidation (not just post-construction) of the layer caused by the tyre–seal interaction stresses;
- further chip embedment caused by the action of vehicle tyres in periods of high temperature.

12.2.1 Chip Re-orientation

If, after the seal has been designed and constructed correctly, higher than expected traffic volumes occur, flushing could be the expected failure mechanism at the end of its design life. This means the seal will flush in the wheelpaths before the binder has hardened and leads to texture loss by chip embedment, wearing of the chip, etc. (see discussion in Section 4.3).

12.2.2 High Binder Application

Premature flushing occurs when the binder application is too high for the traffic volume. This can be caused by design or construction error. It can also occur where the existing surface varies in texture or hardness.

To avoid flushing in wheelpaths the seal design often has to be a compromise between an application rate that suits the wheelpaths, with some possible chip loss elsewhere (between and outside the wheelpaths), and an application rate that suits most of the road. There is some discussion on this topic in Section 9.4.5. Controlled trafficking during the first few days can be used to compact chip on areas outside wheelpaths, discussed briefly in Sections 9.10.3.3 and 11.4.1. Early chip loss can be repaired relatively easily but a flushed surface is more difficult and expensive to repair. Chapter 9 discusses the design philosophy for such situations.

12.2.3 Chip Embedment

Soft substrate and chip embedment are regular causes of flushing and so are taken into account in seal design (Section 9.4.1).

If chip embedment is greater than normal, it may be caused by presence of softer substrates associated with:

- first coat seals;
- fresh asphaltic concrete;
- new grader-laid asphalt, or OGEMs (open graded emulsion mix);
- repairs to poorly constructed and weak pavements, or poorly constructed repairs;
- a pavement weakened by water;
- a pavement flushed with a binder-rich surface;
- a soft pavement caused by build-up of successive seals with an excess of bitumen >12% by weight.

An outline of the effects of soft substrate is given in Section 4.7.4.1.

12.2.4 Binder Rise

Binder rise is a natural action which occurs over the life of a chipseal and can cause flushing and bleeding (Figure 12-1). Some researchers believe that the chips are pushed into the binder rather than the binder rises over the chips. In fact both can happen.

Figure 12-1 Small holes are evidence of binder rise through the action of vapour venting (volcanoes) (see also Figure 4-20).
Photo courtesy of Les McKenzie, Opus

Read Section 4.7.4 and its subsections which describe the principal causes of binder rise and how it leads to flushing.

12.2.5 Flushing

> Flushing occurs as a result of high binder rise and reduces the macrotexture of the road surface until it is so low that it meets one or more of the definitions of flushing given in Section 3.11.6.

If flushing is left untreated:

- safety issues associated with low macrotexture can arise, e.g. extended braking distances in the wet at speed (as discussed in Section 4.9.3.1);
- when the flushed binder has low viscosity in hot weather, bleeding and tracking (Figure 12-2) with associated safety issues can occur (as discussed in Section 12.2.6 below);
- further binder rise can occur, exacerbating the above problems and requiring costly repairs.

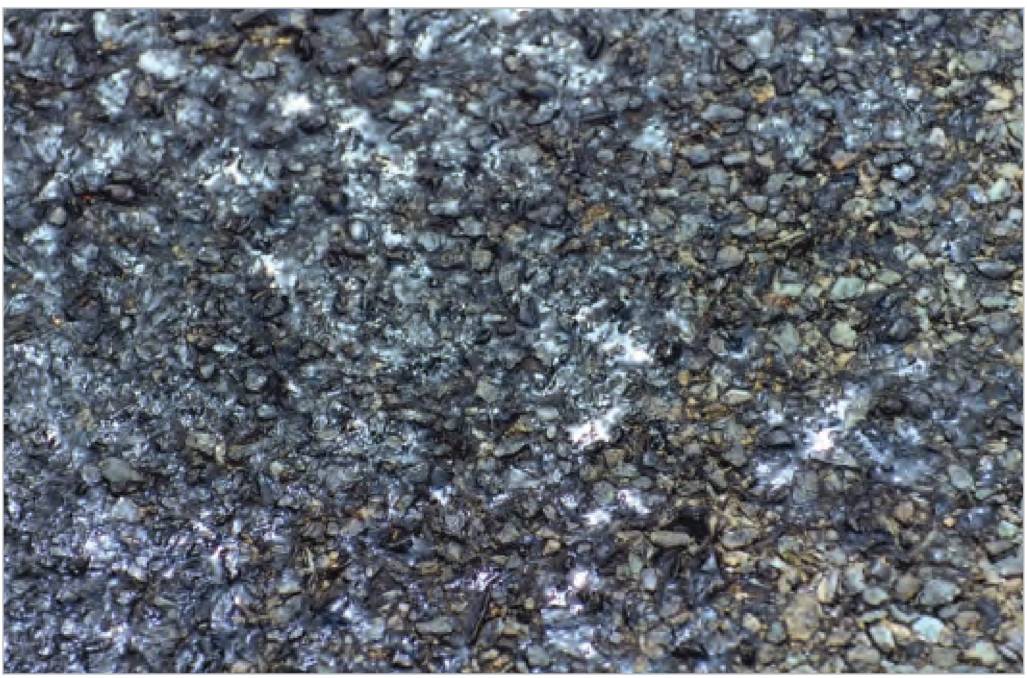

Figure 12-2 Bleeding in progress. Photo courtesy of Mark Owen, Transit NZ

12.2.6 Bleeding

As mentioned above, and discussed in Section 3.11.7, binder rise can result in bleeding (Figure 12-2) which occurs when the surface tension of the binder is broken and tracking can occur (Figure 12-3).

The pavement need not be flushed in order for it to bleed as truck tyres indent up to 1.5 mm into a seal as shown in Figure 9-12, and discussed in Section 9.9.3.3. This mechanism helps to explain why a seal with a good texture can suddenly blacken because binder has been picked up from a surface of seemingly high texture.

It is important to note that a flushed surface may not bleed if the binder is hard enough, the temperature is cold enough, or the binder is contaminated with fines from the road surface.

Figure 12-3 A surface showing both bleeding and tracking on a hot summer day, possibly caused by an old repair patch. This has caused the current chipseal to flush and bleed.

Photo courtesy of Les McKenzie, Opus

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If bleeding is not treated promptly,

- tracking occurs with associated safety issues (e.g. low skid resistance because the microtexture is masked);
- extensive damage to the seal may occur (e.g. heavy or slow moving vehicles have been observed pulling out tyre-width sections of seal, sometimes down to basecourse depth);
- the blackened surface absorbs heat, and will become hotter than the original seal by 10°C or more. This hotter surface can exacerbate the problem leading to widespread bleeding along the pavement.

12.3 Chip Loss

Repairs are essential for a new seal that shows areas of chip loss, to retain seal integrity and to prevent the areas from expanding into a major surfacing problem.

Surplus chip from chip loss by stripping becomes a safety issue and can result in loss-of-control crashes, broken windscreens, injury to the general public from flying chip, and general damage to other road users.

12.3.1 Causes of Chip Loss

Chip loss can occur for a number of reasons which are listed here.

- Low binder application rates.
- Traffic stress, e.g. from high speed, turning, high volumes, or increased heavy traffic volume during the seal's life.
- Cold weather affecting binder characteristics, e.g. sealing in late summer, cold overnight temperatures.
- Wet weather affecting binder characteristics during and after sealing.
- Lack of diluent or adhesion agent.
- Sealing over poorly constructed pre-reseal repairs.
- Cold binder.
- Fretting of the upper chip layer of a two coat seal.
- Dirty chip (Figure 12-4).
- Binder oxidation.
- Stop-start traffic, particularly on up or downhill sections of roads, e.g. rubbish trucks on urban streets.
- Heavy braking and acceleration.
- Scuffing, e.g. using power steering in parking lanes.

Figure 12-4 Chip loss caused by dirty chip in the seal. Photo courtesy of Les McKenzie, Opus

12.3.2 Types of Chip Loss

The three main types of chip loss are:

- Stripping, which occurs generally along wheelpaths, in long strips.
- Attrition, in which the chips are worn away by friction.
- Scabbing, which is chip loss from patches of chipseal.

Some chip loss occurs soon after construction and is related to construction deficiencies, e.g. dirty chip, lack of adhesion agent, excess traffic speeds during or soon after construction. Further chip loss can occur during normal service or if rain falls immediately after sealing.

12.3.3 Extent of Chip Loss

Chip loss or stripping can range from light chip loss between wheelpaths and on the centreline to extensive loss across both traffic lanes.

Once chip loss starts it can increase very rapidly because of lack of support from the surrounding chips. Once the shoulder-to-shoulder lock has been broken, the remaining chips tend to break away along the edges and this can rapidly deteriorate into wholesale stripping (Figure 12-5), leaving a very slick surface of exposed binder with low skid resistance.

Figure 12-5 Chip loss can occur within 48 hours after chipsealing. Photo courtesy of Les McKenzie, Opus

12.4 Other Failure Modes

Most practitioners generally accept that the most common failures following a reseal are either flushing, bleeding or chip loss. Other types of failures, not necessarily in order, can be:

- Chip rollover (including damage from power steering).
- Streaking caused by binder applied too cold.
- Delamination of PMBs and first coats constructed in winter.
- Potholing.
- Cohesive and adhesive failures.

Causes of these failures include:

- Construction faults, such as blocked jets and height of spraybar which cause irregular streaky application of the bitumen.
- Failed pre-reseal repairs.
- Poorly repaired digouts and base failures.
- Increase in heavy traffic loading.
- Diluent content too high.
- Low bitumen application rates.
- Shaded cooler areas, e.g. beneath over-bridges, structures, trees, etc.

12.5 Remedial Treatments

For future reseals, and to eliminate as many of the failures outlined in Sections 12.2 and 12.3 as possible, finding out why a new seal has failed and then choosing the correct method to repair the problem is very important.

> The design life of repairs should at least equal the design life of the original seal coat. But preventing the problem is better than having to treat it. For example, if the failure mode is a flushed or bleeding section of seal which is being tracked down the road, the first priority is to treat the source of the problem to prevent further tracking.

It is not uncommon to see a very flushed and sometimes bleeding seal just before the start of a brand new seal that has been tracked on to the new seal. There the additional binder film on the new seal can cause further bleeding and tracking problems.

Stripping or chip loss can be caused by dirty chip which is not necessarily accompanied by binder deficiency.

> Obviously a good seal design for the original seal coat to avoid stripping or chip loss is preferred, rather than repairing a seal.

Good seal design can be achieved by using harder binders where climate permits, minimising diluent content, not sealing in cold temperatures, and if necessary using a PMB. Remember that although using a PMB may prevent bleeding and tracking, it will not prevent flushing. These principles should also be used in deciding the appropriate repair methods.

In determining the appropriate treatment for a flushed area, it is essential to keep in mind the mechanism that caused the problem.

For example, in a flushed pavement, the cause is layer instability if the problem is a high binder:stone ratio (described in Section 4.7.4.2). For this problem, water blasting is not cost-effective and is only a temporary fix. See Section 6.5.5 and subsections for the analysis and treatment of layer instability.

If rain after sealing is the cause of a stripped pavement in which binder is not deficient, a hot-rolled chip may work. But if the cause was dirty chip, then hot-rolled chip may not work because the original binder is probably contaminated with too much dust.

Treatments can be divided into:

- Treatments for localised failures: can include high pressure water treatment, hot chip, diluent and chip, sandwich sealing, wet lock, and small digouts.
- Treatments for area-wide major failures: where significant or severe loss in design life has occurred, repairs can include the use of fabric (geotextile), open graded mixes, granular overlay, digout and replace, and recycling.

These treatments should be expected to restore the integrity of the pavement surface so that subsequent resealing will last at least as long as the normal design life.

Sometimes the expensive fix is more productive than repeatedly using a high risk cheaper option that is likely to fail. If too much binder is present throughout the layers of chipseals, the best option may be to strip off all the seals (i.e. an Area-wide Pavement Treatment (AWPT) discussed in Section 12.7), or recycle the pavement, because under some conditions a surfacing treatment will be all but impossible to get right.

12.6 Treatments for Localised Failures

12.6.1 Water Blasting

Water blasting (high pressure water treatment) was trialled in New Zealand in the late 1990s (Figure 7-11) and has rapidly replaced the pavement burner as a method of removing excess binder and the pavement burner is now banned (see p.250).

The different types of high pressure water treatments that are available are outlined in Section 7.3.4.2.

All high pressure water treatment units are operator-dependent and care should be taken to avoid removing too much binder.

If binder has been pushed up to the surface by vapour pressure and it is then removed, the binder that is left may not be enough to hold the chip, and result in chip loss or loss of waterproofing.

Water blasting cannot be used on first coat seals, and is high risk even with two-coat-as-first-coat seals. There is a certain binder:stone ratio above which water blasting will not be effective (see Section 6.5.5.3).

12.6.2 Gritting

In the past, common practice has been to lay grit or sand on a flushed chipseal. This is no longer encouraged as field observations have regularly shown that the sand fills the voids between the chips, pushing the bitumen even higher, and making the flushing worse.

For example, Figure 7-12 shows a flushed surface which has been aggravated by gritting (on the left of the photo). A depth of about 5 mm flushed binder was successfully removed in this case by high pressure water treatment, restoring the texture as shown on the right of the photo.

12.6.3 Hot Chip Treatment

The hot chip technique can only be used to treat localised areas where chip loss has occurred, and is usually used when the binder is still soft and a bond can be easily obtained. As such it can be used for the early treatment of construction faults. An advantage of this system is that less diluent or cutter is needed which minimises the risk of future flushing.

Hot chip (often precoated) is obtained from a hot mix asphalt plant. The production temperature depends on the haul distance between plant and job but is normally in the range of 160–190°C. If the chip is precoated the temperature should not be allowed to rise above about 170°C. Above this temperature the precoating bitumen could oxidise too rapidly and, if kept at such high temperatures, the equivalent of 1 to 2 years ageing can occur in a matter of hours.

If uncoated hot chip seems to have a significant quantity of dust, and even though the chip may have a high cleanness value, the dust source could be the hot mix asphalt plant. If so, the plant must be checked to ensure that the drum or pug mill have been well cleaned.

Hot chip can be used by itself (without binder) when enough excess binder remains on the road. However it will not work where the in-situ binder, although enough, is contaminated with fines.

Hot chip can also be used with an application of binder, usually with cutback, or an emulsion binder. In some circumstances emulsion could be the preferred choice as it is more suited to lower application rates than hot bitumen. If extra binder is applied, use only the minimum required so that the repair does not flush as a result of excess binder.

For hot chip, the choice of chip grade depends on the existing underlying chip, traffic stress, and quantity of excess binder. Grades 4, 5 or 6 can be used where no extra binder is required. To ensure full embedment of the chip into the binder, it should always be rolled.

Repair of chip loss on older chipseals is covered in Section 7.3.4.1. Another option for repair is diluent and chip, as described below.

12.6.4 Diluent and Chip

The application of a solvent to a flushed seal or to a seal that is showing chip loss, and then applying chip, is a technique that has been widely used in New Zealand as a localised treatment. The choice of solvent has often been kerosene, as mineral turpentine has a lower flash point and is thus a greater safety hazard. The application rate of the solvent is usually between about 0.1-0.3 ℓ/m^2, and can be applied with a sprayer (Figure 12-6). Adhesion agent may also be required in the solvent mix.

When using diluent and chip, the size of the chip is typically two grades finer than the existing chip (see Figure 12-7). The chip chosen will depend on the quantity of excess binder, and the size of the underlying existing chip. The aim is to get the chip to lock between the existing chips. Grades 4, 5 and 6 are the most common sizes used although Grade 3 has been used at some sites. To improve the success rate of this process precoated chips should be used.

Figure 12-6 Solvent (e.g. kerosene) being applied before it is covered with chip.

Photo courtesy of Mark Owen, Transit NZ

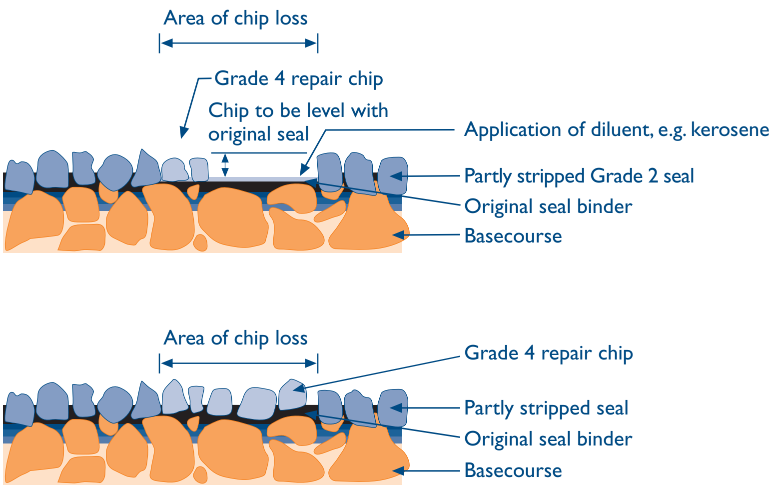

Figure 12-7 Repair of chip loss using diluent and chip.

Diluent and chip should be applied when the air temperature is at least 18°C, and preferably in sunny weather, to ensure that the pavement temperature is as high as possible.

This treatment should be regarded as a relatively high-risk temporary treatment because chip loss can occur. It can also be regarded as a texturing treatment before a reseal. The newly spread chip should always be rolled.

Care needs to be taken in choosing this treatment when any evidence is seen of past flushing. Adding kerosene to the surface modifies the viscoelastic properties of the binder near the surface, and not all the kerosene evaporates off. This could mean acceleration or exacerbation of longer term flushing problems in future surfacing treatments.

12.6.5 Sandwich Sealing

Sandwich seal treatment is appropriate for areas that have flushed through trapped water vapour pressure or chip embedment. It can also be used in place of a texturiser and reseal if the underlying chipseals are stable. It is not advocated for use where the underlying chip seals are unstable.

The sandwich seal technique originated in France and has been used in New Zealand (especially the Napier region) since 1995. It essentially consists of the following construction sequence:

1. large chip (lowest layer);
2. binder;
3. small chip (in surface layer).

Depending on the site a light tack coat of binder can be applied before the first chip. As the binder application rate is only approximately 2/3rd of the binder used for a conventional two coat seal, a sandwich seal (Figure 12-8) has the capacity to absorb excess binder that may exist in the failed seal. Although some seals have used a PMB, successful treatments have been constructed with 80/100 and 130/150 penetration grade bitumens. This design is discussed in Sections 3.7.10 and 9.7.3.

Sandwich sealing has also been used successfully on areas of high stress. As most major roading contractors are now familiar with the technique it can be regarded as a proven treatment but it depends on the design application rate of binder for its success. This system has also been used successfully in the South Island for flushing in wheelpaths.

Figure 12-8 The three layers of a sandwich seal are shown part way through construction.

Photo courtesy of Laurence Harrow, Opus

12.6.6 Wet Lock

This chipseal system can be used when a single coat seal is showing signs of chip loss, particularly early in its life, and is exhibiting signs of wheelpath stripping. It essentially consists of a light seal coat of cutback or emulsion (plus adhesion agent if required) combined with a sealing chip that is one or two sizes smaller than that of the original seal coat.

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Care needs to be taken with the application rate used for a wet lock to avoid flushing. For example if using a Grade 5 chip, the residual binder application rate would be expected to be somewhere between 0.5 ℓ/m² and 0.8 ℓ/m².

Binder enrichment coats may be an option for older seals where the binder is hardening and chip loss is starting, especially if traffic has increased since it was first constructed.

12.6.7 Removal of Remaining Chip

In an extreme case of stripping where a high percentage of chip has come off, the removal of the remaining chip by grader or similar means should be considered, and a new seal should be designed that makes allowance for the residual binder that will be present.

12.7 Treatments for Major Area-wide Failures

12.7.1 General

Details of most of the treatments listed below are supplied in Chapter 7 and other chapters. However, for information and assistance in decision making, a brief outline is given here as well.

12.7.2 Use of Fabrics

A fabric (or geotextile) can be used on a flushed surface. As the fabric has the ability to absorb binder, estimating the quantity of binder to apply so that the binder is sufficient to hold the chipseal as well as to saturate the fabric is very difficult.

The procedure (see Figures 3-25 and 3-26) is to:

- design an application for a tack coat that will account for the excess binder on the existing flushed surface;
- reduce the application rate if appropriate to allow absorption of the excess binder;
- apply the tack coat over the existing surface;
- apply fabric;
- apply new seal.

The problem to be avoided is reducing the binder rates too much so that insufficient binder is available to hold the new seal. In such cases, the chip would be expected to be lost at the beginning of winter.

The design for fabric (geotextile) seals is outlined in Chapter 9 and described in Chapter 3. Some local authorities are reporting success with the technique, but further research is required before it should be regarded as a useful treatment.

12.7.3 Open Graded Mixes

Open Graded Mixes, e.g. Open Graded Porous Asphalt (OGPA), are a very effective technique for the treatment of flushed areas (Figure 3-23). They are however relatively expensive. Of the mix types that are readily available, the TNZ P/11 high strength 'HS mix' would be the most appropriate.

TNZ P/11 HS mix is a 14 mm maximum-size mix with about 15% air voids. When laid to 25 mm thickness, a void capacity of 3.75 ℓ/m^2 will result, which is well in excess of the capacity required for absorbing excess binder. The resulting surface texture is appropriate for high-speed areas requiring high macrotexture depths.

The grading of the HS mix is denser than the other materials in the TNZ P/11 specification and has been found to be resistant to high traffic stresses. This material could be expected to have a life of at least 10 years. A point to note is that the drainage capacity of the Open Graded Mix (OGM) will not function fully because the voids are filled (or partially filled) with excess binder from the underlying flushed surface.

12.7.4 Granular Overlay

A granular overlay is a layer of granular material (particle size greater than 0.6 mm sand according to TNZ M/4 specification), constructed on top of an existing pavement (to improve its shape or increase its strength). A new first coat seal is then constructed on top of the granular overlay.

In an extreme case where a seal has failed because a build-up of multiple seal layers has resulted in an unstable layer, a granular overlay (designed in accordance with Austroads 2004) as an area treatment may be a cost-effective option.

12.7.5 Dig Out and Replace

Where foundation or shallow shear failures occur following a new reseal, dig out and replace should be considered. This is the best option as it removes the problem. Stabilisation (Austroads 1998) is another option but if the available material is already weak the repair will probably fail again.

12.7.6 Recycle

This technique has been developed in the Hawke's Bay region and is advocated for use as an area treatment where multiple seal coats have developed layer instability (Figure 12-9). The Hawke's Bay experience suggests that, where the volume of bitumen in multiple seal layers is >12% and the build-up of seals exceeds 40 mm thickness, then the pavement can have low shear strength and shallow shear can be experienced.

Figure 12-9 Recycling a multiple chipseal that has developed layer instability.

Photo courtesy of Gordon Hart, Transit NZ Napier

However, trigger points for layer instability have been shown by research (Gray & Hart 2003) to be different in different regions. Therefore it is important to investigate and establish layer instability trigger points for the roads locally (see also Section 6.5.5.3).

The recycling technique consists of:

- milling the seal coat and the flushed seal layers;
- milling the underlying basecourse, if necessary;
- incorporating cement;
- adding extra aggregate if necessary.

The treated material is then:

- re-laid;
- compacted; and
- sealed.

A full description of the technique is available in Austroads *Asphalt Recycling Guide* (1997).

Depending on the availability of aggregate in some areas, a granular overlay can be more cost-effective than recycling. This is the case for many South Island roads.

Sometimes the 'Do nothing' option can be taken because its minimum impact is better than a remedial treatment which could worsen the situation. The best approach is to consider each area case by case.

12.8 Reseals at Short Notice

12.8.1 General

One of the purposes of a Pavement Management Strategy (PMS) is to ensure that the RCA (Road Controlling Authority) receives an early warning of a possible need for a reseal, allowing time for adequate preparation, investigation and design. In spite of this precaution, in a few circumstances an unscheduled reseal may need to be carried out at very short notice. These are described below.

12.8.2 Unscheduled Skid Resistance Restoration

Many RCAs have a system of regular inspections and monitoring of the skid resistance of their roads. The most heavily trafficked roads are more likely to suffer from reduced skid resistance and the likelihood of crashes occurring on them is greater. These roads are generally checked annually, but the RCA may choose a reduced frequency for minor roads. This system should give plenty of warning of potential loss of skid resistance.

However should the system fail for whatever reason, and an old surface is below the Threshold Level of skid resistance (as defined in TNZ T/10:2002 specification), prompt action is essential.

Transit's policy on rectifying low skid resistance is contained in TNZ T/10. All RCAs should have their own formal policy on how to identify low skid resistance, and the Austroads *Skid Resistance Guide* (2005) provides advice on developing a Skid Resistance policy. Research is currently being undertaken on skid resistance measurements which may have an effect on these policies.

Note however that a simple reseal is not necessarily the automatic solution to a skid resistance problem. Repairing problems as identified by SCRIM do not always need a new reseal. Instead water blasting may be sufficient to remove surface contamination, e.g. from rubber build-up, while water cutting may be used to correct microtexture deficiencies. (The length of time that the microtexture improvement is effective after these treatments is the subject of a current Transfund study.)

12.8.3 Prevention of Progressive Chip Loss

A more common reason for requiring an urgent reseal is the development of chip loss. Chip loss typically occurs either:

- in the first winter after sealing, when the binder is cold and brittle, and the chip has still not been fully compacted by traffic; or
- late in the life of the seal, when the binder is brittle with age, and its volume has been reduced by oxidation.

Initially only a few chips will be missing. The loss of these few chips however seriously weakens the shoulder-to-shoulder bracing of the chips, which is as important as the grip of the binder in holding the chip in place. The result is more chip loss that further weakens the seal. In any road with significant traffic, the whole process can progress from 1% or 2% loss to complete chip loss over half or more of the surface in a matter of weeks or even less.

Maintenance crews must be trained to be alert to chip loss and report it to the asset manager or supervisor. The initial failures may be at a poor seal joint where there is not enough binder, or at some other localised failure, rather than a seal-wide problem. Initial chip loss needs to be checked urgently, and in severe conditions, a reseal may need to be applied within days.

A voidfill may appear to be a good solution and, in fact, will hold together seal areas that are still mostly intact. However if the seal has already suffered significant chip loss, a voidfill cannot improve already bald areas.

Rectification of the bald patches will be difficult and costly and cannot easily be achieved in winter conditions. This is a compelling reason for quick action when the chip loss is first observed in its early stages. Section 7.3.4.1 gives a discussion of the options for rectifying these problems.

12.9 Conclusion

Although this chapter is about repairing a chipseal because it has failed, it is also about its re-birth or rejuvenation. Even when a pavement fails, and comes to the end of its life, a rehabilitation or reconstruction is possible which will begin the life cycle of the pavement once again. So, although Chapter 12 may be at the end of this book it is not about an end but rather gives a signal that a beginning is about to start.

12.10 References

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Epilogue

Shear failures (which cause shoving), depressions (or rutting), cracking and potholes will inevitably form as a result of pavement ageing and loss of waterproofing. Pavements are always getting older, and weaker or softer because water is leaking into the underlying layers or is not draining away. Pavements deform, seals crack, letting in more water which accelerates the damage. We will always be completing pre-seal repairs and laying new chipseals. Old chipseals will continue to be resealed, and layer instability will always be a problem to watch for and try to prevent. Old pavements will continue to be ripped up, replaced, recycled, or covered over with an overlay, resetting the pavement's life cycle.

Looking towards the future, one has to ask what do we really know about chipseals and how they perform or fail? Even after reading this book chipseals will still fail for you and you will never know why. Modern traffic is getting heavier which wears out chipseals faster. The economy is growing, leading to more tri-axle and quad-axle trucks on the roads, causing damage to chipseal, especially on corners. New Zealand's tortuous alignment of its roads means chipseals are not appropriate on many corners even in low trafficked areas.

We may be coming to the point where the chipseal is no longer viable on many of our state highways, and in many of our urban areas (but for different reasons). What really are the limits of chipseals? Have we just forgotten the skills once practised by the Ministry of Works crews, and enforced by the sealing supervisors, or are we really working under more adverse conditions for chipseals than ever before? Obviously, chipseals will always have their place in relatively straight sections with low traffic volumes and in rural areas.

Can chipseals be made to work anywhere as some would have us believe? Do we need to work more closely with our safety engineers and traffic designers to improve the alignment of New Zealand's roads so that chipseals can really be used anywhere in the rural environment? Are there other technologies to improve chipseals for the future that we haven't fully explored yet?

Remember that chipseal design is not an exact science. You may have taken everything into account and completed a robust chipseal design, but the surfacing or pavement may still fail on the road for no apparent reason. Don't be upset at such failures, but investigate and find the likely causes of failures, and learn from them.

Always remember, about 15 things can go wrong with a chipseal. Get five wrong and your chipseal may still be OK. But get six wrong and your chipseal will fail.

Always try to use emulsions, if you are in a position to be able to make a decision about it, as they are much kinder on the environment and on the sealing crew!

Use multi-sprayers where they are available, and utilise other techniques to ensure that the correct spray rates are used in the wheelpaths and on low-trafficked shoulders and centrelines.

Develop a positive relationship with your client, your contractor, and your consultant when things are going well. Then you will have a base to start from when you need to solve a problem together. Communicate with your colleagues, your client, your contractors and subcontractors. Many problems in the world could have been prevented if people just talked to each other about them.

To cope with the extreme climate experienced in the Mackenzie Basin, South Island, a two coat seal is used on State Highway 80 (with Aoraki/Mount Cook and the Southern Alps in the far distance). Each step of the process is visible: in the centre of the road is a narrow strip of the first layer of bitumen, to its right are the first layer of chips, and then the second layer of bitumen. The second layer of chips is in the process of being spread. Photo courtesy of Lindsay Roundhill, Opus

Glossary

See also list of Abbreviations and Acronyms on pp. xiv-xv.

Note. The following interpretations of terms apply to chipsealing, irrespective of any meaning the words may have for other topics.

Entries in CAPITALS are defined further as a separate entry.

Entries in *italics* are alternative terms that are not defined further.

A

AADT (annual average daily traffic): the total yearly traffic volume in both directions divided by the number of days in the year, expressed as vehicles per day (vpd).

ABRASION: the wearing away of the surface of an aggregate by mechanical action, including trafficking.
Los Angeles Abrasion Test: a test of resistance to abrasion offered by an aggregate under specified conditions.

ABSORPTION: the process of water molecules penetrating the interior of an aggregate particle.

ABUTMENT: an end support of a bridge or similar structure.

ADDITIVE: any substance which is added in small amounts to impart some particular property, e.g. to improve adhesion, lower the viscosity, or modify the end properties.

ADHESION: the action by means of which a fluid substance, e.g. a bituminous binder, sticks to the surface of a solid body, e.g. chip. It arises through intermolecular attraction between the contact surfaces.

ADHESION AGENT: any substance which is added in small amounts to bituminous materials to improve adhesion of the binder to aggregate in the presence of water. May also be referred to as an *Anti-stripping Agent.*

ADSORPTION: the attachment of a substance to the surface of a solid, such as an aggregate particle, by molecular attraction, e.g. condensation of water on a chip surface.

AGGREGATE: a general term for discrete mineral particles of specified size or size distribution, e.g. crushed rock, slag, gravel and sand.
Size may be: COARSE aggregate for material retained on the 4.75 mm sieve; or
FINE aggregate for material passing the 4.75 mm sieve. Also called CHIP.

AGO (*Automotive Gas Oil*): a petroleum distillate used to FLUX bituminous materials. Colloquially known as *Diesel Fuel*.

AIR VOID: see VOID.

ALIGNMENT: the geometric form of the centreline, or other reference line, of the CARRIAGEWAY with respect to the horizontal or vertical axes.

ALLIGATOR CRACKING: see CRACKING.

ALLUVIUM (n); ALLUVIAL (adj.): material (gravel, sand, silt) which has been carried by water and deposited where the water velocity was insufficient to keep it moving. In roading, *alluvial aggregates* usually refer to rounded river-borne aggregates.

ANIONIC EMULSION: a bituminous emulsion which has a negative charge conferred on each bitumen droplet.

ANISOTROPIC: having properties that vary in different directions.

ANTI-FOAM AGENT: a substance, e.g. silicone oil, which when added to a bitumen will reduce surface tension and hence reduce frothing tendency of hot bitumen in the presence of water.

ANTI-STRIPPING AGENT: see ADHESION AGENT.

AP, ALL PASSING; PAP, PREMIUM ALL PASSING: aggregate that passes through certain sized sieves.

APPLICATION RATE: For BINDER, the amount of material applied to a given area of road surface, expressed in litres per square metre (ℓ/m^2). For CHIP, application rates are traditionally specified in terms of area per volume (m^2/m^3).

AQUAPLANING: a condition occurring on a wet road surface where the tyres of a moving vehicle lose contact with the road surface and ride on a film of water. Vehicular control is lost. Also known as *Hydroplaning*.

AREA-WIDE PAVEMENT TREATMENT (AWPT): usually refers to structural pavement treatments applied to substantial lengths of roads, including large areas requiring DIGOUT and replace, or RECYCLING.

ARTERIAL ROAD: a road that carries predominantly through-traffic from one region to another, and is a principal avenue of communication for traffic movements.

ASPHALT: a natural or manufactured mixture in which bitumen is associated with inert mineral matter.

ASPHALT (HOT MIXED); ASPHALT CONCRETE: see ASPHALTIC CONCRETE.

ASPHALT PLANT: see MIXING PLANT.

ASPHALTENE: a constituent of bitumen soluble in carbon disulphide, but insoluble in a selected paraffin hydrocarbon solvent such as n-heptane.

ASPHALTIC CONCRETE: a mixture of bituminous binder and aggregate with or without mineral filler produced in a mixing plant. It is delivered, spread and compacted while hot, for use in road construction. Also known as *Asphaltic Concrete Surfacing*.
Where an asphaltic concrete is applied over existing chipseals, or constructed directly over a new chipseal, the chipseal is called a MEMBRANE SEAL and acts as waterproofing beneath the asphalt layer.

ASSET MANAGEMENT: the application of engineering, financial and management practices to optimise the LEVEL OF SERVICE of an asset, such as a road, in return for the most cost-effective financial input.

ASSET MANAGEMENT SYSTEM: see PAVEMENT MANAGEMENT SYSTEM (PMS).

ATTERBERG LIMIT(S): set of arbitrarily defined boundary conditions in a material, e.g. SOIL, related to water content.

- LIQUID and PLASTIC LIMITS – define the water contents at which a material passes from liquid to plastic state, and from plastic to semi-solid state.
- SHRINKAGE LIMIT – the water content below the Plastic Limit when no further change in volume (shrinkage) will take place.
- PLASTICITY INDEX – the numerical difference between the values of the Liquid and Plastic Limits of a material.

ATTRITION: the wear of chip used for roadmaking. It is measured by the *Micro-Duval Attrition Test*, in which pieces of chip are placed in a closed cylinder, rotated for a given time, and the loss of weight caused by wear is recorded.

AVERAGE GREATEST DIMENSION (AGD): the average of the greatest dimension of a sample of chips, aligned in their greatest dimension.

AVERAGE LEAST DIMENSION (ALD): the average of the least dimension of a sample of chips. The least dimension of a chip is the distance between two parallel plates in contact with the chip when the chip is placed so that the distance is a minimum.

AXLE LOAD: the load applied to a pavement by a single axle.

B

BACKFILL: (noun) fill placed in an excavation.

BALLAST: broken stone of about 100 mm diameter used as a foundation course.

BANDAGING: a treatment for narrow cracks less than 5 mm wide. Hot binder is poured on to the cleaned pavement, spread to make a 2-3 mm thick by 75-100 mm wide bandage.

BARRIER: an obstruction placed to prevent access to a particular area, e.g. prevent vehicles leaving a road.

BASE: the base represents the uppermost structural element of a pavement and can either be asphaltic concrete or basecourse. See BASECOURSE.

BASECOURSE:

- One or more layers of material usually constituting the uppermost structural element of a pavement and on which the surfacing may be placed. It may be composed of fine crushed rock, natural gravel, broken stone, stabilised material, asphalt or Portland cement concrete.

- A graded aggregate used in such a layer.

BATCH: a quantity of materials mixed at the same time.

BATCH PLANT: see also MIXING PLANT. Equipment used to measure by mass or volume the quantities of various ingredients to make up each complete charge for an asphalt mixer.

BATTER: the uniform side slope of walls, banks, cuttings, etc. The amount of such slope or rake, usually expressed as a ratio of horizontal to vertical, distinct from GRADE.

BENCH: a ledge cut or formed in the batter of a cutting or natural slope to provide greater security against slips.

BENEFIT/COST RATIO (BCR): a ratio of the present value of economic benefits derived by the community from transport system improvements over the present value costs of those improvements.

BENKELMAN BEAM: an instrument for measuring the deflection of the surface of a pavement caused by the passage of a dual-tyred single axle carrying a standard axle load.

BERM:
- A grassed area between the kerb and footpath or between the footpath and boundary.
- The shoulder of a road.
- A narrow shelf, path or ledge formed typically at the top or bottom of an earth slope.
- A mound on the outer edge of a road above a fill batter to protect the batter from erosion.

BIND (verb)**:**
- To hold or stick aggregate together in a mass.
- To fill the interstices of small stones or coarse gravels with finer material to provide mechanical and physical binding.

BINDER: a general term for a viscous material used to hold solid particles together as a coherent mass (e.g. bitumen, clay). In a chipseal, it is the waterproof adhesive viscous material that binds to both the existing road surface and the sealing chips of the chipseal as a cohesive mass.

BINDER RISE: a natural action which occurs during the life of a chipseal that can cause flushing and bleeding.

BITUMEN: a viscous liquid or a solid, consisting essentially of hydrocarbons and their derivatives, which is soluble in trichloroethylene. It is almost non-volatile and has thermoplastic properties, i.e. it softens gradually when heated and hardens when cooled. It is black or brown in colour, and has waterproofing and adhesive properties. See also RESIDUAL BINDER.

BITUMEN BURNS CARD: a yellow card which gives the correct treatment for bitumen burns. It is attached to the victim when they go to the doctor or hospital in order to alert medical staff to the special treatment required.

BITUMEN DISTRIBUTOR: see DISTRIBUTOR.

BITUMEN EMULSION: a liquid in which a substantial amount of bitumen or bituminous binder is dispersed as fine droplets (the DISPERSED PHASE) in water (the CONTINUOUS PHASE), and stabilised by means of one or more emulsifying agents. It is available in two basic types, CATIONIC and ANIONIC, and in several grades (*Quick Break, Slow Break, or Stable Grades*), according to the rapidity of BREAKING (*setting*).

BLEEDING: the extrusion of a bituminous binder onto the road surface, generally in hot weather. It is distinguished from FLUSHING, which is a solid smooth surface caused by binder rise that may be the end result of Bleeding.

BLIND: (verb) to spread a thin layer of suitable material to absorb excess binder or to assist in remedying a slippery or loose condition, or to fill excess surface voids.

BLOCK CRACKING: a pattern of cracking of a pavement surface which appears as a series of connected rectangles.

BLOWN BITUMEN: bitumen produced by hardening the distillation residue of a crude petroleum by blowing air or steam through it at elevated temperatures.

BOIL OVER: The rapid increase in volume caused by the presence of water in hot bitumen and the subsequent overflow of bitumen from a tank. May be called a *Foam Over*. See also FLASHING.

BONY: lacking small particles; particularly on the surface of an unsealed road surface or shoulder.

BOULDER: a rounded or sub-angular stone or piece of rock of large size, usually larger than 300 mm.

BOUND MATERIAL or PAVEMENT: granular material with particles bound together by bitumen, cement, lime, fly ash etc., to improve the strength and stability properties of the aggregate.

BPN (BRITISH PENDULUM NUMBER): units of surface friction measured by the BPT.

BPT (BRITISH PENDULUM TESTER): device for measuring the surface friction or SKID RESISTANCE of a pavement surface.

BREAKING: separation of particles of bituminous binder (the DISPERSED PHASE) from the water (the CONTINUOUS PHASE) in a BITUMEN EMULSION, to form a continuous film. When this occurs, the colour changes from brown to black.

BRIDGE: a structure designed to carry a road or path over an obstacle by spanning it.

BROOM: a device for sweeping (used for *Brooming*) to:

- remove dust and loose foreign material before spraying a chipseal;
- uniformly distribute aggregate that has been spread inconsistently;
- remove loose aggregate from completed chipseal.

BULK DENSITY: the mass of material (including solid particles and contained water) per unit volume including voids.

BUND: watertight wall designed to contain any liquids accidentally escaping from tanks, drums or other equipment caused by leaks, damage or incorrect operation.

C

CALCINED BAUXITE: a very high PSV (high skid resistance) chip produced by heating bauxite ore in a kiln. Applied as a high skid resistance road surfacing using epoxy or polyurethane as a binder.

CALIFORNIA BEARING RATIO, CBR: a ratio expressed as a percentage between a test load and a standard load. A standardised testing procedure (initiated by Californian State Highways Department in 1929) for comparing the strengths of basecourses for roads (and airfields).

CAMBER: the transverse convexity given to the surface of a carriageway or footway.

CAPACITY: the maximum rate of flow at which persons or vehicles can reasonably be expected to traverse a point or uniform segment of a lane or road during a given period of time under the prevailing road, traffic and control conditions.

CAPE SEAL: a two coat seal in which the first coat is a chipseal, and the second coat is a slurry seal applied soon after (within 1-2 weeks) to fill the texture of the chipseal.

CAPPING LAYER: a layer of material placed on the road bed to provide a working platform for construction equipment, and not considered to be part of the pavement.

CARCINOGENIC: capable of causing cancer.

CARRIAGEWAY: that portion of a road or bridge devoted particularly to the use of vehicles, inclusive of shoulders and auxiliary lanes. Divided roads are considered to have two carriageways. May be called ROADWAY.

CATCH DRAIN: a surface channel constructed along the high side of a road or embankment, outside the batter to intercept surface water.

CATCH PIT: a concrete pit at the end of a water channel to settle out solids before the flow enters a pipe drain. Also known as a *Gully trap, Mud tank,* or *Sump*.

CATIONIC EMULSION: a bitumen emulsion which has a positive charge conferred on each bitumen droplet. See BITUMEN EMULSION, ANIONIC EMULSION.

CEMENT: a general term for substances that bind aggregates. In concrete work it generally refers to PORTLAND CEMENT.

CEMENT CONCRETE PAVEMENT: a general term for a PORTLAND CEMENT CONCRETE (PCC) rigid pavement.

CEMENT STABILISATION: the controlled application of CEMENT to improve the load-carrying capacity of a pavement layer (usually the BASECOURSE) or the SUBGRADE.

CENTISTOKE: the unit of kinematic viscosity normally used to define binder viscosity. One centistoke (cSt) = 1 mm^2/second. See also VISCOSITY.

CENTRELINE:

- The line which defines the axis or alignment of the centre of a road or other work.
- A marked line on the centre of the carriageway separating opposing traffic streams.

CHANNEL: the drain which accepts water directly from the pavement. See also KERB & CHANNEL (K&C), SURFACE WATER CHANNEL.

CHIP: crushed aggregate of similar size, used for road surfacing, particularly in chipsealing.
Sizes range from 4.75 mm to 19 mm.

CHIP LOSS: loss of chips from a sealed surface.

CHIP ROLLOVER: chip is rolled out of its original position.

CHIP SPREADING: the action of spreading the chip over a binder film which has been sprayed onto the road surface.

CHIPSEAL: a WEARING COURSE consisting of a layer or layers of uniformly sized aggregate or sealing chip, spread over a film of freshly sprayed binder and subsequently rolled into place. Called *Surface dressing* in UK, *Sprayed seal* in Australia.

CLAY: very fine (<75mm) complex silicates formed by the natural decomposition of rocks. It shrinks on drying and expands on wetting.

CLAY INDEX: a measure (%) of the expandable clay minerals in the <75 µm fraction in an aggregate or in a crushed rock powder.

COARSE AGGREGATE: a general term used to differentiate between various sizes of aggregate, usually material retained on a 4.75 mm sieve. Includes Grades 3 and 2 (7.5-10 mm; 9.5-12 mm ALD).

COHESION: the ability of a material to resist, by means of internal forces, the separation of its constituent particles.

COLD MIX: a mixture of bituminous binder, graded coarse and fine aggregate, with or without mineral filler, produced warm or cold in a mixing plant. It is delivered in a workable condition for stockpiling and ultimate spreading and compaction. The mix is spread and compacted cold. Also known as PREMIX.

COMBUSTIBLE: describes a material that, once ignited, is capable of self-sustained burning in air.

COMPACTION: the process of reducing the volume of a material by inducing packing of its particles to increase the density or reduce content of air voids, by *Rolling, Tamping* or other mechanical means.

CONDITION: a quantitative description of the condition of an asset, often expressed through the results of a survey of pavement defects. See also PAVEMENT RATING.

CONSISTENCY: a general term for the physical state of a semi-fluid or plastic material associated with its resistance to deformation or to flow.

CONSOLIDATION: the process by which earth or soil reduces in volume over a period of time usually involving loss of water.

CONSTRUCTION JOINT: a joint made in construction to separate the mass of the work into several portions for convenience of construction.

CONTINUOUS PHASE: the liquid (e.g. water) in which a substantial amount of bitumen or bitumen binder is dispersed as fine droplets (the DISPERSED PHASE) in a BITUMEN EMULSION.

COPOLYMER: a polymer that contains two or more kinds of monomer in the same molecule, e.g. SBS.

CORE: a cylinder drilled out of a pavement for testing purposes.

CORRUGATION: a pavement defect consisting of closely spaced ripples running across the line of traffic, generally where braking and acceleration of vehicles occurs.

COST EFFECTIVENESS: an economic measure defined as the effectiveness of an action or treatment in terms of present worth of life-cycle costs.

CRACKING:

- Alligator cracking (or Crocodile cracking in Australia): small semi-regular polyhedral shaped contiguous areas of cracking.
- Block cracking: a pattern of cracking of a pavement surface which appears as a series of connected rectangles.
- Reflective cracking: visible cracks in the pavement surfacing, caused by propagation of cracks

through to the pavement surface from the underlying pavement layer.

- Longitudinal and Transverse cracking: long cracks that run along or across the road.
- Shrinkage cracking: cracks caused by shrinkage of old bituminous surfaces.

CRACK FILLING; CRACK SEALING: means of filling cracks, usually by BANDAGING.

CREEP:
- Slow natural movement of a material.
- Slow plastic deformation of a material under stress; measured by the *Creep test*.

CROSSFALL: the slope, at right angles to the alignment, of the surface of any part of the carriageway.

CROSS SECTION: a vertical section, generally at right angles to the centreline. On drawings it commonly shows the road to be constructed, or as constructed.

CROWN: the highest point on the cross section of a carriageway with two-way crossfall.

CRUSHED GRAVEL: a gravel in which all or most of the particles have been crushed.

CRUSHER DUST: continuously graded fines remaining after removal of coarser (>5 mm) aggregate from crushed aggregate by screening. Dust or fines produced by crushing gravel or rock.

CULVERT: one or more adjacent pipes or enclosed channels for conveying a watercourse or stream below the formation level of a road.

CURE: to stiffen or harden by evaporation of volatile constituents or by chemical reaction to achieve the desired end state of a material, such as chipseal, emulsion or concrete.

CUT:
- The depth from the natural surface of the ground down to the subgrade level (see also CUTTING),
- To excavate.

CUT-OFF DRAIN: an interceptor drain constructed along the top of a cutting or batter to prevent surface water running down the face.

CUTBACK BITUMEN (or CUTBACK) (noun): a bitumen the viscosity of which has been temporarily reduced by the addition of a volatile diluent (CUTTER), such as KEROSENE, to make it more fluid for ease of application.

CUTBACK (verb): to reduce temporarily the viscosity of a bituminous material by blending it with a volatile material (CUTTER).

CUTTER (Cutter Stock): a volatile distillate added to bitumen to temporarily reduce its viscosity, e.g. KEROSENE, *Turpentine*.

CUTTING:
- The portion of the road where the finished road surface is below the natural surface.
- The addition of a solvent, usually kerosene, to bitumen to reduce its viscosity.

CYCLE PATH: separate carriageway devoted to the use of pedal cycles.

CYCLEWAY: portion of road or footpath devoted to the use of pedal cycles.

D

DECIBEL (dB): a measure of sound. Sound is measured as a ratio of the pressure of the sound waves to the pressure of the quietest sound just detectable by the human ear. A decibel (dB) is $1/10^{th}$ of a Bel. Measures commonly used for levels of sound are L_{eq}, L_{10}, L_{max}.

DECK: the part of a bridge which directly carries traffic loads.

DEFLECTION: the vertical elastic (recoverable) deformation of a pavement surface caused by the application of a load by the tyres of a standard axle.

DEFLECTION BOWL: the depressed shape produced at the surface of a pavement when a load is applied.

DEGRADATION: the wear and breakdown of an aggregate under compaction equipment or while in service, and caused by rubbing or grinding within the mass.

DENSE-GRADED MIX: a bituminous mix made with graded chip, with or without added mineral filler and low in voids. It depends on grading for stability. See also OGEM, OGPA, SMA.

DENSIFICATION: reduction in voids and an increase in dry density of an aggregate.

DEPRESSION: a road defect in which the road surface has sunk.

DESIGN LIFE: the period during which the performance of a pavement or structure, e.g. riding quality, is expected to remain acceptable.

DESIGN PERIOD: a period considered appropriate to the function of the road. It is used to determine the total traffic for which the pavement is designed.

DESIGN PROCESS: process for arriving at a final design for a transport project and normally divided into three distinct phases:

1. *Functional Design:* preparation of the conceptual design with enough detail to ensure that the design will function as intended.
2. *Preliminary Design:* finalised design in terms of calculations, specifications and estimates so that all aspects of the design have been determined. See also PRELIMINARY ENGINEERING.
3. *Documentation:* preparation of plans and documents describing the design sufficiently for it to be constructed.

DESIGN SPEED: a speed fixed for the design of minimum geometric features of a road.

DESIGN TRAFFIC: the cumulative traffic, expressed in terms of EQUIVALENT STANDARD AXLES (ESAs), predicted to use a road over the structural design life of the pavement.

DESIGN VEHICLE: a hypothetical road vehicle whose mass, dimensions and operating characteristics are used to establish design requirements.

DESIGN VOLUME: the number of vehicles expected to use a road, adopted for the purposes of geometric design, normally expressed as the number of vehicles per hour or per day.

DESIGN WATER CONTENT: the highest water content of the subgrade soil likely to be reached for a significant period during the design life of the road.

DESIGN YEAR: the predicted year in which the design traffic would be reached.

DIESEL FUEL: a petroleum distillate used as a FLUX or CUTTER with bituminous materials. Also known as AGO (*Automotive Gas Oil*).

DIGOUT: a pavement repair where soft or defect-ridden pavement is excavated and new basecourse material is added. Either a new first coat seal or a surfacing of hot mix asphalt is applied on top.

DILUENT: A substance which has the effect of reducing viscosity when added to bitumen. See also CUTTER or FLUX.

DIPSTICK: a steel rod for direct measurement of the volume of binder in the tank (or DISTRIBUTOR).

DISCHARGE: the volumetric rate of water flow.

DISH CHANNEL: a channel with a shallow U-shaped cross-section.

DISPERSED PHASE: the bitumen or bitumen binder dispersed as fine droplets in the liquid (e.g. water or CONTINUOUS PHASE) in a BITUMEN EMULSION.

DISTRIBUTOR: also called *Bitumen Distributor* or *Bitumen Tank and Sprayer.* It is built specifically for storing hot bituminous BINDER at the correct temperature for spraying.

DIVIDED ROAD; DIVIDED CARRIAGEWAY: a road having a separate carriageway for traffic travelling in opposite directions.

DRAG: (noun) a simple towed frame used to re-distribute running course over an unsealed surface; (verb) to use a drag.

DRAG BROOM: a towed frame carrying several broom heads, used for levelling or re-distributing sealing chip.

DRAIN: a channel formed at the surface or a culvert, pipe or other similar construction for drainage, for intercepting and removing water.

DRAINAGE: natural or artificial means for intercepting and removing surface or subsurface water (usually by gravity).

DRIVEWAY: a defined area used by vehicles travelling between a carriageway and a property adjacent or near to the road. Also called *Access Way.*

DROP OUT: a road fault where the downhill edge of the pavement has slipped away.

DRUM PLANT or *Continuous Plant*: See MIXING PLANT.

DRY DENSITY: ratio of the mass of dry material, after drying to constant mass at 105°C, to its undried volume. Also the weight of a dry unit volume of a material.

DRYER: a rotating metal cylinder in which aggregates (chip) are dried and heated by an oil or gas burner.

DRY LOCK SEAL: an application of small chip to a new chipseal, usually after some traffic has used the new seal. No binder is applied before spreading the dry lock chip.

dTIMS: Deighton's Total Infrastructure Management System software program used for predictive modelling of road deterioration.

DUCTILITY: the ability of a substance to undergo plastic deformation without breaking.

DUCTILITY TEST: a test to measure the extent to which a standard-sized test piece of bitumen can be elongated under specific test conditions, until it passes a pre-set length or before it breaks.

DURABILITY: the ability of a material to continue to provide the service for which it is intended.

E

EARTHWORKS: a general term to describe all operations involved in loosening, removing and depositing or compacting earth, soil, or rock.

EDGE BREAK: a road failure where the edge of the seal breaks away.

EDGE LINE: a line used to differentiate the outer edge of the traffic lanes from the shoulder.

EDGE RUTTING: a defect where ruts appear at the edge of the seal, usually in the unsealed shoulder.

ELASTICITY: the property of a material in which deformation is linearly related to load and is recoverable.

ELASTOMER: an elastic material such as natural or synthetic rubber, which is added to bitumen to modify its performance as a binder.

elv (EQUIVALENT LIGHT VEHICLES): a concept equating one heavy vehicle to 10 light vehicles or cars.

EMBANKMENT: a construction (usually of earth or stone) to raise the ground (or formation) level above the natural surface.

EMBEDMENT: the action of pushing the chips down into the binder or substrate.

EMULSION: see BITUMEN EMULSION.

ENRICHMENT SEAL: a light application of bituminous binder, with or without a fine cover of chip, for the purpose of increasing the binder content of a road surface. Also called FOG COAT, REJUVENATING SEAL.

EQUILIBRIUM SKID RESISTANCE: the equilibrium level at which skid resistance stabilises. It is reached after polishing by traffic has reduced the initial *Microtexture* (see TEXTURE) and SKID RESISTANCE.

EQUILIBRIUM SCRIM COEFFICIENT (ESC): a correction applied to SCRIM data to adjust for between-year variations in SKID RESISTANCE.

EQUIVALENT STANDARD AXLE (ESA): the number of standard axle loads which are equivalent in damaging effect on a pavement to an 8.2 tonne dual-tyred standard given vehicle or axle loading.

EXCEPTION REPORT: a report on the assets which are performing below the required LEVEL OF SERVICE, and are exceptions to an otherwise compliant road network.

EXPANSION JOINT: a space between two parts of a structure or pavement, formed to allow small relative movements with or without provision of means to preserve functional continuity.

F

FAILURE: a pavement is considered to be in a failed condition when the surface has become distorted to the extent that it is no longer safe for vehicle use.
Chipseal Failure generally relates to either loss of waterproofness of the chipseal, endangering the integrity of the underlying pavement; or loss of chip; or loss of skid resistance through flushing or polishing.

Pavement Failure generally relates to a pavement surface which has become distorted to the extent that it is no longer safe for vehicle use.

FALLING WEIGHT DEFLECTOMETER (FWD): a device to measure surface deflection of a pavement under a dynamic load in order to evaluate its structural adequacy.

FATIGUE: the deterioration of a pavement or a test specimen caused by the action of repetitive loads.

FATIGUE CRACKING: a visible crack in the WEARING COURSE eventually resulting from the propagation of cracks caused by fatigue in the underlying pavement layer.

FATTING UP: the development of a pavement surface containing an excess of bituminous binder or puddle-up fines. A colloquial name for FLUSHING, BLEEDING.

FATTY: containing an excess of binder or puddled-up fines.

FEATHER: to blend an asphaltic concrete patch into the existing pavement surface.

FEATHER EDGE: the surface of the pavement layers between the shoulder hinge point and the subgrade surface.

FILL: see also EMBANKMENT.
- The depth from the formation surface to the natural surface.
- To deposit fill.
- Material that has been deposited in a fill area.

FILLER (MATERIAL): finely ground material, e.g. particles of rock, hydrated lime, Portland cement or other non-plastic mineral matter, predominantly finer than 0.075 mm added to asphaltic mixes or slurries to reduce air voids (by filling) and to stiffen the binder.

FILTER FABRIC: a material which allows water to pass through but prevents the passage of fines; a type of GEOTEXTILE.

FINE: in this book, FINE refers to the smaller chip sizes of Grades 4 (5.5-8.0 mm), 5 (4.75-9.5 mm), and 6 (6.7-15 mm).

FINES (FINE AGGREGATE; FINE CHIP): material passing the 4.75 mm sieve. ATTERBERG LIMIT tests are carried out on soils passing the 0.425 mm sieve.

FINE CRUSHED ROCK: a graded aggregate prepared by crushing rock for use as chip in pavement construction, normally 19.0 to 26.5 mm maximum size.

FIRE POINT: the temperature at which sufficient vapour is given off by a flammable product, under standard test conditions, to ignite and continue to burn. This temperature is slightly higher than a FLASH POINT.

FIRST COAT SEAL: an initial seal on a prepared unsealed surface, which is usually a basecourse.

FLAKY AGGREGATE: particles which have one dimension considerably less than the other two dimensions making them elongated.

FLAME TUBE (FLAME TUBE HEATER): a means of heating bitumen, normally applicable to smaller sized vessels or tanks. It consists of an oil or gas-fired burner in a tube with a flue pipe and the tube is immersed in the product to be heated.

FLAMMABLE: a combustible substance, solid, liquid, gas or vapour, which is easily ignited in air. The term is preferred to *inflammable*. The term *non-flammable* refers to substances which are not easily ignited but it does not necessarily indicate that they are non-combustible.

FLASHING (FLASH OFF): the rapid evolution of vapour from volatile liquids or water.

FLASH POINT: the lowest temperature at which the application of a small flame in a prescribed manner causes a vapour to ignite (flash). The flash point is usually measured using the Cleveland Open Cup Method.

FLEXIBLE PAVEMENT: a pavement consisting of an unbound granular basecourse with a top surface of chipseal or thin AC. The surfacing is less than 45 mm thick. See also RIGID PAVEMENT.

FLUSHED SURFACE: a smooth pavement surface caused by the presence of binder.

FLUSHING: see also BINDER RISE, BLEEDING. Loss of *Macrotexture* (see TEXTURE), either through presence of solid binder high up around the sealing chip, or chip embedment, or chip loss.

FLUX: a relatively non-volatile distillate used as an additive which is blended with bitumen to permanently or semi-permanently reduce the viscosity of the bitumen, e.g. AGO (*diesel fuel*).

FLUXED BITUMEN: a bitumen which has had its viscosity reduced by the addition of a less volatile diluent (FLUX).

FLY ASH: a fine-grained waste product obtained from the combustion of pulverised fuel in power stations.

FOAMED BITUMEN: or *Expanded Bitumen*, is a hot bituminous binder which is temporarily converted to a foamed state by the addition of about 2% (by weight of bitumen) of water in controlled conditions.

FOG COAT: a very light application of binder sprayed onto the road surface over an ageing coarse-textured chipseal. (It is not a PRIME.) Usually the binder is emulsion with low bitumen content. Also called ENRICHMENT SEAL, REJUVENATING SEAL.

FOOTPATH; FOOTWAY: a public way reserved for the movement of pedestrians and manually propelled vehicles (e.g. prams); a pedestrian facility on a bridge.

FORMATION: the surface of the finished earthworks, excluding CUT, FILL or BATTERS.

FORMATION LEVEL: the general level of the surface of the ground proposed or obtained on completion of the earthworks.

FORWARD WORKS PROGRAMME: the principal output of asset management, detailing specific maintenance treatments required for TREATMENT LENGTHS on a road network. It covers the next 10 years as a minimum, but 20 year programmes are common. The *Current Work Programme* is extracted from it.

FOUNDATION: the soil or rock on which a structure rests. Also known as SUBGRADE when under a pavement.

FRETTING: see CHIP LOSS, RAVELLING, SCABBING, STRIPPING.

FRICTION COURSE: an obsolete term for a bitumen aggregate surfacing mix. See OGPA (Open-Graded Porous Asphalt).

FROST HEAVE: The movement of a pavement or soil surface caused by expansion of water freezing within it.

FURNITURE: see ROAD FURNITURE.

FUSION POINT: the temperature at which a substance liquefies, often referred to as a *Melting Point.*

G

GABION: a rectangular wire-mesh cage filled with boulders, used to retain embankments and river banks.

GANGSPRAYER; GANGBAR: see SPRAYBAR.

GAP GRADED: an aggregate or chip with both fine and coarse material but without one or more of the intermediate size fractions. See also SINGLE-SIZED and WELL-GRADED Aggregate/ Chip.

GEOTEXTILE: a synthetic fabric composed of flexible polymeric materials, woven or unwoven, used in geotechnical or general engineering works, for strengthening, for retaining or restricting movement of water or sediment as a filter, e.g. in swamps, or as a strain absorbing membrane (SAM).

GEOTEXTILE SEAL: a seal constructed usually by a light application of binder, over which a geotextile fabric is laid. The fabric is sprayed with binder until it is saturated. Chip is then spread, followed by rolling.

GRADE: has at least 6 definitions.

1. The rate of longitudinal rise or fall of a carriageway with respect to the horizontal, expressed as a ratio or as a percentage. Also called GRADIENT.
2. To design the longitudinal profile of a road.
3. To shape or smooth an earth, gravel, or other surface by means of a GRADER or similar implement.
4. Bitumen penetration grades of 80/100, etc.
5. To arrange aggregates or other material in accordance with particle sizes.
6. A designation given to the size of sealing chips, i.e. Grades 1, 2, 3, 4, 5, 6 (from TNZ M/6 Specification for Sealing Chip).

GRADED AGGREGATE: aggregate having a wide and continuous distribution of sizes from coarse to fine, the largest size being several times larger than the smallest size.

GRADER: a motor-powered wheeled machine with a blade mounted centrally between the axles, used to shape road surfaces.

GRADIENT:
- A length of carriageway sloping longitudinally.
- The rate of longitudinal rise or fall of a carriageway with respect to the horizontal, expressed as a ratio or as percentage (See also GRADE definition 1).

GRADING:
- The operation of cutting and spreading material with a grader (see also GRADE definition 3).
- The particle size distribution of a material (see also GRADE definitions 5 and 6).

GRANULAR MATERIAL: material with a particle size no finer than SAND.

GRASS VERGE: grass area on the side of a road.

GRAVEL: a mixture of non-cohesive mineral particles occurring in natural deposits, generally passing a 75 mm sieve with a substantial portion retained on the 4.75 mm sieve.

GREENFIELD DEVELOPMENT: a development for roads or other structures which begins with a landscape that is in its natural state.

GRIT: fine angular mineral aggregate, usually passing a 4.75 mm sieve.

GROUND LEVEL: the reduced level of any particular point on the surface of the ground.

GROUND WATER: water flowing or lying under the natural surface of the ground; contained in the soil or rocks, below the WATER TABLE.

GROUTING: the operation of pouring or forcing a liquid binder, such as bitumen, into the interstices of a pavement surface, a structure or a natural formation, under the action of gravity or applied pressure. Also used in concrete work.

GUARDRAIL: a rail erected to restrain vehicles which are out of control. Also called ROAD SAFETY BARRIER.

GULLY TRAP: see CATCH PIT.

H

HAIR CRACK: a thin, narrow crevice or fissure running irregularly across the surface of a concrete or clay product, not penetrating deeply.

HAND SPRAYER: spraying equipment which discharges binder through a jet at the end of a hand-held lance.

HARDENING: in the short term, is the increase in viscosity as a freshly sprayed bituminous binder cools or cures. In the long term it is the ageing and oxidising of a bituminous binder.

HARDNESS: the resistance of a rock to scratching or abrasion. Mineralogical hardness is by comparison with an arbitrary reference scale (Moh's Scale of Hardness).
In chipseal design, hardness of an existing seal or substrate is considered because sealing on a soft surface is undesirable.

HAZARD: a physical situation with significant potential for human injury, damage to property, or damage to the environment. An occurrence, process, substance or situation that is an actual or potential cause or source of harm.
Significant Hazard: a hazard that is an actual or potential cause or source of serious harm, or harm which depends on the frequency or extent of exposure to the hazard, or harm which does not occur or is not easily detectable until a significant time after exposure.

HEAVE: upward movement of soil caused by expansion or displacement resulting from phenomena such as moisture absorption, removal of overburden, pile driving or frost.

HEAVY VEHICLE (Heavy Commercial Vehicle HCV): rigid trucks with or without a trailer, or articulated vehicle with at least three or four axles. A vehicle capable of being laden to a gross laden weight exceeding 3.5 tonnes.

HIGH PRESSURE WATER TREATMENTS: a collective term for WATER BLASTING and WATER CUTTING. Jets are used to direct very fine streams of water at the road to restore *Macrotexture* by removing excess binder at the chipseal surface. They have replaced the pavement burner treatment which has been phased out.

HIGHWAY: a principal road in a road system.

HORIZONTAL CURVE: a curve in the plane or horizontal alignment of a carriageway.

HOT MIX ASPHALT (HMA): aggregate and bitumen heated and mixed while hot, transported to the site of construction, laid and compacted while hot. See ASPHALTIC CONCRETE and PLANT MIX.

HOT WORK: work involving flames or equipment which might cause ignition of any flammable vapours present.

HYDRATED LIME: see SLAKED LIME.

HYDROCARBON: a substance composed only of molecules of carbon and hydrogen.

HYDROPHILIC MATERIAL: material (e.g. aggregate) showing a relatively high affinity for water.

HYDROPHOBIC MATERIAL: material (e.g. bitumen) showing no affinity for water.

HYSTERESIS: in the context of SKID RESISTANCE, relates to the contribution of *Macrotexture* (see TEXTURE) to skid resistance through the inelastic deformation of a vehicle tyre, resulting in loss of energy.

I

IGNITION POINT (IGNITION TEMPERATURE): the lowest temperature at which, under standard test conditions, the vapour of a solid, liquid or gas will take fire and continue to burn.

IGNITION SOURCES: accessible sources of heat or energy capable of igniting flammable atmospheres.

IMPERMEABLE: cannot be penetrated by a fluid such as air or usually water.

IMPERVIOUS: relatively waterproof soils, such as clays, through which a fluid, e.g. air or water, cannot percolate or only very slowly.

INERT ATMOSPHERE: a virtually oxygen-free atmosphere, usually of nitrogen or carbon dioxide, used to prevent oxidation or combustion.

INERT MATERIAL: a material which does not exhibit any binding or cementitious properties, or is not chemically reactive.

INFRASOUND: the low frequency component of sound (below 20 Hz).

INITIAL BOILING POINT (IBP): the temperature at which a distillate such as kerosene begins to boil.

IN-LINE BLENDING: blending, usually of diluents with a bituminous binder, by addition of the diluent to the binder while it is being pumped through a pipe.

IN SITU: a material, or operation carried out on a material, in place, e.g. its original position in the field.

INTERCEPTOR DRAIN: a type of side drain that prevents water from flowing towards the road, and is normally sited away from the road.

INTERMEDIATE COURSE: any course between the base- and surface courses.

INTERSECTION: a place where two or more roads cross. Also called *Node*.

INVERT: the lowest portion of the internal surface of a drain or culvert.

ISOKINETIC: having equal rates of movement in all directions.

ISOTROPIC: having properties that are equal in all directions.

J K

JUNCTION: a place where two or more roads meet.

KERB: a raised border of rigid material formed at the edge of a carriageway or pavement.

KERB & CHANNEL (K&C): combined kerb and drainage channel, to capture and discharge run-off.

KEROSENE: a hydrocarbon used as a DILUENT.

L

LAKE ASPHALT: a natural bitumen found in well-defined surface deposits, e.g. Trinidad Lake asphalt.

LANDSLIDE: a movement of the surface of a hillside, generally resulting from natural causes.

LANE: see TRAFFIC LANE.

LANE LINE: a line (usually painted), other than the centreline which divides adjacent traffic lanes.

LATERAL FRICTION: the force which, when generated between the tyre and the road surface, assists a vehicle to maintain a centrifugal path where a road changes direction.

LATEX: a naturally occurring rubber emulsion (i.e. the sap of the rubber tree).

LAYER: portion of a pavement course placed and compacted as an entity.

LAYER INSTABILITY: inadequacy in the structural performance of multiple seal layers, where the combined thickness is greater than 40 mm and more than 12% binder is present in the layer.

LEVEL OF SERVICE: the outcome that the road asset provides for the end user. It may be a fixed standard (and not to be exceeded) or a desirable target.

LIFE: the time (in years) that a road surface remains in service.

LIME MORTAR: a mixture of cement or lime with sand and water.

LIME STABILISATION: the controlled application of lime to improve the load-carrying capacity of a pavement layer (usually the basecourse), or of the subgrade.

LIMESTONE: calcium carbonate, $CaCO_3$, sometimes used as a filler. The material from which burnt lime (CaO), QUICK LIME and SLAKED LIME are derived.

LINE OF SIGHT: the direct line or uninterrupted view between a driver and an object of specified height above the carriageway in their lane of travel.

LINK: the portion of road between two INTERSECTIONS (or nodes).

LIQUID BITUMEN: bitumen which is liquid at 25°C, according to the penetration test.

LIQUID LIMIT: see ATTERBERG LIMIT(S). The moisture content, as a % of its dry mass, at which a material passes from the plastic to the liquid state under specified test conditions.

LIVELY: the state of being workable as applied to premix patching materials; bitumen that is in or on the road surface which still retains its original properties, i.e. will liquefy in hot weather causing bleeding. The opposite of old oxidised inert bitumen.

LOCKED-IN TYPE SEAL: a WET LOCK or DRY LOCK SEAL.

LONGITUDINAL SECTION or PROFILE: the shape of a pavement surface measured as vertical distances from some datum parallel to the traffic. (See also TRANSVERSE PROFILE, CROSS SECTION and VERTICAL ALIGNMENT.)

M

MACADAM: uniformly sized interlocking stones, bound with smaller stone, gravel, etc., which are forced into the gaps by brooming, watering and rolling to form a road surface. The road may be water-bound, cement-bound, or coated with (tar or) bitumen. If the latter it is called *Tarmacadam* or *Tarmac*.

MACROTEXTURE: see TEXTURE.

MANHOLE: see SERVICE HOLE.

MARGINAL AGGREGATE: a local aggregate which does not meet conventional aggregate specifications but is suitable for specific uses in a pavement.

MARKING: any line painted on the road to control traffic movement or parking.

MATRIX: a mixture of binding material and fine aggregate in which larger aggregate is embedded or held in place.

MAXIMUM DRY DENSITY: the dry density of a soil obtained by a specified amount of compaction at the OPTIMUM MOISTURE CONTENT.

MECHANICAL BOND: the bond obtained in a MACADAM or other pavement created by the interlocking of angular fragments of aggregate.

MECHANISTIC ANALYSIS: a design procedure based on stress analysis and on elastic material behaviour in pavements.

MEDIAN BARRIER; MEDIAN STRIP: see ROAD SAFETY BARRIER.

MEDIUM COMMERCIAL VEHICLE (MCV): two-axle heavy trucks without a trailer, over 3.5 tonnes gross laden weight.

MELTING POINT: see FUSION POINT.

MEMBRANE SEAL: a seal composed of straight-run BITUMEN, with little or no CUTBACK, and a light covering of chip. Covered soon after construction with ASPHALTIC CONCRETE.

MICROSURFACING: a surface dressing comprising a specially graded aggregate mixed with a polymer modified emulsion (PME) binder (of 3% maximum polymer). See also SLURRY SEAL.

MICROTEXTURE: see TEXTURE.

MIX: the proportions of ingredients in a batch of concrete or asphalt.

MIXING PLANT (ASPHALT PLANT): equipment used to manufacture hot asphalt mixes.

MODIFICATION: the improvement of properties of a material by the addition of small quantities of additive, e.g. lime, cement, for stabilisation.

MODULUS: a ratio of the stress (force per unit area) to strain (deformation per unit area), expressed in units of stress. It is a measure of a material's resistance to deformation.
For bitumens, the modulus depends on both the temperature and the time the load is applied. In loading conditions that give rise to non-permanent deformations (i.e. material returns to its original dimensions) the resulting modulus is *Young's modulus* (*E*), or the *Modulus of Elasticity*.

MOISTURE CONTENT: see WATER CONTENT.

MOTORWAY: a defined class of road for which certain activities or uses are restricted or prohibited by legislative provision. Also called *Expressway, Freeway*.

MPD (MEAN PROFILE DEPTH) (mm): the measure of texture given by SCRIM+ and Transit New Zealand's STATIONARY LASER PROFILER (SLP).

MSSC: Mean Summer SCRIM Coefficient.

MTD (MEAN TEXTURE DEPTH) (mm): the volumetric patch test using glass spheres of 0.15 to 0.3 mm diameter.

MULTICOAT SEAL: a two coat chipseal, and other chipseals, having more than one layer of chip.

MULTIPLE LANE: a carriageway with more than one traffic lane.

MULTIPLE SEAL: any seal with two or more layers, e.g. TWO COAT, RACKED-IN, and SANDWICH seals.

N

NAASRA: National Association of Australian State Road Authorities; superseded by Austroads.

NATURAL ASPHALT: a naturally occurring bitumen, e.g. Trinidad Lake Asphalt.

NOMINAL SIZE: a designation of an aggregate, chosen to give an indication of the largest sized particle present.

NORMAL CROSS SECTION: the cross section of the carriageway where it is not affected by superelevation or widening.

NORSEMETER RoAR: a machine for measuring skid resistance.

NUCLEAR DENSOMETER: an instrument for the non-destructive measurement of the density and moisture content of pavement layers.

O

OGEM, OPEN GRADED EMULSION MIX: see OGPA for comparable description.

OGPA, OPEN GRADED POROUS ASPHALT: a gap-graded hot mixed asphalt containing a mix of binder and larger sized aggregates with only small amounts of fine material, with relatively high void content, and depending largely on mechanical interlock for stability. It has interconnected voids which aid drainage of road surface water.

OPTIMUM MOISTURE CONTENT (OMC): the moisture content at which a specified amount of compaction will produce the maximum density under specified test conditions.

OVERBURDEN: soil or other material which has to be removed to enable the material beneath it to be quarried or excavated.

OVERLAY: a layer of material constructed on top of an existing pavement to improve its shape or increase the strength.

P

PAH: polycyclic aromatic hydrocarbons.

PAP (PREMIUM ALL PASSING): see AP (ALL PASSING).

PARTICLE SIZE: the diameter of the aggregate or chip particle, i.e. minimum square-hole sieve opening that allows the particle to pass through.

PARTICLE SIZE DISTRIBUTION (psd): the proportion by weight of particles of different sizes in a granular material (aggregate, chip) as determined by sieve analysis. See also GRADE, GRADING.

PATCHING: the repair of depressions, holes or other defective places in a pavement by adding material to restore the surface.

PAVEMENT:

- The portion of the road, excluding shoulders, that is placed above the design subgrade level for the support of, and to form a running surface for, vehicular traffic. It is supported by the subgrade.
- Also used to describe the sealed area of the footpath or other sealed areas.

PAVEMENT DISTRESS: the deterioration of the pavement shown by visible surface defects.

PAVEMENT MANAGEMENT SYSTEM (PMS): a systematic method of information collection and decision making, to permit the optimisation of use of resources for maintenance and rehabilitation of pavements.

PAVEMENT PERFORMANCE: the relationship of serviceability to age of the pavement.

PAVEMENT RATING: a method of systematically describing the condition of a pavement, usually by visual inspection.

PAVEMENT SERVICEABILITY: the measure of the pavement's ability to serve its function at any time.

PENETRATION GRADE: determines the hardness of a roading bitumen by measuring the distance in tenths of a millimetre that a standard needle weighted with 100 g will sink (penetrate) in 5 seconds into a bitumen sample, at 25°C.

PENETRATION GRADE BITUMEN: a bitumen compliant with the required specification and named for its penetration grade. It is produced by vacuum distillation usually, followed in some cases by solvent extraction or a partial oxidation process. Such bitumens are principally used for road surfacing or industrial applications.

PERMEABILITY: the property of an aggregate which permits a fluid, e.g. air or water, to pass through it when subjected to pressure.

PERMIT TO WORK: a document issued by an authorised person or persons permitting specific work to be carried out in a defined area during a stated period of time, provided that specified safety precautions are taken.

PERSONAL PROTECTIVE EQUIPMENT (PPE): includes high visibility vest, hard hat, gauntlet gloves, flame-retardant overalls, boots, and specialist protective equipment appropriate to the job in hand.

PERVIOUS: describes a material through which water can pass.

PITCH: the solid or semi-solid residue from the partial distillation or evaporation of oils from coal tar. (Not to be confused with BITUMEN.)

PIT-RUN GRAVEL: material obtained from a natural deposit of gravel without separation or addition of other material.

PLANT MIX: a general term for mixtures of bituminous binder and aggregate produced in a central mixing plant. See also PREMIX.

PLASTIC LIMIT: see ATTERBERG LIMIT(S). the moisture content, expressed as % of dry mass, at which a material passes from the plastic to the non-plastic state, under specified test conditions.

PLASTIC MATERIAL: a material in a condition when it can be easily remoulded.

PLASTICITY INDEX: see ATTERBERG LIMIT(S). The numerical difference between the values of the LIQUID LIMIT and the PLASTIC LIMIT of a material.

PMB (POLYMER MODIFIED BITUMEN): a bitumen with polymer added, usually up to 5-6% by mass. Polymers tend to reduce the temperature sensitivity of the binder, and some polymers make the binder more elastic.

PME (POLYMER MODIFIED EMULSION): a polymer-modified bitumen that has been emulsified.

POLISHED STONE VALUE (PSV): a measure of how a stone will polish under standard conditions. The PSV test is primarily used to identify aggregates (chip) that will retain their microtexture (i.e. will not polish) under traffic.

POLISHING: the action of vehicle tyres and fine road detritus on road surface chips which smooths the surface.

POLYMER: high molecular weight, usually organic, compound made up of many units, identical to each other (*monomers*), and joined in a regular way, e.g. polypropylene. Some polymers may be used to permanently modify bitumen. Usually polymers provide improved temperature/ viscosity response and/or greater fatigue resistance.
Copolymer: a polymer that contains two or more kinds of monomer in the same molecule, e.g. Styrene-butadiene rubber SBR, Styrene-butadiene styrene SBS.

POLYMER MODIFIED BITUMEN; POLYMER MODIFIED EMULSION: see PMB, PME.

POROSITY: ratio of the volume of voids in a material to its total volume.

PORTLAND CEMENT: an artificial cement as defined in AS 1315. Usually called CEMENT.

PORTLAND CEMENT CONCRETE (PCC): concrete in which the binding material is PORTLAND CEMENT. Usually called *Concrete*.

POTHOLE: a hole in the pavement, frequently round in shape, resulting from loss of pavement material caused by the action of traffic.

PPE: see PERSONAL PROTECTIVE EQUIPMENT.

PRECOATING: coating an aggregate with a bituminous material to improve the rate at which it is wetted, or to improve the adhesion of a bituminous binder.

PRELIMINARY ENGINEERING: work of locating and designing, making surveys and maps, preparing specifications and estimates, and doing other engineering work before letting a contract for construction of a transport project. See also DESIGN PROCESS.

PREMIX: a mixture of bitumen and chip, usually stored in a stockpile and used for patching.

PREP; PREPARATION; PRE-SEAL REPAIR: any activity undertaken in the period up to a year before chipsealing, to prepare the surface for the chipseal, e.g. DIGOUT, CRACK FILLING, lichen removal.

PRETREATMENT SEAL: treatment applied to a surface as a pretreatment, e.g. for reducing texture variance. See also TEXTURISING SEAL.

PRIME; PRIMER; PRIME COAT: a low viscosity, fluid, bituminous material applied to a prepared base without cover aggregate, before the initial application of a seal. Used to improve penetration of the binder into the base surface, to wet any surface dust layer, and to adhere to the stone beneath. Not used often in New Zealand.

PROFILE: the shape of a pavement layer or surface measured in a vertical plane, from a datum, parallel to the traffic flow, or at right angles or transverse to the traffic flow.

PUBLIC ROAD: a public place which has been provided for use by the public for traffic movement and has been declared, or proclaimed, notified or dedicated.

PUMPING: the ejection of water and fine particles in suspension through joints or cracks in a pavement caused by the action of traffic, or by ground water pressure.

Q

QUALITY ASSURANCE (QA): all planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements as to the quality of a product.

QUALITY CONTROL: the operational techniques and activities that are used to fulfil defined requirements for quality production.

QUARRY: an open-surface working from which rock is obtained.

QUARRY DUST or FINES: the finest sized material most of which passes a 4.75 mm sieve, produced from a crushing or screening plant. Also known as CRUSHER DUST.

QUARRY WASTE: reject material from a crushing or screening plant containing a wide range of aggregate or chip sizes.

QUICK LIME: calcium oxide, CaO, used as an additive (with granular form) in soil stabilisation. Also referred to as *Burnt Lime*.

R

RACKED-IN CHIPSEAL: one application of binder and two applications of chip are made in the following sequence:

- A single application of binder is applied, followed by application of a large chip;
- A further application of a smaller chip is made.

The first application of large chip has spaces into which the smaller chip can fall between the large chip, and adhere to the layer of binder below.

RAISED PAVEMENT MARKER (RPM): a device used to supplement or replace traffic lines on the road surface. It may be reflectorised (RRPM).

RAMM (Road Assessment and Maintenance Management system): a computer-based system to manage the maintenance and rehabilitation of pavements and associated roading features.

RAP (Reclaimed Asphalt Pavement): obtained from milling or excavation of asphalt pavements. The crushed and graded product can be added during manufacture and included as a percentage of a new asphaltic concrete.

RATING: see PAVEMENT RATING.

RAVELLING: the loosening of aggregate from the surface of a pavement. Also called CHIP LOSS, *Fretting,* SCABBING, STRIPPING.

RCA or ROAD CONTROLLING AUTHORITY: the authorities responsible for roading within their jurisdiction, e.g. Transit New Zealand for the national State Highway system; District or City Councils for roads within Local Government regions including roads within urban boundaries.

RECYCLING: re-using existing materials or incorporating waste materials such as glass, tyres, slag.

RE-CIRCULATION: pumping binder from a tank, through a pipe system and back to the tank.

REFLECTIVE CRACKING: visible cracks in the pavement surface, caused by propagation of cracks through to the pavement surface from the underlying pavement layer.

REFLECTORISED RAISED PAVEMENT MARKER (RRPM): a RAISED PAVEMENT MARKER with reflectors, fixed in a CARRIAGEWAY.

REHABILITATION: an area treatment that restores a distressed pavement to improve its serviceability for a further design period. Usually it is a complete excavation and replacement of basecourse and surfacing for an entire TREATMENT LENGTH.

REINFORCEMENT (*reinforced concrete*): steel rods, bars or other reinforcing materials, embedded in concrete, masonry or brickwork, for the purpose of resisting particular stresses.

REJUVENATING SEAL: a seal composed of a light application of binder, with no chip, and sprayed over an ageing coarse-textured chipseal. Usually the binder is emulsion with low bitumen content. Also called FOG COAT or ENRICHMENT SEAL.

RESEAL: a seal applied to an existing sealed, asphalt, concrete or timber surface. Also known as *Resurfacing*.

RESIDUAL BINDER: the non-volatile fraction of a binder that remains in service after evaporation of volatiles.

RESILIENT MODULUS: ratio of stress to recoverable strain under repeated loading conditions. Also referred to as *Elastic Stiffness*.

RHEOLOGY: the science of the flow of matter. Effectively the study and evaluation of time–temperature dependent responses of materials, e.g. bitumen, that are stressed or subjected to an applied force. Rheological properties of bitumen include: age hardening, ductility, penetration, temperature susceptibility, shear susceptibility, stiffness, viscosity.

RIGID PAVEMENT: a pavement constructed of Portland cement concrete or several layers of structural asphalt, generally 110 mm or more thick. See also FLEXIBLE PAVEMENT.

RIPRAP: medium to large sized rocks placed to protect a structure (e.g. a bridge) against scour.

RISK: the likelihood of human injury, damage to property, or damage to the environment, from a specified hazard, weighted against probability and consequence.

ROAD: a route trafficable by motor vehicles. In law, it is the public right-of-way between the boundaries of adjoining properties. It is owned or administered by an RCA.

ROAD CAPACITY: see CAPACITY.

ROAD CATEGORY: Urban Arterial – in urban areas with traffic volumes >7000vpd; Urban Other – carry <7000 vpd; Rural Strategic – connect main centres and carry >2500 vpd; Rural Other – other roads outside urban areas. See Transfund NZ's *Project Evaluation Manual* (2002) Appendix A2.2.1 for details, and *Land Transport Rule (2002) Vehicle Dimensions and Mass* for latest information.

ROAD CLASSIFICATION: consistent terminology and designation of roads to provide a basis for planning and decision making by national and local government agencies responsible for various aspects of road administration.

ROAD FURNITURE: a general term covering all signs and devices for the control, guidance and safety of traffic, and the convenience of road users, e.g. barriers, GUARDRAILS, lighting, parking meters, poles and posts, all signs and traffic lights.

ROAD GEOMETRY: the overall shape of the road.

ROAD HIERARCHY: the grading of roads according to increasing or decreasing importance of their traffic-carrying or other function. See also ROAD CATEGORY.

ROAD INVENTORY: schedule of all road characteristics, i.e. control devices, parking restrictions, road widths, number of traffic lanes, etc.

ROAD MAINTENANCE: the work required to keep a road at its specified level of service. It includes work on the road structure, furniture and drainage system. The work tends to be piecemeal rather than large scale works, as it is carried out as required throughout the year.

ROAD MARKING: a line painted on the road to control traffic movement or parking.

ROAD RESERVE:
- A legally described area within which facilities such as roads, footpaths and associated features may be constructed for public travel. Often called a road.
- The entire right-of-way devoted to public travel, including footpaths, verges and carriageways.

ROAD SAFETY BARRIER: a rail or fence erected to restrain vehicles which are out of control. See also GUARDRAIL.

ROADWAY: the portion of a road or bridge devoted particularly to the use of travelling vehicles, inclusive of shoulders and auxiliary lanes. A divided road has two roadways. See also CARRIAGEWAY.

ROAD WORKS: a general term for any work on a road for construction, repair or maintenance.

RoAR (NORSEMETER): a machine used to measure SKID RESISTANCE of a pavement surface.

ROCK: a term used generally to describe a stone larger than about 150 mm.
A geological term to describe a kind of mineral matter, e.g. igneous rock, sedimentary rock.

ROLLER: an item of equipment designed to compact soil and pavement layers, such as pneumatic-tyred, rubber-coated vibrating drum, or combination rollers.

ROLLING: see COMPACTION.

ROLL OVER: see CHIP ROLLOVER.

ROUNDABOUT: an intersection of two or more carriageways at a common level, where all traffic travels in one direction around a central island (usually circular), to induce weaving movements in lieu of direct crossings.

ROUGHNESS: the consequence of irregularities in the longitudinal profile of a road with respect to the intended profile. It is measured by the unidirectional displacement of a standard (NAASRA) test vehicle (ROUGHNESS METER) relative to its axle, as the vehicle travels over the surface at a standard speed.

ROUGHNESS METER: a device for measuring vehicle response to roughness. Traditional devices measure the vertical displacement of an axle to a vehicle body, as the vehicle travels over the surface at a standard speed. Modern roughness meters use lasers to measure road surface texture. May be a *Roughometer*, a (NAASRA) *Roughness Response Meter,* or *Laser Profilometer.*

RUBBER: naturally occurring polymer of isoprene. Available as an emulsion called LATEX.

RUNNING COURSE: a thin layer of loose stone which protects the surface of an unsealed road.

RUN-OFF:

- A general term for water (normally from rainfall) flowing across the surface of the ground.
- The amount of water precipitated onto a catchment area which flows as surface discharge from the catchment area past a specified point.

RUT: a longitudinal depression in a pavement caused by the passage of the wheels of vehicles.

RUTTING: the longitudinal vertical deformation of a pavement surface, measured at right angles to the traffic flow and across the wheelpath.

S

SAM (Stress Absorbing Membrane): a chipseal, which may be a single coat, two coat, or racked-in seal, that uses a PMB (Polymer modified binder).

SAMI (Stress Absorbing Membrane Interlayer): usually constructed with a PMB and a single covering of chip. An asphaltic mix surfacing is then constructed on top.

SAMPLE: a representative portion of a material, such as aggregate.

SAMPLING: the selection of a representative portion of a material, such as aggregate, for the purpose of ascertaining its characteristics.

SAND: natural mineral particles which pass through a defined sieve, e.g. 4.75 mm or 2.36 mm sieves, and are retained on a 0.075 mm sieve. Free of appreciable quantities of clay and silt.

SAND CIRCLE: a test used to determine the average texture depth of a pavement surface. A circle is made with a standard volume of sand, and its diameter relates to the volume of voids. The test is in accordance with TNZ T/3 Specification: *Measurement of texture by the Sand Circle Method.*

SANDWICH SEAL: a seal applied as a layer of large chip spread directly on the existing surface followed by a relatively light application of binder. A finer chip is then spread directly onto the sprayed binder, and rolled to compact the seal.

SBR Styrene-butadiene rubber: a polymer used for modifying bitumen.

SBS Styrene-butadiene-styrene: a polymer used for modifying bitumen.

SCABBING: loss of patches of chips from a chipseal. See also CHIP LOSS, *Fretting,* RAVELLING, STRIPPING.

SCALPING: a process in a quarry crushing plant where separation of two grades of rock takes place. The removal of unwanted material using grizzly bars from excavated rock before crushing.

SCARIFYING: the systematic disruption and loosening of the top of a pavement or of natural ground by mechanical or other means.

SCREED: (noun) strip of wood or metal which is used to strike off or finish a surface to the required shape or texture; (verb) to carry out this action.

SCREEN: a large sieve usually mechanically operated, used to separate material by size. The sieving surface may be either flat or cylindrical in form.

SCREENINGS: aggregate or chip of small size, usually passing a 26.5 mm sieve and retained on a 4.75 mm sieve.

SCRIM or Sideway force Coefficient Routine Investigation Machine: a machine used to measure wheelpath skid resistance.

SCRIM+: a SCRIM machine with additional equipment to measure road condition (e.g. roughness, rutting & texture) and road geometry, in addition to wheelpath skid resistance.

SEAL: a thin layer of bituminous binder sprayed onto a pavement surface which prevents water entering the underlying pavement and having a layer of aggregate rolled in. Depending on the application sequence, seals are referred to as first coat, second coat, and reseals. See also CHIPSEAL.

SEAL COAT: a bituminous waterproofing layer on the surface of a pavement.

SEALED SHOULDER: that portion of the sealed carriageway beyond the traffic lane, located between the traffic lane edge line and the edge of the seal, generally flush and contiguous with the sealed carriageway. See also SHOULDER.

SEALING CHIP: see AGGREGATE, CHIP, and GRADE (definition 6).

SEASONAL VARIATION: the fluctuation in skid resistance after the equilibrium level has been reached, in which it tends to increase in winter and decrease in summer.

SECOND COAT SEAL: previously, the term given to a seal placed on top of a primed or first coat sealed surface and before subsequent reseals. The term is obsolete as all second coat seals are now considered as RESEALS.

SEEPAGE: small quantities of water percolating through a porous material.

SEGREGATION: separation of coarse aggregate from fine material or from the rest of a bituminous mix. Liable to occur in stockpiles of aggregates, or during transportation of aggregate or hot mix.

SELECTED FILL: fill complying with specified requirements.

SERVICEABILITY: the degree to which a facility such as a road meets relevant requirements or standards.

SERVICE HOLE: a shaft with a removable cover that leads down to a sewer, drain or other underground service. Also called *Manhole*.

SET UP: to harden or cure by evaporation of volatiles, e.g. of a cutback binder.

SETTLEMENT: a downward movement of the soil or of the structure it supports by the reduction of the voids in the underlying material.

SFC or SIDEWAY-FORCE COEFFICIENT: the ratio of the resistance to sideways motion of the tyre of a vehicle (on a specified pavement) and the normal force on that wheel related to the vehicle's mass. SCRIM machines measure this force.

SHALE: sedimentary argillaceous rock characterised by, or able to be split into, thin laminae.

SHALLOW SHEAR: a defect occurring where an upper pavement layer loses stability and shoves. It is caused by vehicle loading.

SHAPE CORRECTION: correcting the longitudinal or cross-sectional shape of a road, using an OVERLAY.

SHEAR FAILURE: a form of failure in a material when the shear stress exceeds the available shear strength on a plane.

SHEAR STRENGTH: the maximum shear stress that the mass of material can withstand under a specified set of loading conditions. It is controlled by normal pressure on the shear plane, drainage conditions, or rate of strain. It is a function of the effective stress, cohesion and the angle of shearing resistance.

SHOULDER: the portion of the carriageway beyond the traffic lanes that is contiguous and flush with the surface of the pavement.

SHOULDER HINGE POINT: the point in a cross section of a road at which a side slope would intersect with the unsealed shoulder or, in the absence of an unsealed shoulder, the sealed shoulder.

SHOVING: lateral displacement of the pavement structure caused by braking, accelerating or turning vehicles.

SHRINKAGE: volume change in either the base, subgrade or occasionally in the asphalt mix.

SHRINKAGE CRACKS: interconnected cracks forming a series of large blocks, usually with sharp angles. Frequently caused by volume change or SHRINKAGE.

SHRINKAGE LIMIT: see ATTERBERG LIMIT(S).

SIDE CHANNEL: see SURFACE WATER CHANNEL.

SIDE DRAIN: a longitudinal surface drain or ditch usually U-shaped and generally located between the surface water channel and the legal road boundary. It prevents water flowing onto the road or into its pavement layers.

SIDE SLOPE: that area of road formation, located between the SHOULDER HINGE POINT and the surface water channel, having a gradient steeper than 12:1.

SIDEWAY FORCE COEFFICIENT: see SFC.

SIEVE: a box or tray, the base of which is made of woven wire or similar material or perforated metal plate, with apertures of defined shapes and sizes, e.g. 13.2 mm, 9.5 mm, 6.7 mm, 4.75 mm, 2.36 mm.

SIGHT DISTANCE: the distance measured along the carriageway over which objects of defined height are visible to a driver.

SIGNIFICANT HAZARD: an actual or potential cause or source of serious harm, or harm which depends on the frequency or extent of exposure to the hazard, or harm which does not occur or is not easily detectable until a significant time after exposure.

SILT: a material intermediate in particle size between sand and clay (i.e. 0.06–0.002 mm). Usually non-plastic.

SINGLE COAT CHIPSEAL: a single sprayed application of sealing binder followed immediately with a single application of chip which is spread and rolled into place.

SINGLE-SIZED AGGREGATE/CHIP: an aggregate or chip in which the particle size distribution is limited to a very narrow range. See also GAP-GRADED and WELL-GRADED Aggregate/ Chip.

SKID RESISTANCE: the frictional resistance provided by the pavement surface to the vehicle tyres during braking or cornering manoeuvres, which opposes skidding. It is usually measured on wet surfaces.

SLAKED LIME: calcium hydroxide, $Ca(OH)_2$, also referred to as *Hydrated Lime,* and supplied in powdered form.

SLIP: a movement or fall of earth in a cut or bank.

SLOPE: the inclination of a surface with respect to the horizontal expressed as rise or fall in a certain longitudinal distance. Also an inclined surface.

SLP, STATIONARY LASER PROFILER: a machine used to measure *Macrotexture* (roughness) of a pavement surface.

SLURRY SEAL: a surface dressing comprising a specially graded aggregate mixed with an emulsion binder, and a small percentage of cement and water. Not to be confused with MICROSURFACING which has a PME as binder.

SMA: see STONE MASTIC ASPHALT.

SOAK PIT: a large hole filled with rock or stone to create a large surface area in the surrounding ground so that surface run-off can soak away.

SOIL: unconsolidated inorganic and organic material derived from weathering or breakdown of rock and decay of organic material (from plants and animals). The upper weathering layer above bedrock.

SOUND LEVELS: pressure levels measured in decibels (dB) or adjusted decibels (dBA). See also DECIBEL.

SPAN:

- The distance between the centres of adjacent supports of a bridge, beam or truss.
- The superstructure of a bridge between two adjacent supports.

SPECIALISED SURFACING: a surfacing designed to provide skid resistance (e.g. incorporating CALCINED BAUXITE chip), to delineate uses of a pavement (e.g. coloured bus lanes).

SPECIFICATION: a document containing best practice in construction and maintenance of roads, including specifications for materials, paving, surfacings, road formation, equipment, traffic control, quality assurance. Most of the specifications referred to in this book are dated to indicate the versions that were used. Specifications referred to in contract and other works documents may not be dated, to indicate that the latest version available is to be used.

SPRAYBAR: a multiple DISTRIBUTOR for spraying binder. Also called *Gangsprayer* or *Gangbar.*

SPRAYING:

- Application of bitumen on surface to be sealed.
- Use of chemicals and hot water to control vegetation.

STABILISATION/ STABILISE: to modify any natural material to improve, correct a known deficiency, or maintain its load-carrying capacity, usually by adding lime, cement, emulsion, or water.

STABILISED MATERIAL: any material which has been stabilised.

STABILITY (of asphalt): the ability to resist deformation under load, without permanent loss of shape.

STANDARD AXLE LOAD: a single axle with dual-tyred wheels loaded to a total mass of 8.2 tonnes (80 kN).

STIFFNESS: the resistance of a material to permanent or recoverable deformation.

STOCKPILE: a heap or stack of material held in stock for future use.

STOICHIOMETRIC AIR: the amount of air needed to provide enough oxygen atoms to match up with each carbon and hydrogen atom in a fuel, so that no oxygen, carbon or hydrogen is left over after combustion is complete.

STONE MASTIC ASPHALT (SMA): a gap-graded hot mixed asphalt which has a high proportion of coarse aggregate that interlocks to form a stone-on-stone skeleton to resist permanent deformation. The stone skeleton is filled with a mastic of bitumen and filler to which fibres are added to provide adequate stability of the bitumen, and to prevent drainage of binder during transport to the site and placement.

STRAIGHT-RUN BITUMEN: the residuum obtained after vacuum distillation of crude oil, not subjected to further processing such as air-blowing or solvent extraction.

STRAIN: the change of shape as a result of an applied stress, expressed as a ratio of increase or decrease divided by the original length. Elastic strain is wholly recoverable.

STRATEGIC ROAD: a road which connects main centres of population, and carries >2500 vpd.

STREET: a road within an urban locality.

STRESS: the force on a member divided by the area which carries the force, expressed in N/mm^2 or MPa.

STRIPPING: see CHIP LOSS.
- Displacement of binder from a chip surface by action of water, e.g. in an asphaltic mix.
- Loss of chip from a chipseal, generally along wheelpaths.
- The removal of formwork from concrete.
- The removal of the upper layer of soil or over-burden.

SUB-BASE: the material laid on the SUBGRADE below the BASECOURSE either for the purpose of making up additional PAVEMENT thickness required; to prevent intrusion of the subgrade into the base; or to provide a working platform. Usually constructed from aggregate, stabilised aggregate or stabilised soil, of larger size than material used in the basecourse.

SUBGRADE: the trimmed or prepared portion of the formation (the ground) on which the pavement is constructed. Generally taken to relate to the upper line of the formation.

SUBSTRUCTURE: the piers and abutments (including wing walls) of a bridge which support the superstructure.

SUMP: see CATCH PIT.

SUPERELEVATION: the continuous transverse slope normally given to the carriageway at horizontal curves.

SUPERSTRUCTURE: the part of a bridge structure which is supported by the piers and abutments.

SURFACE COURSE: see SURFACING, WEARING COURSE.

SURFACE SEAL: a thin layer of bitumen and chip which prevents ingress of water into the pavement.

SURFACE WATER CHANNEL: an open drain or ditch formed for the collection and drainage of water run-off from the road's surface. The width of the channel shall be a minimum of 1.0 m (0.5 m either side of the invert).

SURFACING: the uppermost part of a pavement specifically designed to resist abrasion from traffic and to minimise the entry of water. It may be chipseal, asphaltic mix, or other material. See WEARING COURSE, TOP COURSE. Also called *Surface Course.*

SWALE: an open vegetated drainage channel or shallow trough-like depression designed to carry, detain, partly treat and promote the filtration of stormwater run-off, usually 5–10 m wide.

SWEEPING: the removal of loose material from a pavement by means of a broom.

SWEEPINGS: material removed by sweeping, usually referring to chips.

T

TACHOMETER: a counter that records the cumulative number of pump revolutions. They are fitted to DISTRIBUTORS.

TACK COAT: a thin application of binder to improve adhesion between two seal layers, e.g.

between two layers of asphaltic mixes, or between an old chipseal and a new asphaltic mix layer.

TAMP: to COMPACT a loose material by repeated blows.

TAR: a viscous product resulting from the destructive distillation of carbonaceous material, coal being the most common source. (Tar, not to be confused with BITUMEN, is no longer used for roadmaking in New Zealand.)

TENSILE STRENGTH TEST: determination of strength and elasticity of a material when tested in tension under specified test conditions.

TEXTURE: irregularities in the pavement surface classified in three groups by their dimensions:

Group	Horizontal (mm)	Vertical (mm)
Microtexture	0 – 0.5	0 – 0.2
Macrotexture	0.5 – 50	0.2 – 10
Megatexture	5 – 50	1 – 50

TEXTURISING SEAL: a pretreatment to prepare a surface for a reseal by reducing texture variance, or to reinstate texture. Also called PRETREATMENT SEAL.

TOE DRAIN: an interceptor drain constructed along bottom of a batter to collect batter RUN-OFF.

TOE WALL: a low retaining wall constructed at the foot of an earth slope.

TOP COURSE (or *Top Surface*): a pavement layer constructed on top of the basecourse layer. This layer is constructed of material with a smaller top size than the basecourse layer. See also SURFACING.

TOPPINGS: fine material from rock crushing, usually including dust, passing through a 4.75 mm sieve.

TRACKING: a term used in chipsealing for the black discolouration in the WHEELPATHS caused by low viscosity binder being carried or tracked on vehicle tyres from its source (usually from on-road BLEEDING).

TRAFFIC: a generic term covering any vehicles, persons or animals travelling on a road.

TRAFFIC FLOW: the number of vehicles passing a given point during a specified period of time.

TRAFFIC ISLAND: a defined area, usually at an intersection, from which traffic is excluded and which is used for control of vehicular movements and for pedestrian refuge.

TRAFFIC LANE: a portion of the paved carriageway allotted for the use of a single line of vehicles.

TRAFFIC VOLUME: the number of vehicles flowing in both directions past a particular point in a given time (e.g. vehicles per hour, vehicles per day (vpd)). See also TRAFFIC FLOW.

TRANSVERSE PROFILE: the shape of a pavement surface measured as vertical distances from a datum perpendicular to traffic flow.

TREATMENT LENGTH: a uniformly performing section of pavement, but different to sections on either side of it. May be lengths of road scheduled for resealing.

TRIAXIAL TEST: a test to determine the stress–strain properties of a pavement material in which a cylindrical specimen of the material is subjected to a 3-dimensional stress system. The axial strain is related to the applied stress.

TRIMMING: finishing off the formation accurately to the designed profile.

TWO COAT CHIPSEAL: a chipseal with two applications of binder and two applications of chip applied in the following sequence:

- an application of sprayed binder followed immediately with an application of large size chip;
- a second application of sprayed binder, and another application of finer chip.

Both coats are applied one after the other with little to no time delay between coats.

U

ULLAGE: the air space left when a container is nominally full; the unused part of the capacity of a container. Ullage ensures that any subsequent expansion of the liquid does not cause overflow or excessive hydraulic pressure. The ullage space is usually measured at 15°C.

UNBOUND GRANULAR MATERIAL/BASE: aggregate or soil which contains no additives or binder such as bitumen or cement. A base comprised of granular or mechanically stabilised materials. It cannot resist significant tensile stresses.

UNIFORMLY GRADED: an aggregate having a limited particle-size distribution approaching a single size.

UNSEALED SHOULDER: that portion of the carriageway, located between the edge of seal and the shoulder hinge point, having a slope generally no steeper than 12:1, except on curves where the superelevation may increase the slope.

UTILITIES SERVICES: services such as gas, water, electricity, telephone, sewer, and stormwater. Also called *Underground Services*.

V

VAPOUR VENTING: water vapour trapped in or below a seal rises and creates a bubble of binder rising to the pavement surface between the chip. When pricked the bubble, known as a VOLCANO has a drop of water inside. The volcanoes tend to join up, ultimately resulting in a large area of flushed surface.

VEHICLE CLASS: classification of vehicles by type, or by number of axles. Vehicles may be:
Passenger cars (LV); Light (LCV, up to 3.5t); Medium (MCV, over 3.5t); Heavy Commercial Vehicles (HCV-I with 3 or 4 axles; HCV-II with 5 or more axles); Buses. See Transfund NZ's *Project Evaluation Manual* (2002) Appendix A2.2.1 for details, and *Land Transport Rule (2002) Vehicle Dimensions and Mass* for latest information.

VEHICLE TYPE: classification of vehicles by type, e.g. car, station wagon, utility, light commercial vehicle, etc., and/or by number of axles.

VERGE: the area of road located between the shoulder hinge point and the road boundary.

VERTICAL ALIGNMENT: the longitudinal profile along the design line of a road.

VERTICAL CURVE: a curve in longitudinal profile of a carriageway to provide for gradual change of grade.

VIBRATING PLATE COMPACTOR: an automotive machine which compacts by applying vibration to the heavy metal plate on which it operates.

VIBRATING ROLLER: a roller that uses vibration to assist compaction, characterised primarily by frequency, amplitude and mass.

VISCOELASTICITY: the combined viscous and elastic response of a material to an applied stress. A viscoelastic material demonstrates both energy storage (elastic) and energy dissipation (viscous) responses to mechanical deformation.

VISCOMETER: an instrument for measuring viscosity. Bitumen viscosity is usually measured using capillary tube glass viscometers.

VISCOSITY:

- The resistance of a fluid to flow, caused by internal friction from inter-molecular cohesion.
- The numerical assessment of this property made according to a prescribed method.
- The ratio of the shear stress to the rate of shear strain of a Newtonian liquid.

A high viscosity liquid does not flow easily. The viscosity of bitumen (or its cutbacks) is usually measured by the time taken for a known volume to flow by gravity through a calibrated capillary tube at a specified temperature. The result, *kinematic viscosity,* is expressed in mm^2/s (or centistokes cSt).

v/l/d (Vehicles per Lane per Day): the volume of traffic expressed as vehicles per lane per day.

vpd (Vehicles per Day): the number of vehicles observed passing a point on a road in both directions for 24 hours.

VOID: a space within a material, between particles, that is not occupied by solid matter. Voids may be filled with air (*Air Voids*), water or binder (bitumen).

VOID CONTENT: ratio of volume of voids to total volume of the material, expressed as %.

VOID RATIO: ratio of volume of voids to the volume of solids in a material.

VOIDFILL SEAL: a seal for filling the voids in an existing coarse textured chipseal surface. It is a single very light application of binder, followed by a single application of fine chip designed to fit into the texture of an existing chipseal surface.

VOLATILE SOLVENT: a low boiling point hydrocarbon distillate used in the manufacture of cutback bitumen to produce a binder with a temporarily low viscosity which will increase again as the solvent evaporates, e.g. white spirit.

VOLCANO: see VAPOUR VENTING.

WXYZ

WALK-OVER INSPECTION: a search for road defects carried out by inspecting the road at a walking pace.

WATER BLASTING: a HIGH PRESSURE WATER TREATMENT that uses a water pressure of approximately 15,000 psi at high volumes, much greater than used for WATER CUTTING.

WATER CONTENT: the quantity of water which can be removed from the aggregate or soil by heating at 105°C, until no further significant change in mass occurs. Usually expressed as a percentage of the dry weight. Sometimes called *Moisture Content*.

WATER CUTTING: a HIGH PRESSURE WATER TREATMENT that uses ultra-high pressure (up to 36,000 psi) but low volumes of water. The pressure provides the cutting action.

WATER TABLE: the natural level at which water would stand in an unpumped bore hole, well or other depression, under conditions of equilibrium.

WATERPROOFING: the process of rendering surfaces or material impervious to water.

WATERWAY: a channel or stream; or an area available for water to pass through or under a structure.

WEARING COURSE: the surface layer of a pavement on which the traffic travels. It is specifically designed for waterproofing, skid and abrasion resistance. See also SURFACING, may be called TOP COURSE.

WEATHERING: the changes in rock resulting from exposure to influences of the atmosphere.

WEATHERED: (generally of aggregates) partly decomposed or otherwise affected by exposure to weather.

WELL GRADED: a chip having a particle-size distribution extending over a wide range of particle sizes without excess or deficiency of any specific sizes within the range. See also SINGLE-SIZED and GAP-GRADED Aggregates/Chips.

WET LOCK SEAL: a seal coat applied to another seal with a light application of binder.

WETTING: the process of a liquid spreading over a solid, e.g. binder over chip.

WHEELPATH, also called *Wheel track*: the path taken by the wheels of a vehicle using a road.

WINDROW: the long ridge of material formed by a grader or earth-moving machine.

WORKABILITY: the ability of a material to be manipulated, usually with reference to its placement and compaction.

ZONE: a portion of a study area, designated as such for particular land use and traffic analysis purposes.

Index

References in this index are to page numbers in the text.

The page numbers in *italics* are references to figures, those in **bold** are to definitive information.

The Preface, Acknowledgments, Abbreviations & Acronyms (pp. vii-xv) and Glossary (pp. 485-509) have not been indexed.

The index is arranged alphabetically. Prepositions and the like at the beginning of subheadings have been ignored in determining subheading order. The ampersand '&' has been used in place of the word 'and'.

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