

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

8.1	Bitumen	261
8.1.1	Introduction	261
8.1.2	Penetration Grading, Viscosity, and Other Properties of Bitumen	262
8.2	Additives to Bituminous Binders	272
8.2.1	Cutters and Fluxes	272
8.2.2	Adhesion Agents	273
8.2.3	Precoating Materials	275
8.2.4	Antifoaming Agents	278
8.3	Emulsions	278
8.3.1	Introduction	278
8.3.2	Bitumen Emulsions	279
8.3.3	Handling and Storage of Bitumen Emulsions	286
8.3.4	Sampling Bitumen Emulsions	287
8.3.5	Testing Bitumen Emulsions	288
8.3.6	Advantages of Emulsions	290
8.4	Polymers	291
8.4.1	Introduction	291
8.4.2	PMBs in New Zealand	291
8.4.3	Manufacture of PMBs	292
8.4.4	Handling and Storage of PMBs	293
8.4.5	Safety	294
8.4.6	Polymer Types	294
8.4.7	Uses of PMBs	297
8.4.8	Binder Application Rates	301
8.4.9	Contract Specification Requirements	303
8.4.10	Risks of Failure when using PMBs	304
8.4.11	Conclusion	305
8.5	Sealing Chips	305
8.5.1	Introduction	305
8.5.2	Aggregate Sources	305
8.5.3	Aggregate Types	307
8.5.4	Extraction of Rock	308
8.5.5	Production of Aggregate	308
8.5.6	Stockpiling	311
8.5.7	Quality Control	311
8.5.8	Aggregate Tests	312

Chapter 8 Chipsealing Materials (continued)

8.6	Materials for Slurry Sealing	320
8.6.1	Aggregate	320
8.6.2	Emulsion	321
8.6.3	Cement	321
8.6.4	Water	322
8.7	References	323

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, pitch¹-like materials obtained from refining crude petroleum 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.

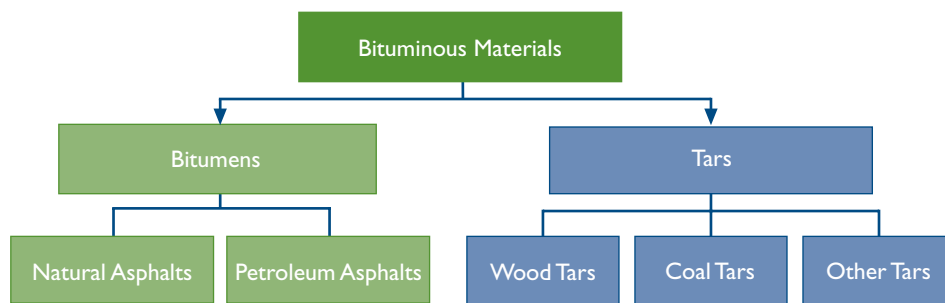


Figure 8-1 Types of bituminous materials available for sealing pavements. Note that tars are no longer used in New Zealand.

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 Roothing 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 Roothing 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 properties² 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

The penetration test (ASTM D5) determines the hardness of a roading bitumen by measuring the distance, in 1/10ths 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.

² Rheology – the science of the flow of matter.

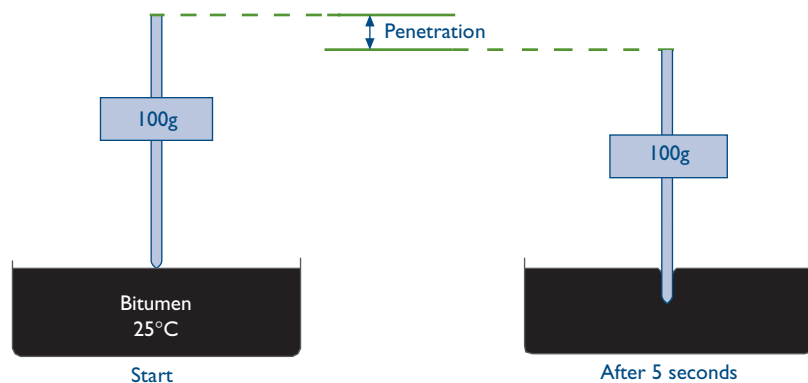


Figure 8-2 Standard penetration test used for TNZ M/I Specification for roading bitumens.

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 $\text{mm}^2/\text{second}$ (Figure 8-3). This is the SI (International System) unit for the identical older unit, the centistoke (cSt).

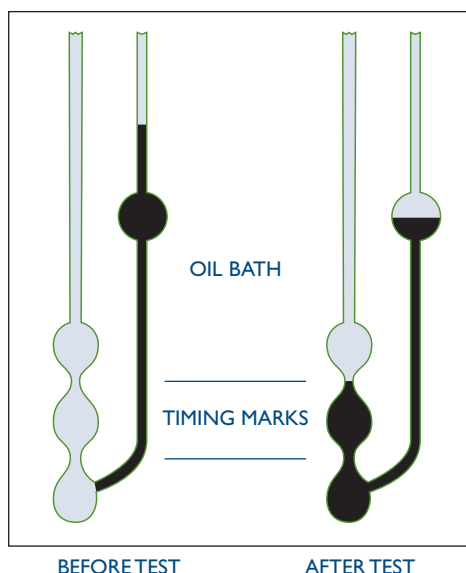


Figure 8-3 Measuring the viscosity of a bitumen by viscometer.

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

8

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

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'):

$$S_{t,T} = \frac{\sigma}{\epsilon_{t,T}}$$

- where:
- $S_{t,T}$ = Stiffness modulus at a given time t and temperature T
 - σ = Applied constant uniaxial tensile stress
 - $\epsilon_{t,T}$ = 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 ($E = \sigma/\epsilon$) 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° .

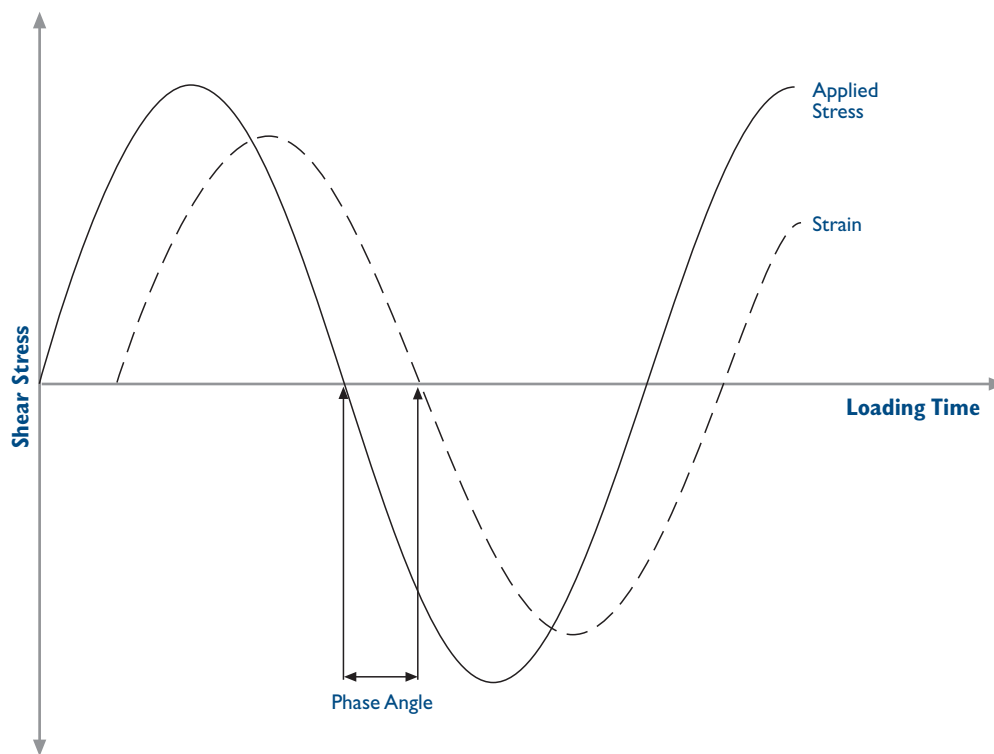


Figure 8-5 Dynamic test for measurement of shear modulus.

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 Safaniya³ 180/200, 80/100 and 40/50 bitumen grades at 40°C.

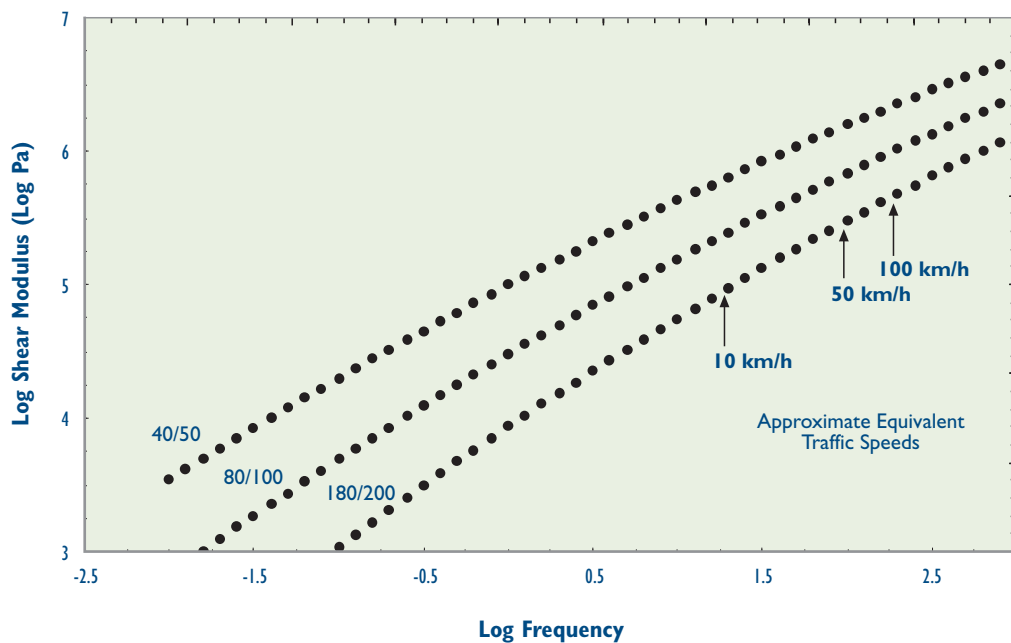


Figure 8-6 Master curves for Safaniya³ bitumen grades (40/50, 80/100, 180/200) at 40°C, showing the effect of the frequency used in the test procedure on shear modulus.

³ Bitumen from Safaniya oilfield, Persian Gulf.

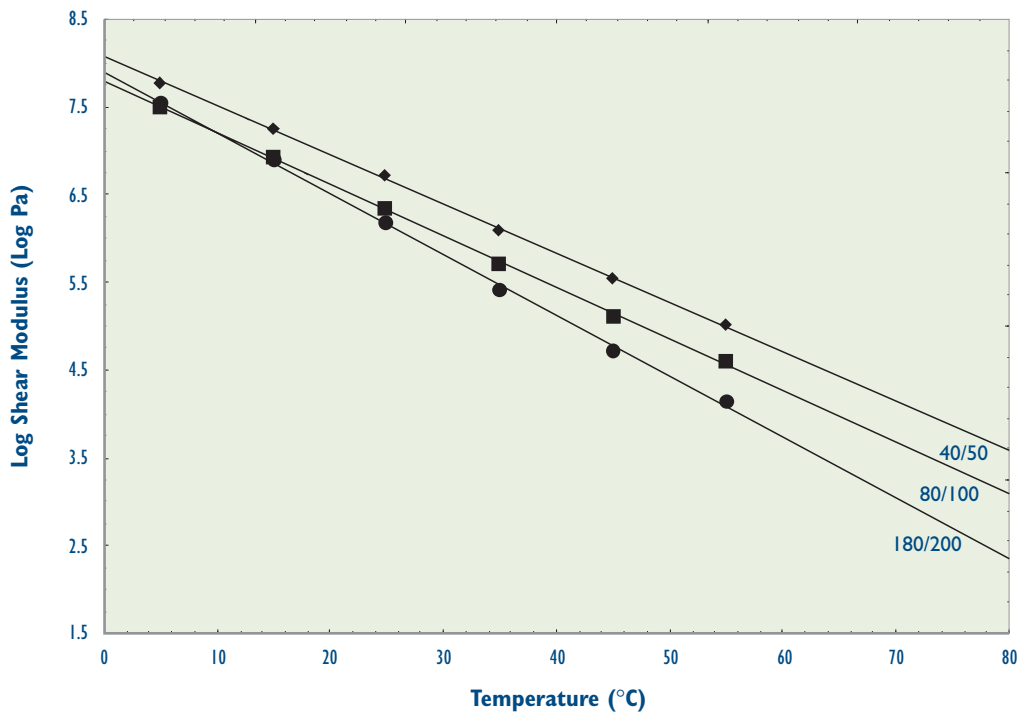


Figure 8-7 Modulus curves for three Safaniya bitumen grades (40/50, 80/100, 180/200) at 20 Hz frequency, showing the effect of temperature.

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).

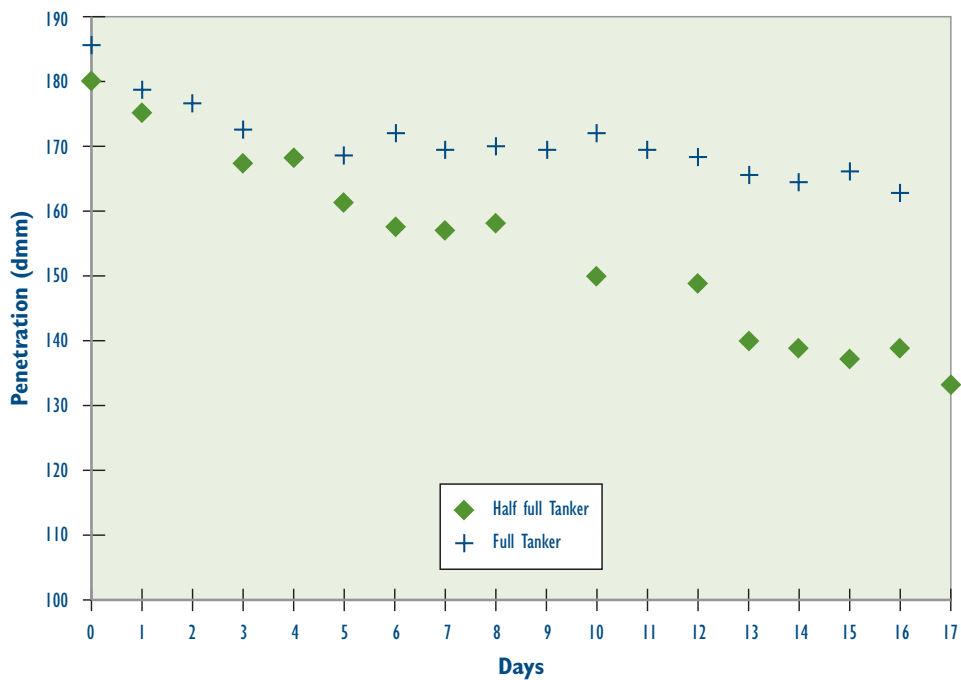


Figure 8-8 Changes in penetration (by needle at 25°C) of 180/200 grade bitumen stored at 170°C for 17 days in two bitumen distributor tanks, one tank half-full (and therefore more air), compared with a full tank (with little air) (from Tyne 1994).

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 $\% = \frac{25\text{pph}}{125} = \frac{1}{5} = 20\%$

and to convert from pph to %, where there is only one additive, use

$$\% = \frac{\text{pph}}{100 + \text{pph}}$$

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.

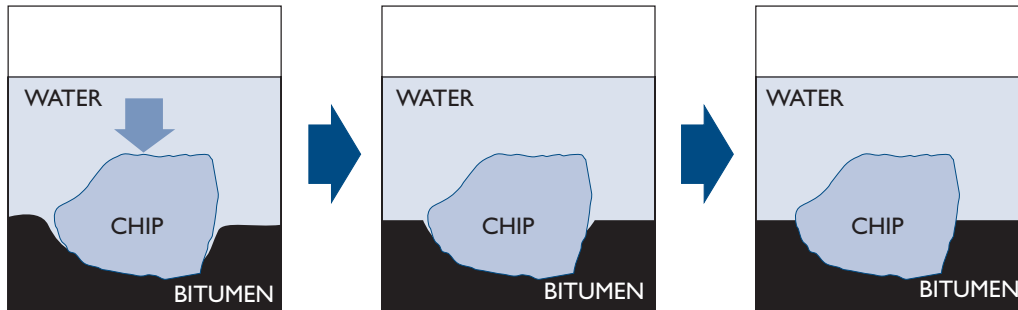
8.2.2.1 Adhesion and the Effect of Water

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).

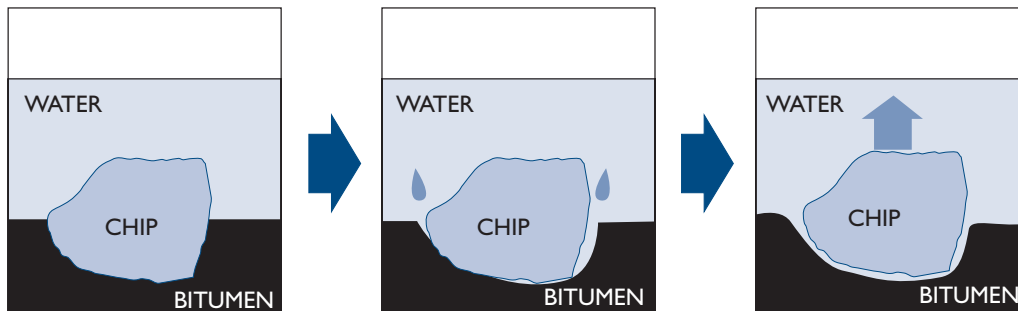
On surfaces with high volumes of traffic (i.e. heavily trafficked), the effects of stripping can be greatly accelerated because water trapped under fast rolling tyres is pumped through microscopic holes in the binder, building up very high pressures in the water trapped beneath the binder. This helps 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.

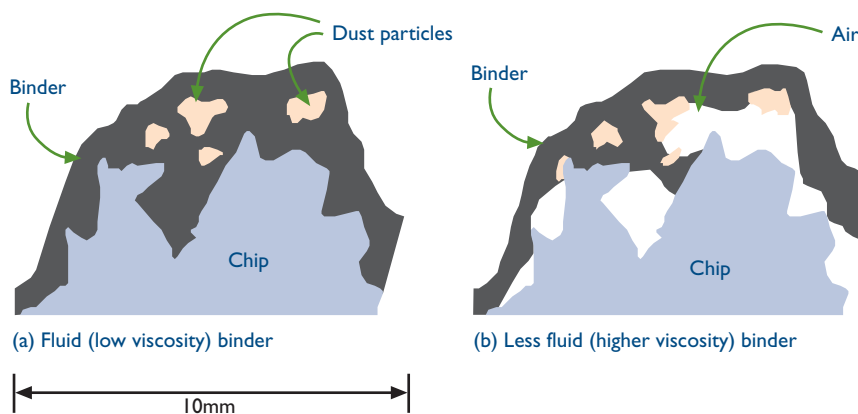


Figure 8-10 The success of adhesion of binder to chip in the presence of dust is related to the viscosity of the binder. This is how low viscosity prime coats work.

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 precoat material to the bituminous sealing binder ensures a good waterproofing bond even if a slightly less fluid binder is used. The bond between the precoat material and the chip is made in the controlled conditions of the precoat 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.

Most antifoaming agents are silicone-based, diluted with AGO, and added to the bitumen at about 1.0% by weight.

8

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'.

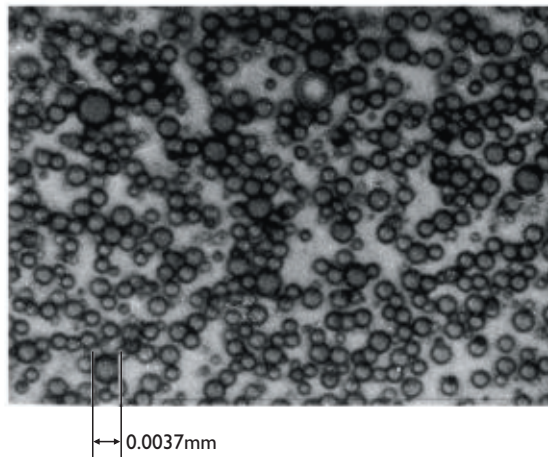


Figure 8-11 Droplets of an oily liquid dispersed in another liquid to form an emulsion (from Austroads 2004).

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.

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.

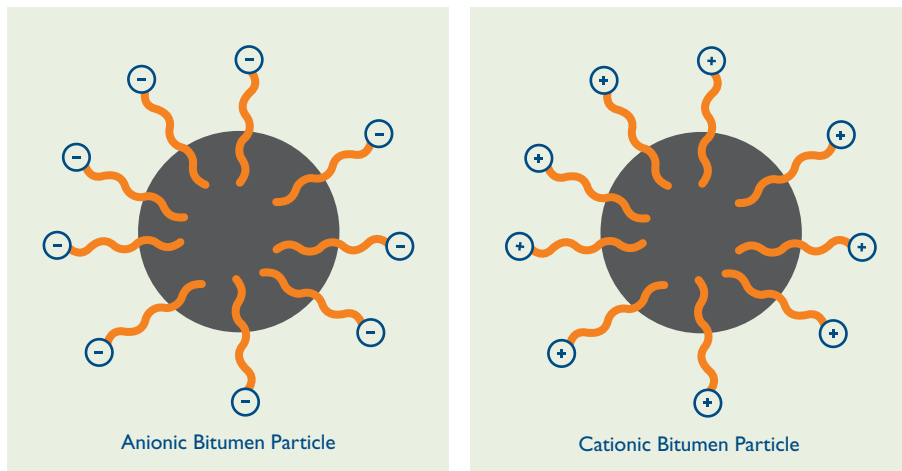


Figure 8-12 Concept of anionic (negatively charged) and cationic (positively charged) bitumen droplets.

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.

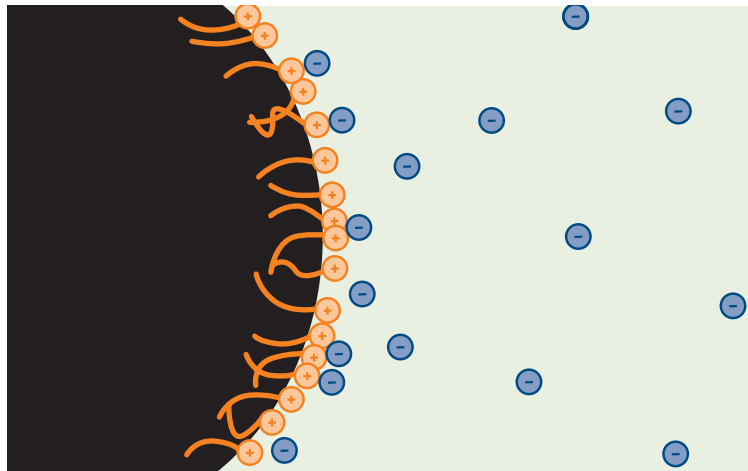


Figure 8-13 Bitumen droplet in a cationic emulsion.

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.

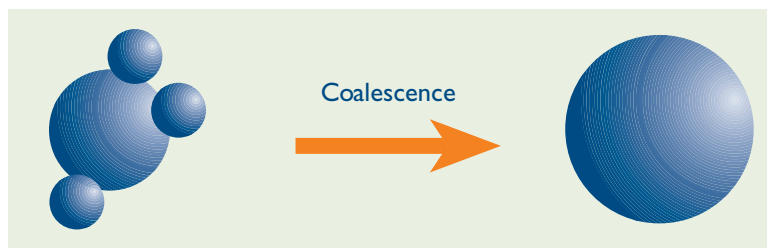


Figure 8-14 Emulsifier prevents coalescence of the droplets before it is sprayed onto the road. When the bitumen breaks on the road, droplets coalesce to form a film.

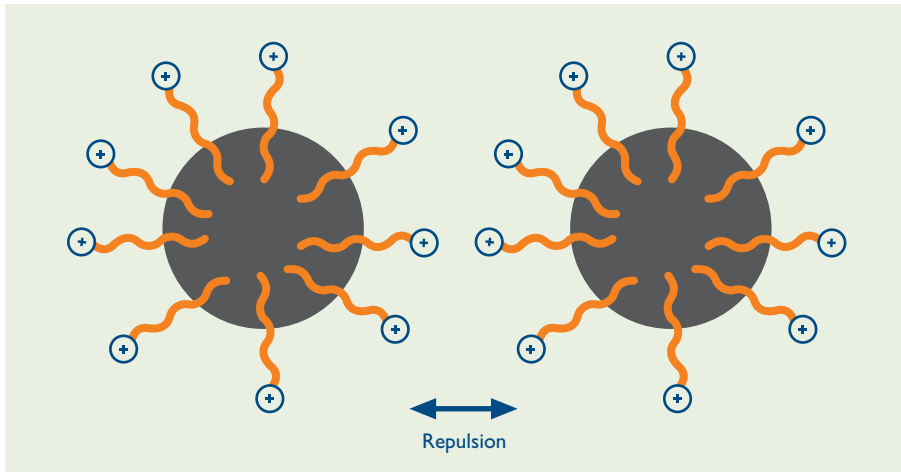


Figure 8-15 Repulsion of like-charged droplets in an emulsion.

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.

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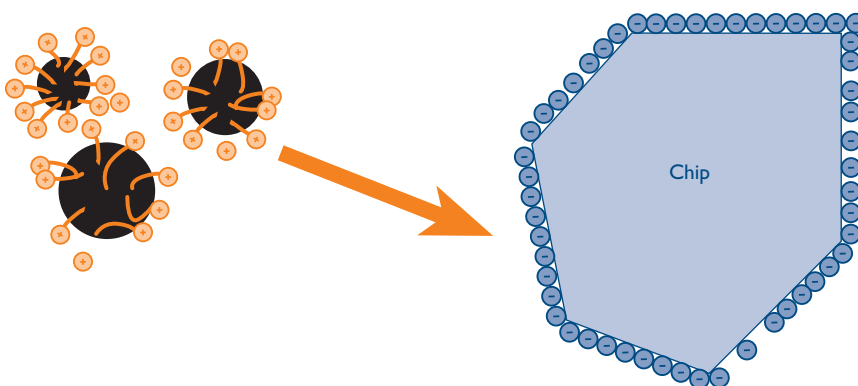


Figure 8-16 Attraction of cationic droplets to moist surface of a chip in the process of breaking.

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.

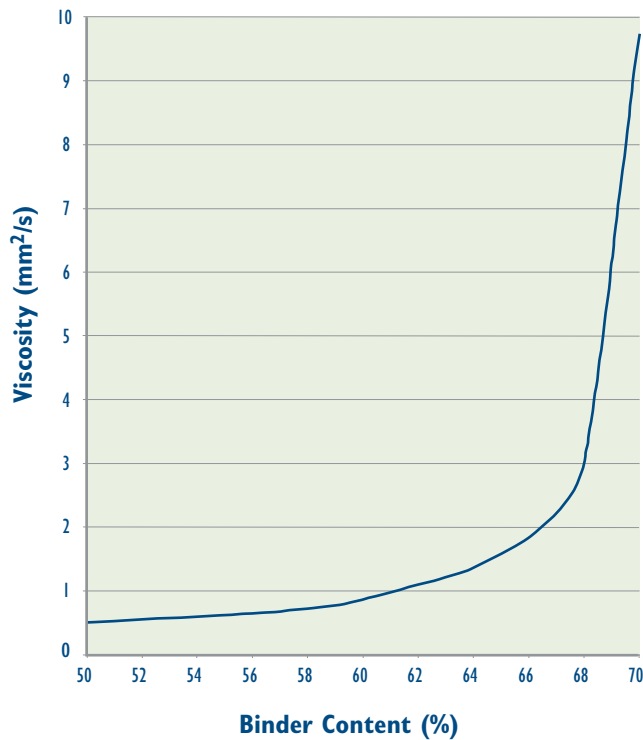


Figure 8-17 Effect of binder content on emulsion viscosity. As % binder increases, so does viscosity.

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 AS 1160 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

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.

While emulsified binders may contain diluents for storage reasons and to aid droplet coalescence and improve green-strength⁴ 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.

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.



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 PME. 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/m² 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 pre-coated chip and two-coat or raked-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

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 petrologists⁵ 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'.

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.

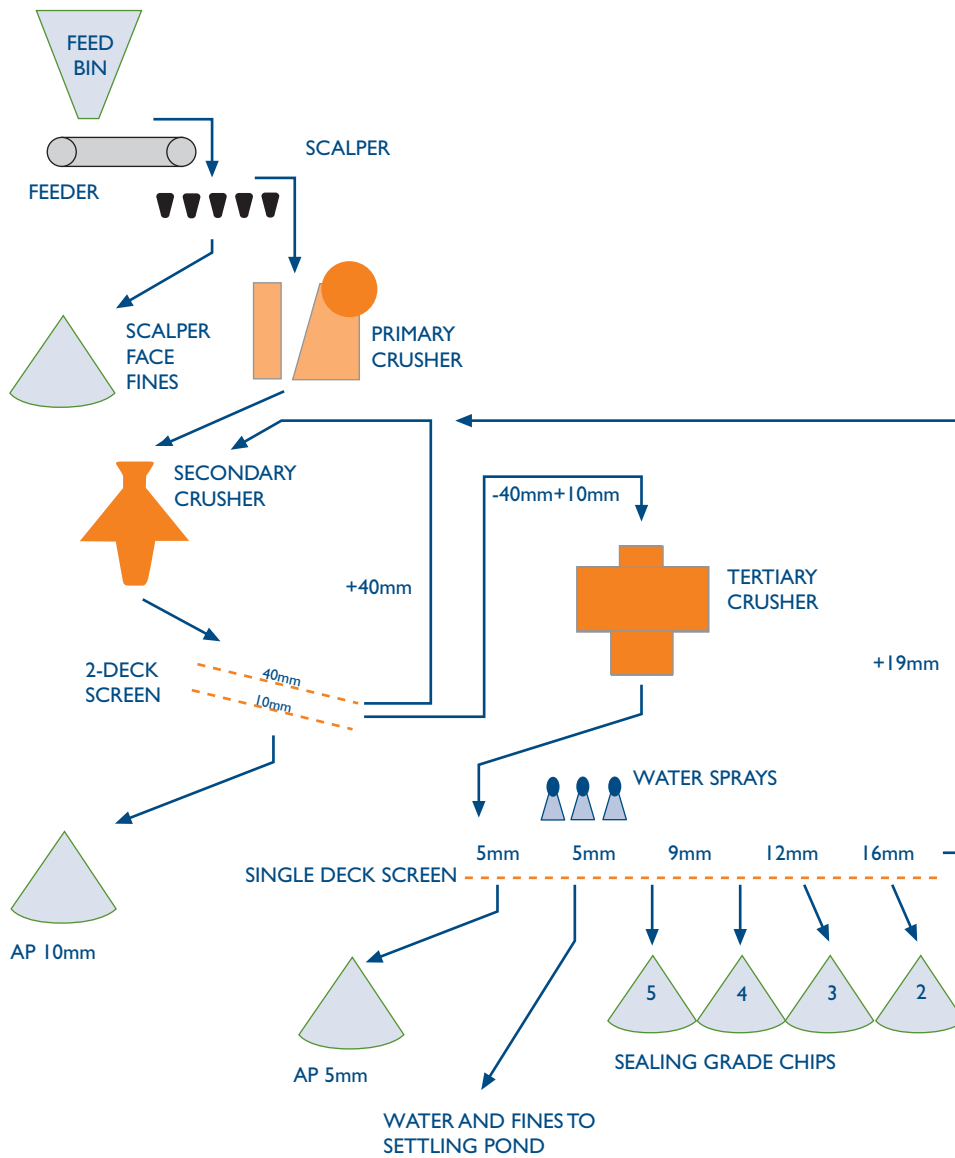


Figure 8-21 Typical crushing and screening process for quarried rock.

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).

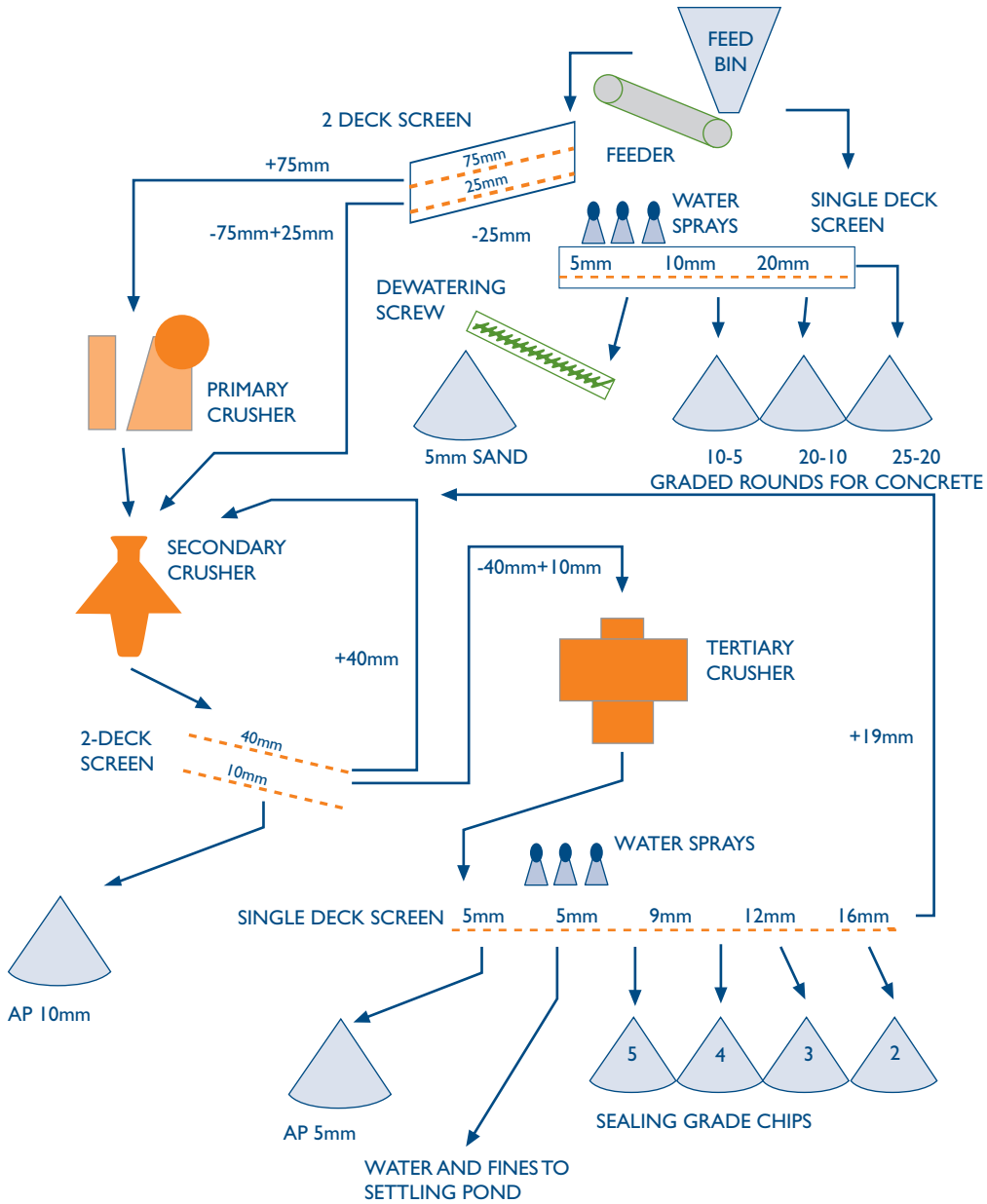


Figure 8-22 Typical crushing and screening process for natural gravels.

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.

8

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.

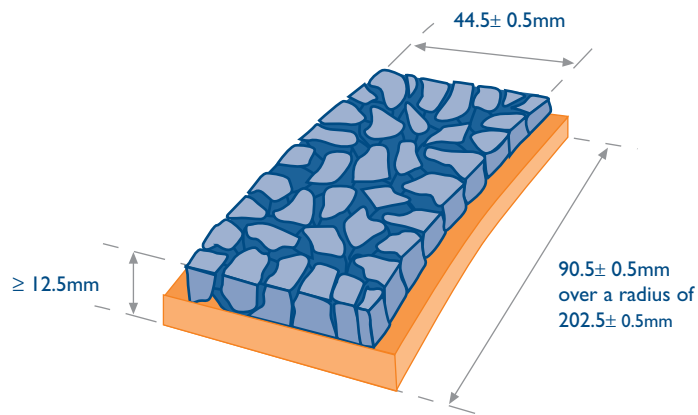


Figure 8-23 Prepared test sample showing chips embedded in epoxy.

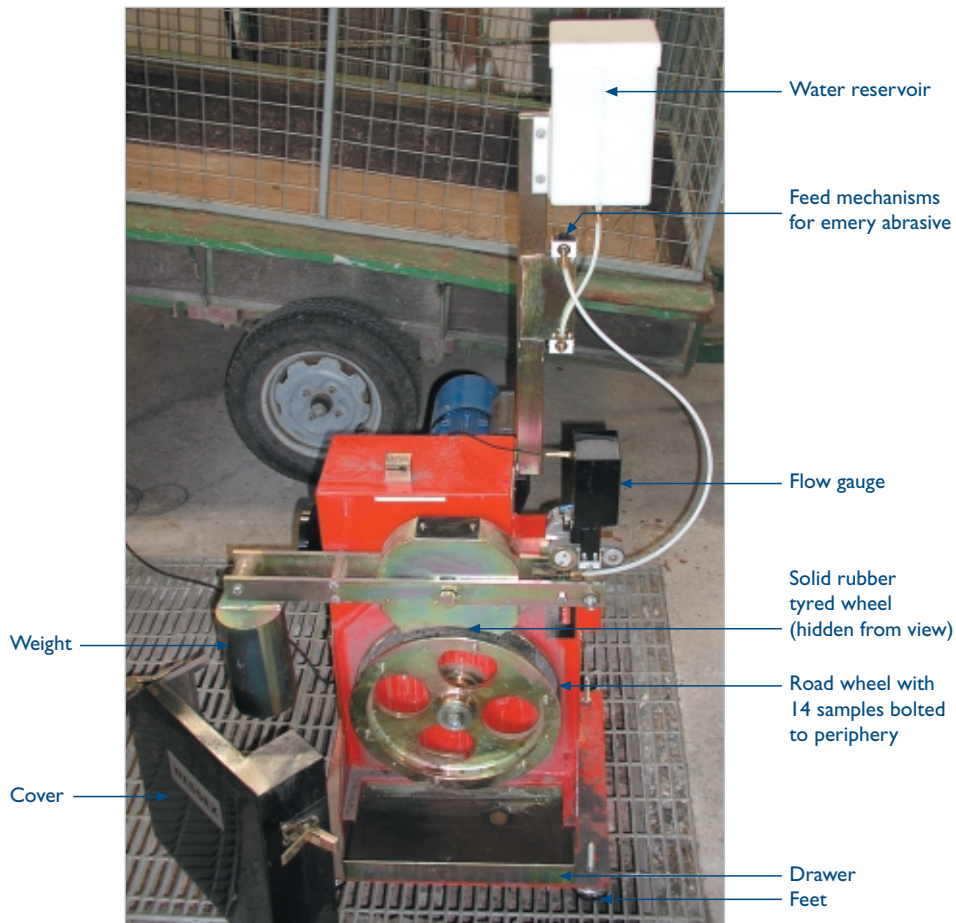


Figure 8-24 Polished Stone Value (PSV) Test apparatus.

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.

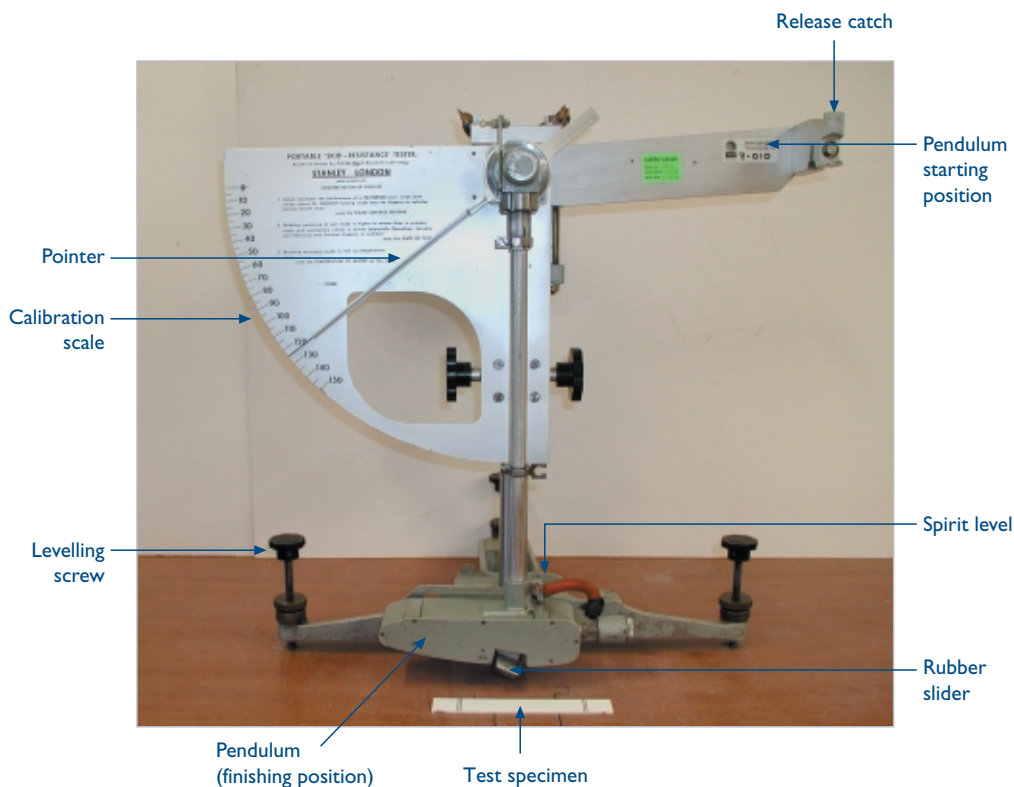


Figure 8-25 Standard British Pendulum Test (BPT) Apparatus after a test. See also Figure 4-22 of a BPT in action. Photo courtesy of Shirley Potter, Opus

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).

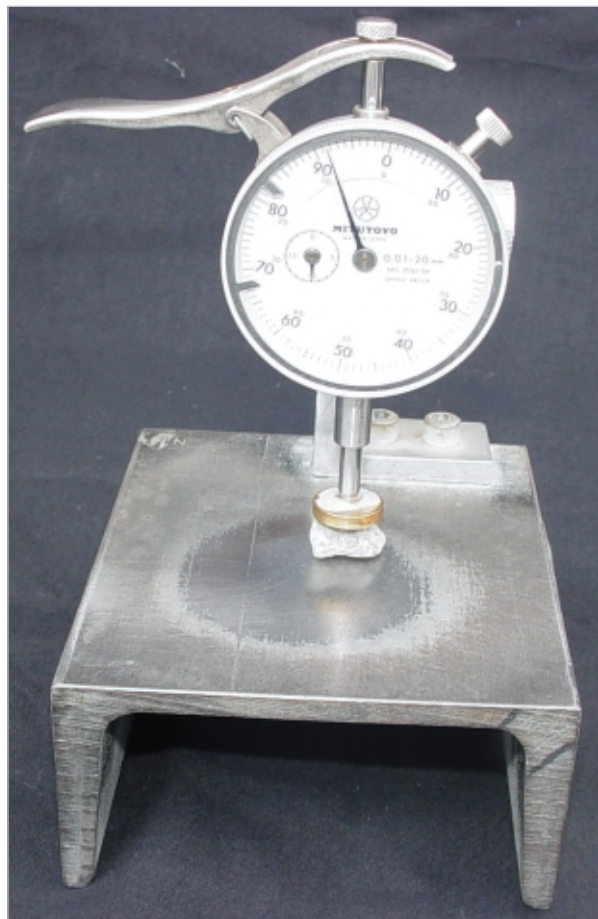


Figure 8-27 ALD (Average Least Dimension) apparatus.

Photo courtesy of Joanna Towler, Transit NZ

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.

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 ± 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.

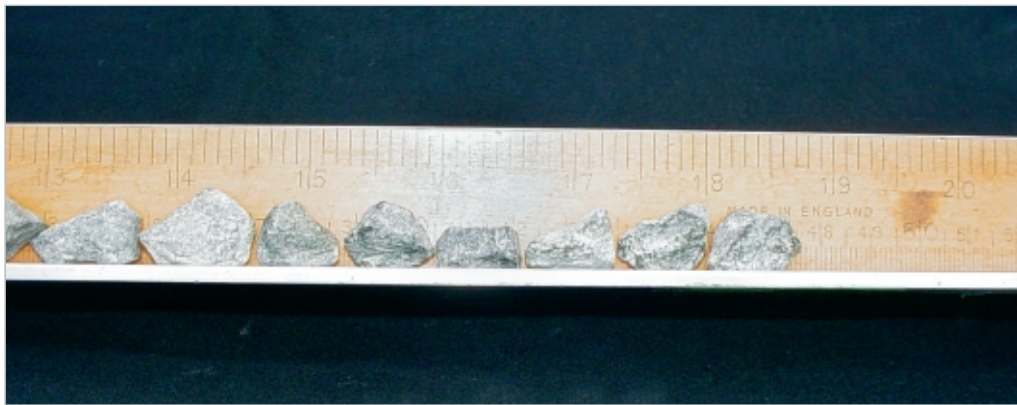


Figure 8-28 AGD (Average Greatest Dimension) apparatus. Photo courtesy of Joanna Towler, Transit NZ

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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Test 3.9 The cleanness value of coarse aggregate. *NZS 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*.

