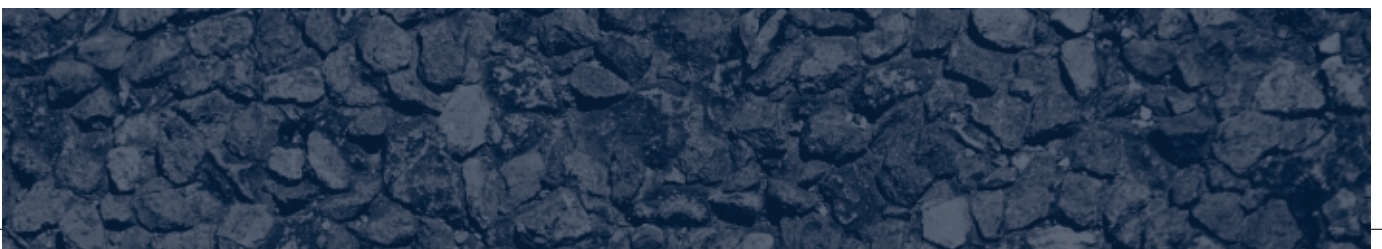


CHAPTER
FOUR

Typical Chipseal Performance



Chapter 4 Typical Chipseal Performance

4.1	Introduction	93
4.2	Post-Construction Performance	94
4.2.1	Loss of Diluent	94
4.2.2	Effects of Rolling	96
4.2.3	Effects of Temperature	97
4.3	Long-term Performance	100
4.4	Texture Change	103
4.4.1	Single Coat Seals	103
4.4.2	Two Coat Seals	105
4.5	Reasons for Resealing	106
4.6	Expected Seal Lives	108
4.7	Reasons for Shorter Life	110
4.7.1	Polishing	110
4.7.2	Chip Loss	111
4.7.3	Cracking	111
4.7.4	Flushing	111
4.8	Reasons for Extra Long Life	118
4.9	Skid Resistance	119
4.9.1	Introduction	119
4.9.2	Relationship between Skid Resistance and Crashes	121
4.9.3	Road Factors Influencing Wet Road Skid Resistance	122
4.10	References	132

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

Photo courtesy of Terry Hann, Wreford Hann Photography Ltd

Chapter 4 Typical Chipseal Performance

4.1 Introduction

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

Chipseal performance can be considered in two distinct phases:

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

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

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

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

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

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

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

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

4.2 Post-Construction Performance

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

4.2.1 Loss of Diluent

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

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

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

application. The results of longer term monitoring indicated that 30-35% of the kerosene remained by the end of the following winter.

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

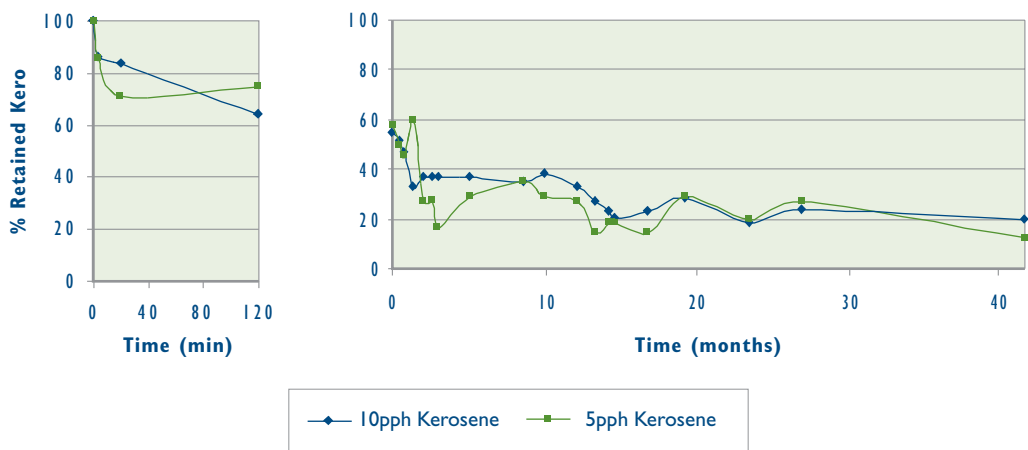


Figure 4-1 Estimate of kerosene content made by measuring weight loss from samples over a period of 5 years (Ball 1999). Approximately 20% of the added kerosene evaporated while being sprayed, and 30% within 2 hours.

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

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

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

4.2.2 Effects of Rolling

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

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

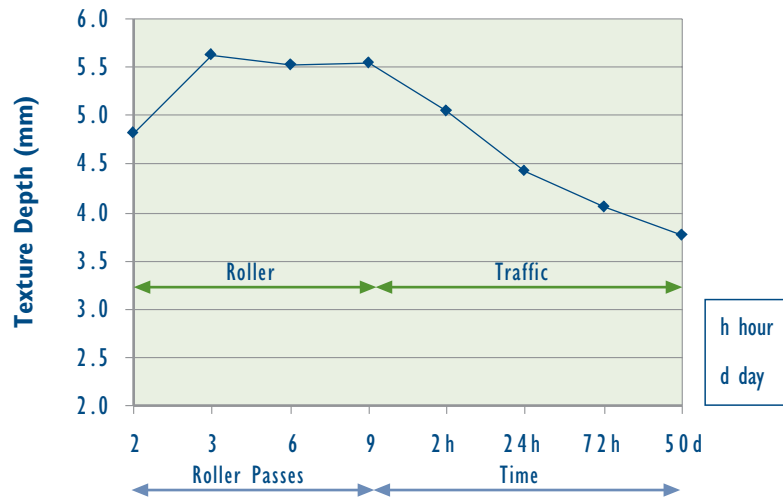


Figure 4-2 The change in texture depth (which is a measure of compaction) that occurs in the early life of a seal (adapted from NRB RRU 1989).

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

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

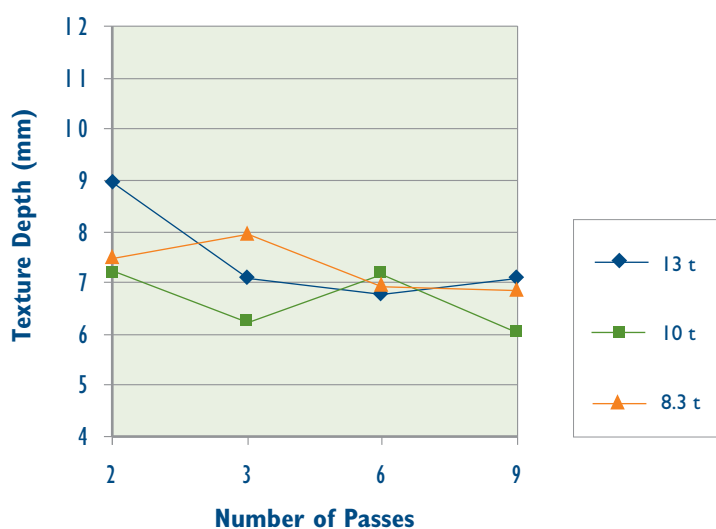


Figure 4-3 Effect of roller mass (8.3 tonnes, 10t, 13t) and number of passes on the compaction of a single coat chipseal (Hudson et al. 1986).

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

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

4.2.3 Effects of Temperature

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

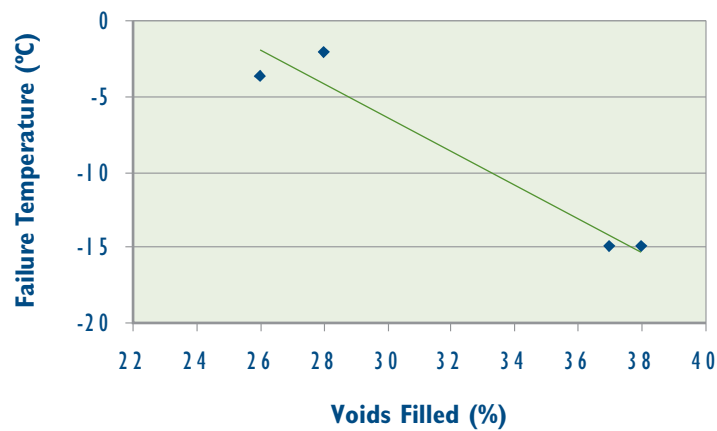


Figure 4-4 Temperatures at which failure by chip loss occurs in seals using 180/200 grade bitumen and subjected to impact as for traffic stress. The trends reflect field behaviour (from Ball et al. 1999).

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

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

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

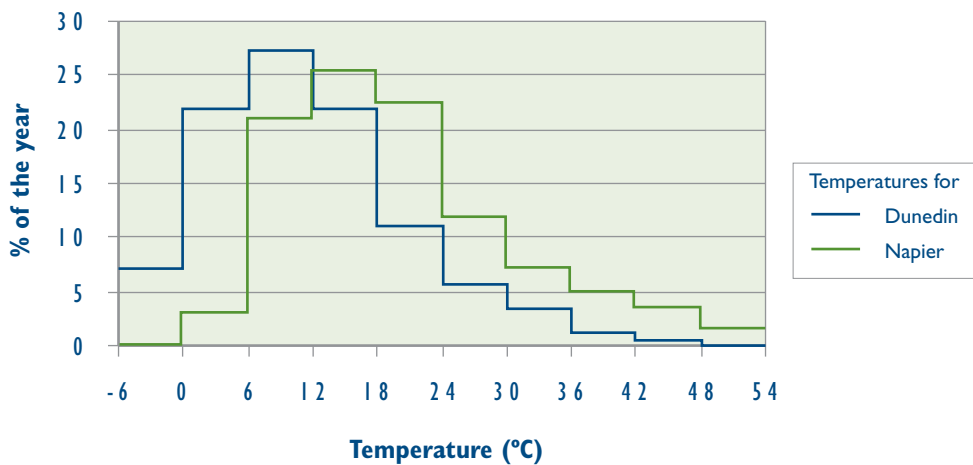


Figure 4-5 A comparison of pavement surface temperatures for Dunedin and Napier to show why chip loss is more likely to occur in Dunedin pavements.

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

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

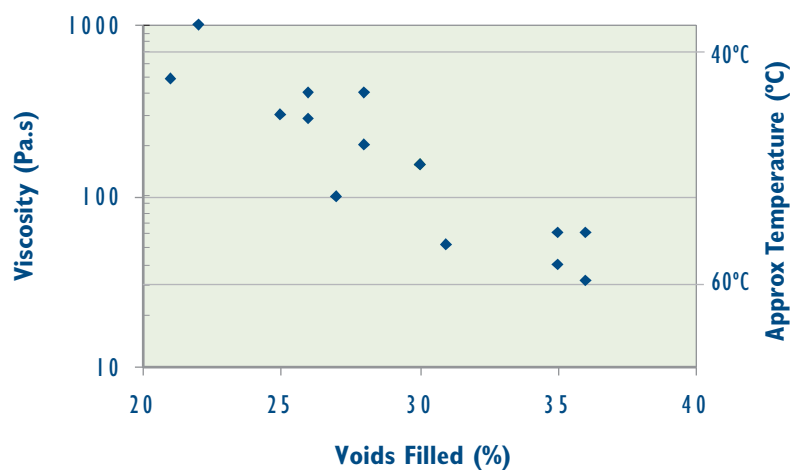


Figure 4-6 The effect of binder viscosity and % voids filled on the strengths of seals compacted in the laboratory (from Ball et al. 1999).

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

4.3 Long-term Performance

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

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

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

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

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

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

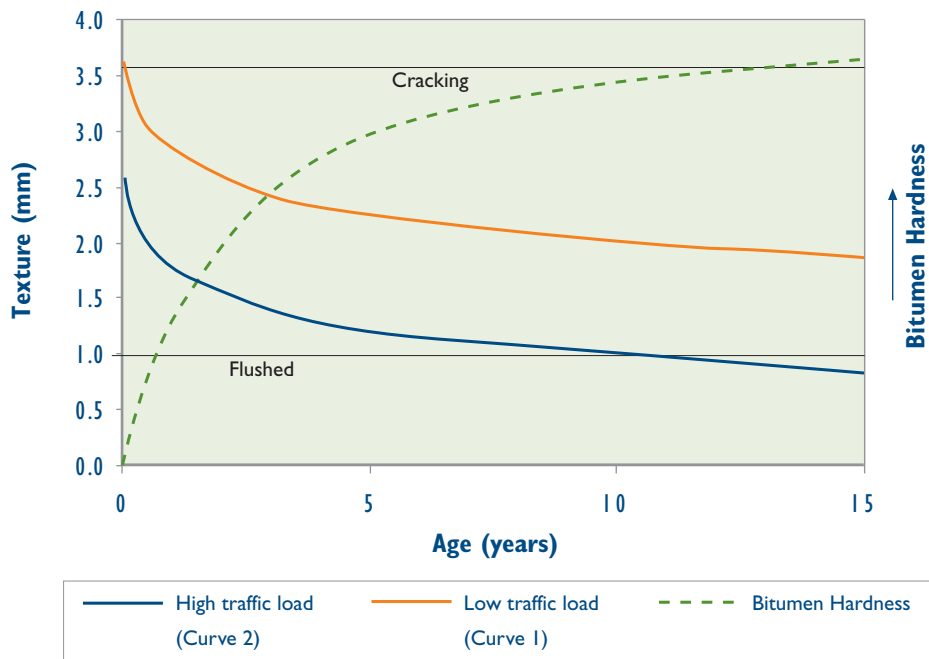


Figure 4-7 Over 15 years the ageing process related to oxidation of the bitumen causes hardening, leading to cracking or chip loss, or loss of texture by traffic compacting the chip, leading to flushing. Bitumen hardness and texture depth (mm) are shown for a low deflection, less flexible pavement, under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

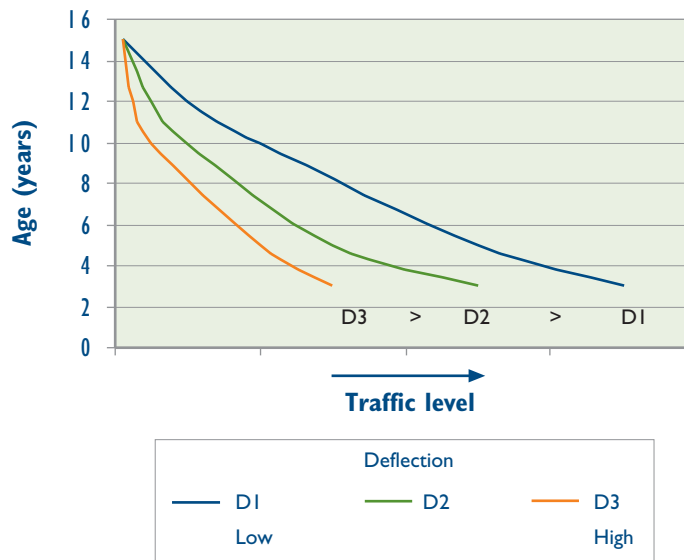


Figure 4-8 The time taken for a chipseal to crack under the effect of 3 levels of deflection: D1 (low), D2, D3 (high). (Deflections 1, 2, 3 are relative units.)

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

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

End of seal life can be caused by:

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

Increased seal life can be affected by:

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

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

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

4.4 Texture Change

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

4.4.1 Single Coat Seals

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

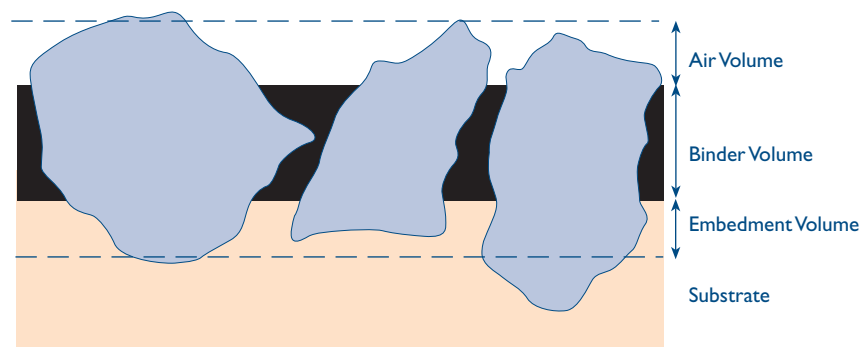


Figure 4-9 The voids concept as it applies to a single coat seal: spaces between chips are taken up by air, binder or embedment in the underlying substrate (from Potter & Church 1976).

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

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

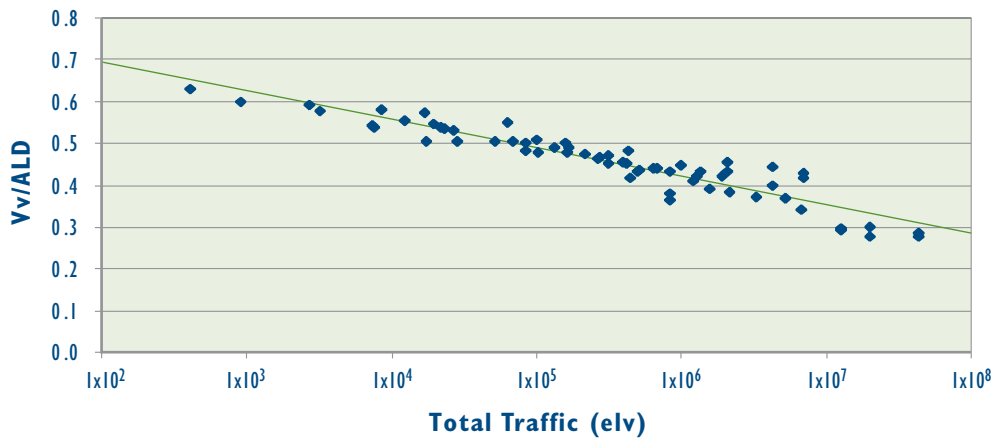


Figure 4-10 Relationships between volume of voids (Vv), chip ALD, and traffic volume (elv) for single coat seals on roads in Lower Hutt (from Patrick 1999).

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

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

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

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

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

Location	Lower Hutt	Bay of Plenty	Canterbury	Whangarei	Rotorua
No. of Tests	64	28	48	367	60
r ²	0.88	0.74	0.66	0.45	0.30
A	0.83	1.08	0.95	0.82	0.085
Standard error	0.02	0.07	0.04	0.02	0.119
B	-0.068	-0.110	-0.074	-0.061	0.100
Standard error	0.003	0.013	0.008	0.003	0.020
elv min	4x10 ²	2.2x10 ⁴	1.0x10 ⁴	1.2x10 ⁴	1.2x10 ⁵
elv max	4.4x10 ⁷	1.1x10 ⁶	1.5x10 ⁶	3.6x10 ⁷	1x10 ⁷

4.4.2 Two Coat Seals

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

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

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

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

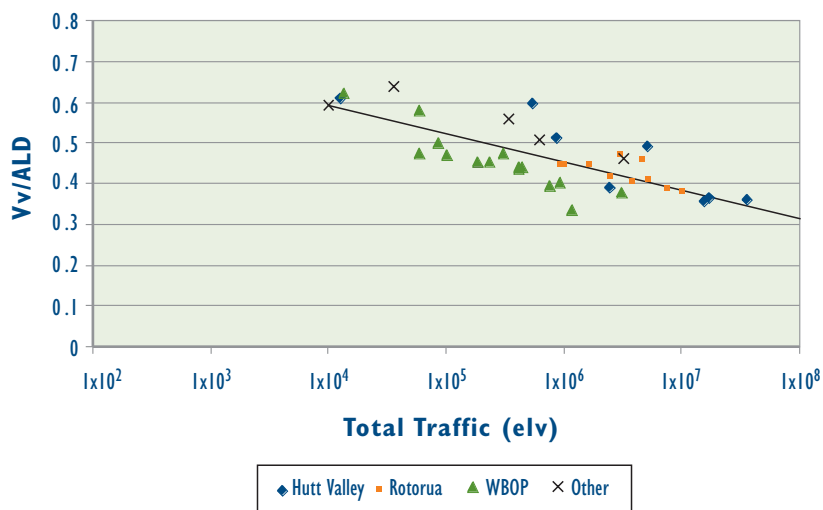


Figure 4-11 Relationships between volume of voids (Vv), chip ALD, and traffic volume (elv) for two coat seals on roads in Hutt Valley, Rotorua, Western Bay of Plenty and other areas in North Island (from Patrick 1999).

4.5 Reasons for Resealing

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

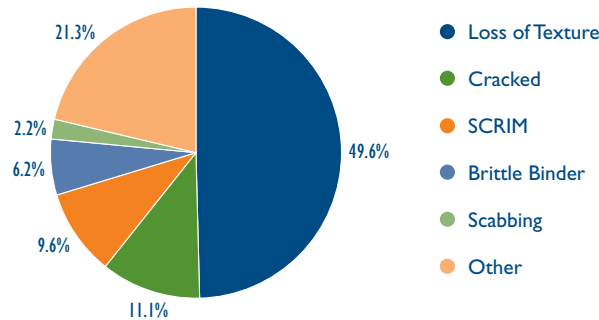


Figure 4-12 Reasons for resealing pavements on New Zealand state highways during the 2003 sealing season.

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

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

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

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

SRA State Roading Authorities

LG Local Government

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

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

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

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

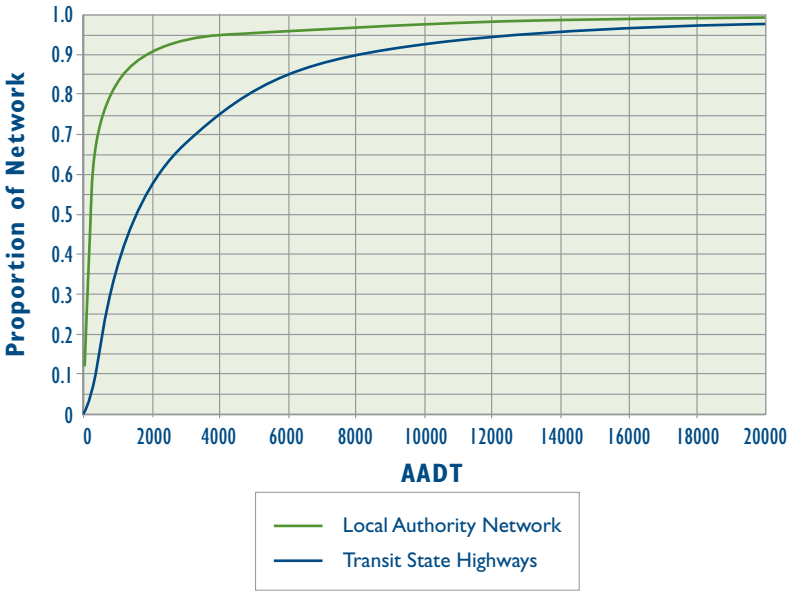


Figure 4-13 An estimate of the distribution of traffic volumes on New Zealand roads in 2000 (from National Traffic Database).

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

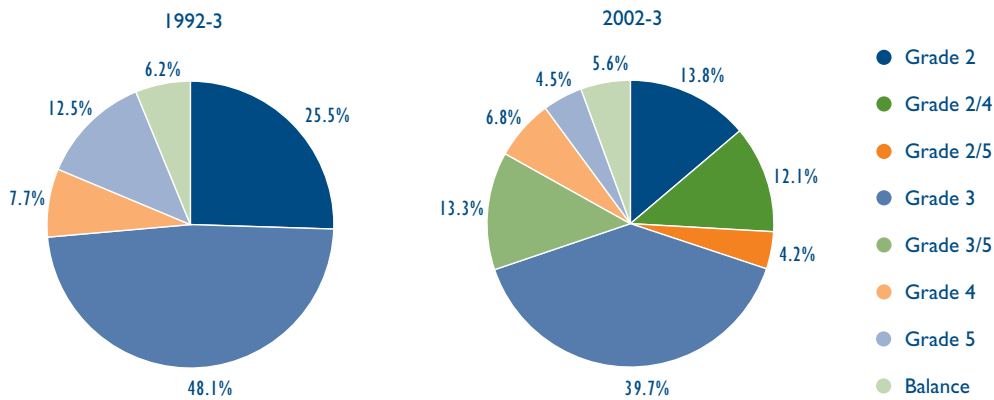


Figure 4-14 The use of multicoat seals, e.g. two coat and racked-in, has increased significantly over the last 10 years on state highways in New Zealand.

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

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

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

4.6 Expected Seal Lives

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

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

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

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

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

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

4.7 Reasons for Shorter Life

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

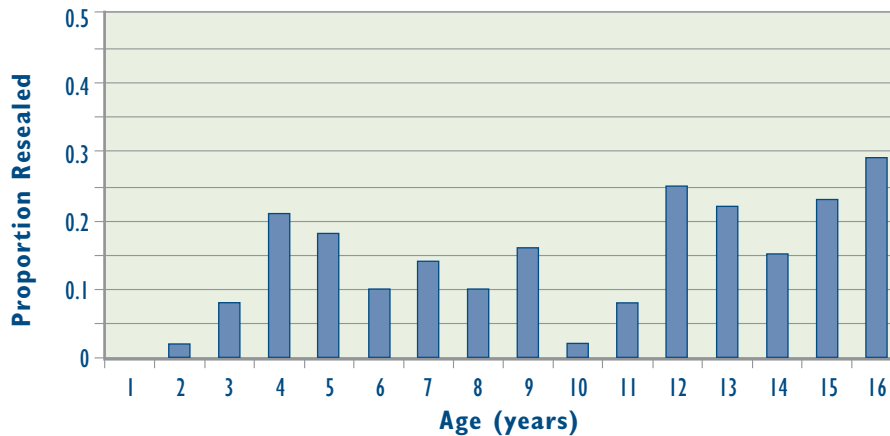


Figure 4-15 Distribution of seal lives for Grade 3 chipseals on New Zealand state highways at 2000 to 4000 vpd traffic volumes.

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

- Polishing
- Chip loss
- Cracking
- Flushing

4.7.1 Polishing

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

4.7.2 Chip Loss

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

4.7.3 Cracking

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

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

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

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

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

4.7.4 Flushing

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

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

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

4.7.4.1 Soft Substrate

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

A soft substrate can occur because of sealing

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

On granular bases

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

Over hot mix asphalt

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

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

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

Over pavement repairs

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

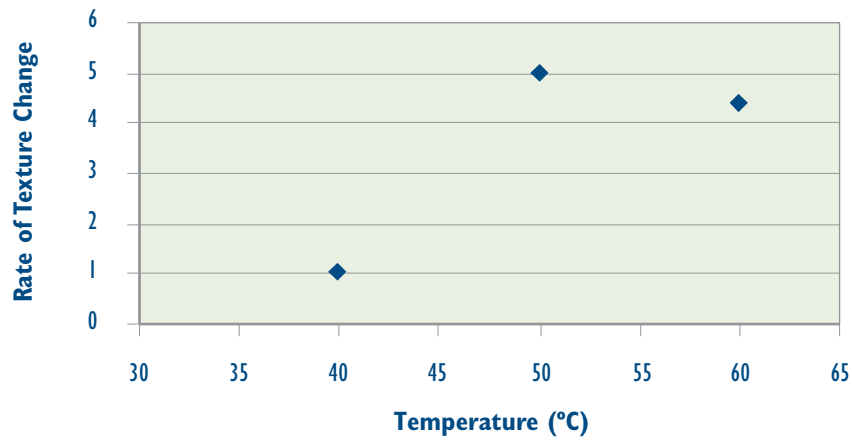


Figure 4-16 Rate of change of texture of a chipseal over hot mix asphalt under laboratory rolling.

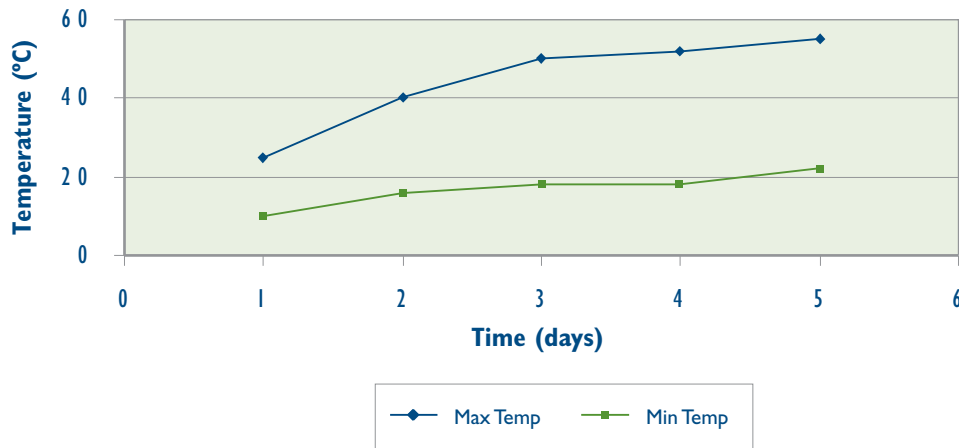


Figure 4-17 Temperature build-up over a number of sequential days in a pavement surface accelerates chip embedment.

Over weak pavements

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

4.7.4.2 Layer Instability

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



Figure 4-18 A flushed and tracked repair patch.

Photo courtesy of Les McKenzie, Opus

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

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



Figure 4-19 Shear failure on a bridge deck.

Photo courtesy of Gordon Hart, Transit NZ Napier

Symptoms

The common symptoms of pavements affected by layer instability are

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

In many cases other near-surface maintenance problems such as shallow shear and cracking may be observed. Rutting can also be attributed to the deteriorating performance of the surfacing layers, but before treatment it must be verified that such deformation

is not evident in the pavement structure below. (See Chapter 7 for information on treatment for rutting.)

Contributing Causes

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

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

As the volume of binder in the layer approaches levels where layer stability will cause flushing, the viscosity of the binder becomes critical. Diluents applied to the surface may permanently affect the viscosity of the binder near the surface and accelerate deterioration of the layer, and therefore onset of flushing.

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

4.7.4.3 Binder Rise

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

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

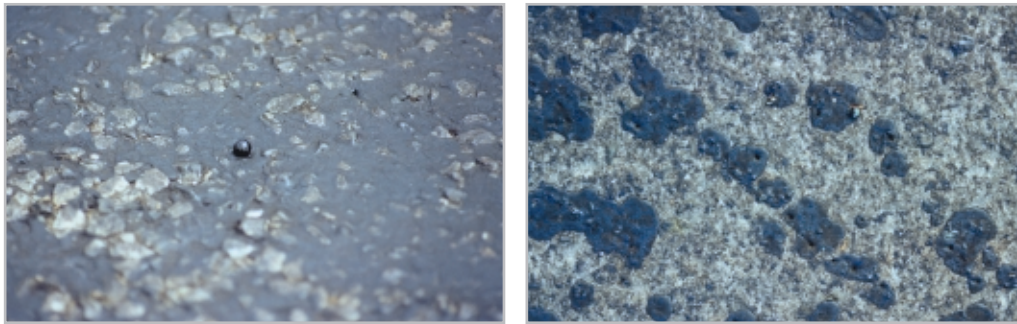


Figure 4-20 Binder rise showing vapour venting.

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

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

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



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

Photo courtesy of Joanna Towler, Transit NZ

4.8 Reasons for Extra Long Life

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

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

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

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

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

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

4.9 Skid Resistance

4.9.1 Introduction

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

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

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

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

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



Figure 4-22 Machines used in New Zealand for measuring skid resistance. Clockwise from top left: SCRIM. Top right: RoAR. Bottom right: GripTester.

Bottom left: British Pendulum Tester.

Photos courtesy of Mark Owen, Transit NZ
Photo courtesy of Shirley Potter, Opus

New Zealand has also developed and introduced a skid resistance policy. The policy was introduced in 1998 and is based on the use of a SCRIM to monitor the wet road skid resistance of the state highway network. The benefits of introducing this skid policy have been significant, with reductions of 35% in wet skidding crashes and benefit/cost ratios² in excess of 40 achieved.

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

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

4.9.2 Relationship between Skid Resistance and Crashes

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

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

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

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

Site Category	Site Definition	Investigatory Level (IL)	Threshold Level (TL)
1	Approaches to: <ul style="list-style-type: none"> • Railway level crossings • Traffic lights • Pedestrian crossings • Roundabouts • Stop and Give Way controlled intersections (where the State Highway traffic is required to stop or give way) • One Lane Bridges (including bridge deck) 	0.55	0.45
2	<ul style="list-style-type: none"> • Curve < 250m radius • Down gradients > 10% 	0.50	0.40
3	<ul style="list-style-type: none"> • Approaches to road junctions (on State Highways or side roads) • Down gradients 5-10% • Motorway junction area including On/Off Ramps 	0.45	0.35
4	<ul style="list-style-type: none"> • Undivided carriageways (event-free)* 	0.40	0.30
5	<ul style="list-style-type: none"> • Divided carriageways (event-free)* 	0.35	0.25

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

4.9.3 Road Factors Influencing Wet Road Skid Resistance

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

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

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

4.9.3.1 Macrotexture and Microtexture

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

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

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

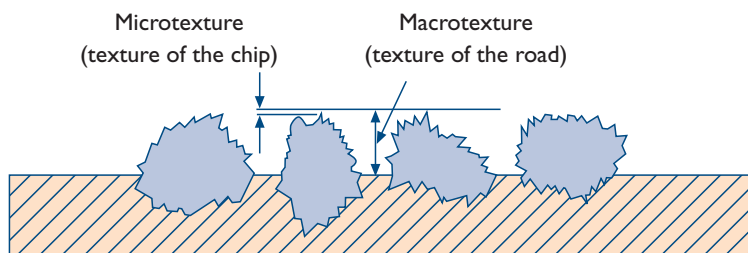


Figure 4-23 The relationship of macrotexture and microtexture of a road surface.

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

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

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

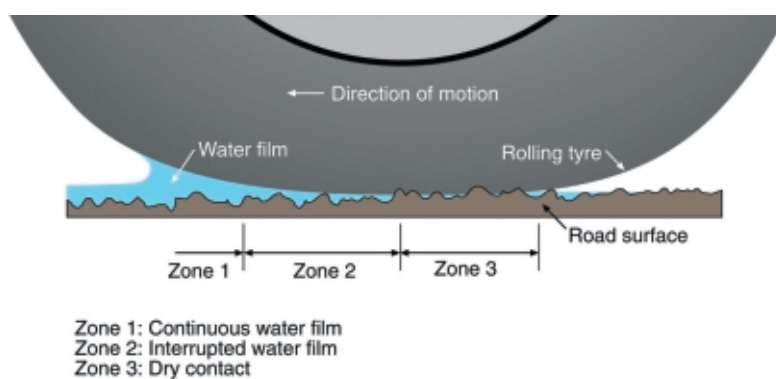


Figure 4-24 Tyre interface on a wet road.

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

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

At all vehicle speeds, the influence of microtexture is important. At low speeds (up to about 50 km/h) it is the predominant influence on skid resistance. As vehicle speeds

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

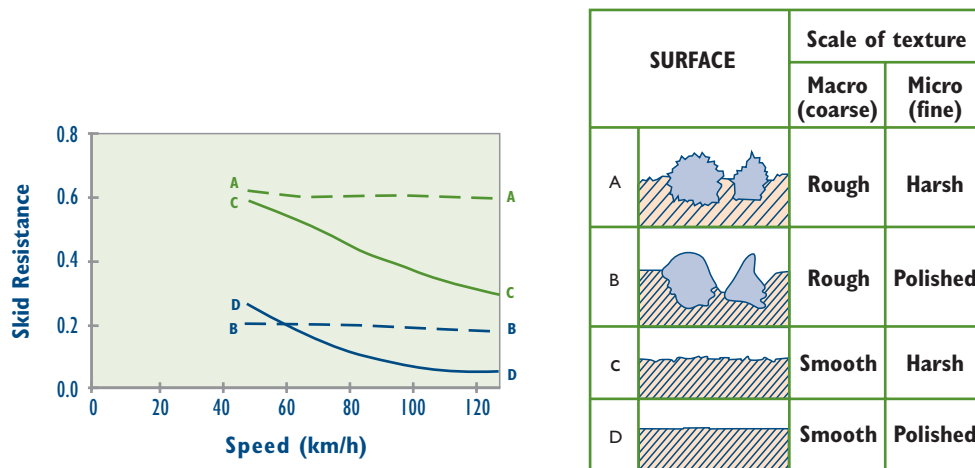


Figure 4-25 Effect of microtexture, macrotexture, and speed on skid resistance.

4.9.3.2 Water Film Thickness

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

4.9.3.3 Vehicle Speed

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

4.9.3.4 Equilibrium Skid Resistance

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

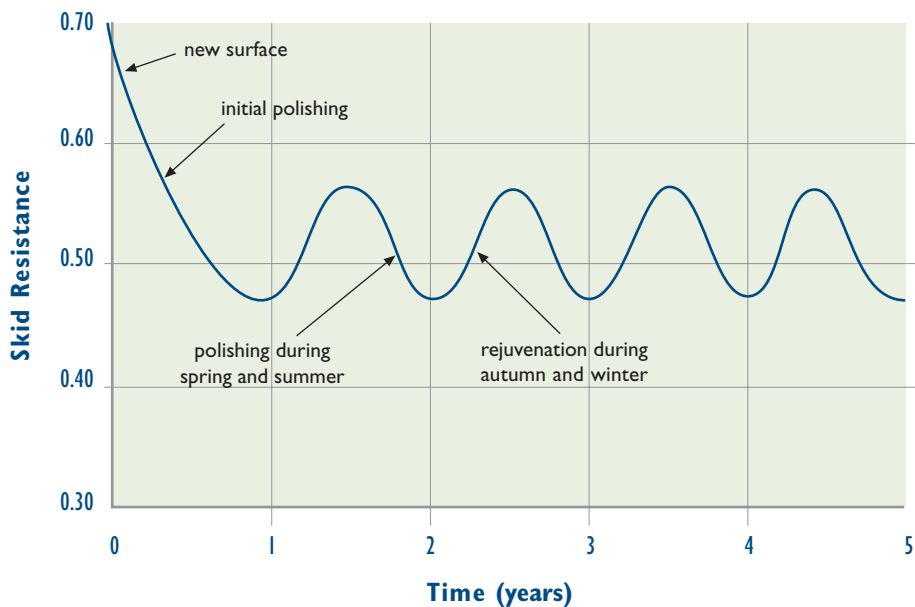


Figure 4-26 Effect of polishing on a new surface, showing initial high skid resistance followed by stabilisation at an equilibrium level.

4.9.3.5 Seasonal Variation

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

Tests carried out at a series of trial sections between 1988 and 1992 on New Zealand roads showed very pronounced seasonal changes in skid resistance, with minimum summer values being approximately 30% lower than peak winter values. A study in Australia showed that seasonal variation was evident in all states except Queensland. UK studies have shown that the variation is related mainly to seasonal changes in the

grading of the abrasive material lying on the road or embedded in vehicle tyres. Polishing of the road surface chip can also be caused by action of small particles caught in vehicle tyres.

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

Effects of Seasonal Variations on Measuring Skid Resistance

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

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

New Zealand Mean Summer SCRIM Coefficient

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

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

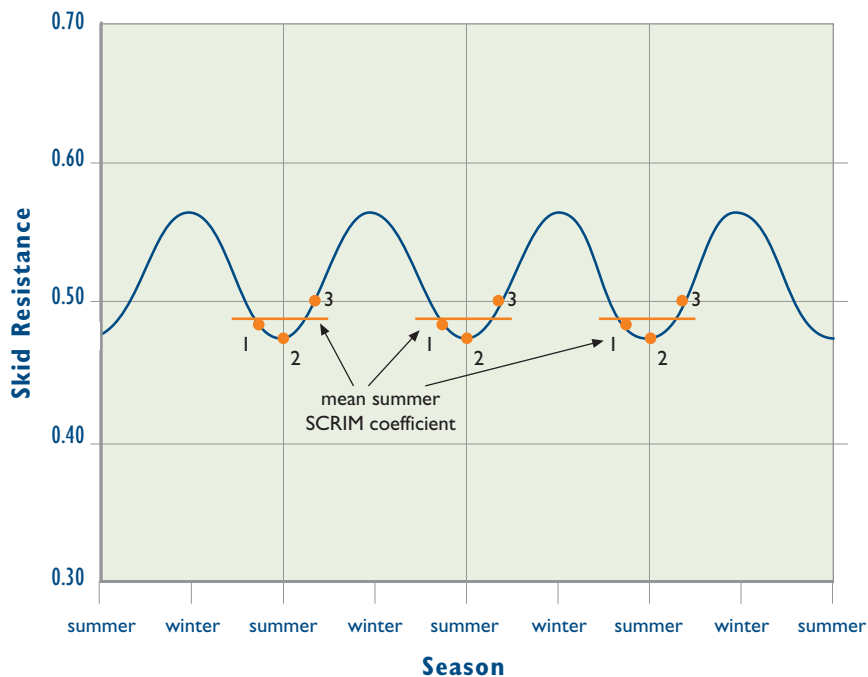


Figure 4-27 At each seasonal site, three SCRIM measurements (1, 2, 3) are made at different times during the summer. The average skid resistance for the summer for each site is calculated to obtain the Mean Summer SCRIM Coefficient (MSSC).

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

Equilibrium SCRIM Coefficient

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

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

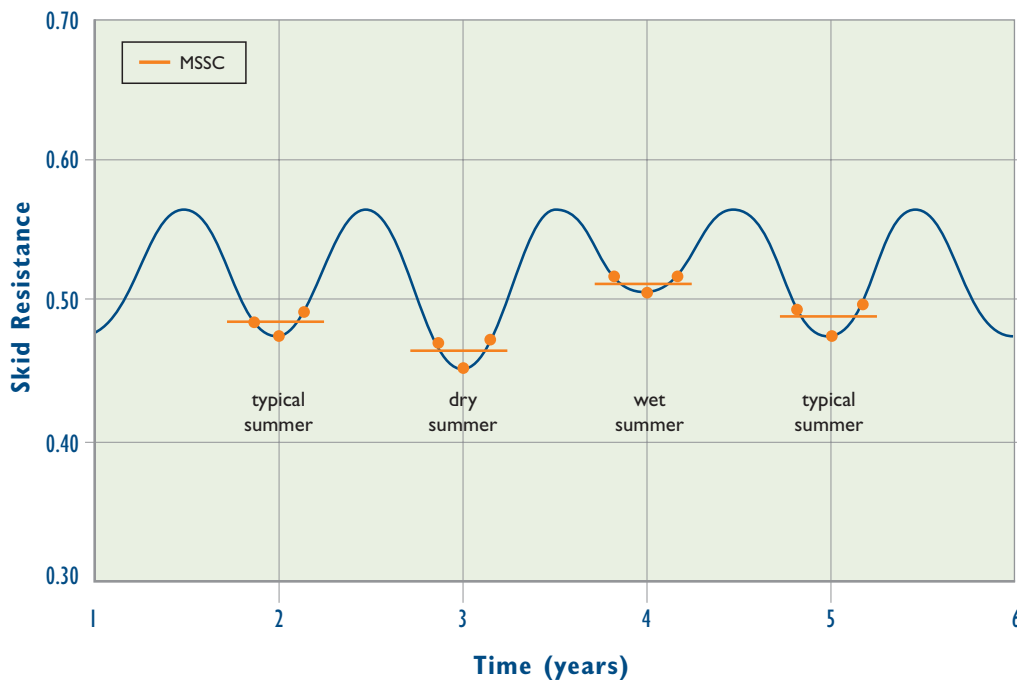


Figure 4-28 Year-on-year variations in weather patterns reduce the effectiveness of skid resistance policy in wet summers and cause over-reaction in dry summers.

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

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

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

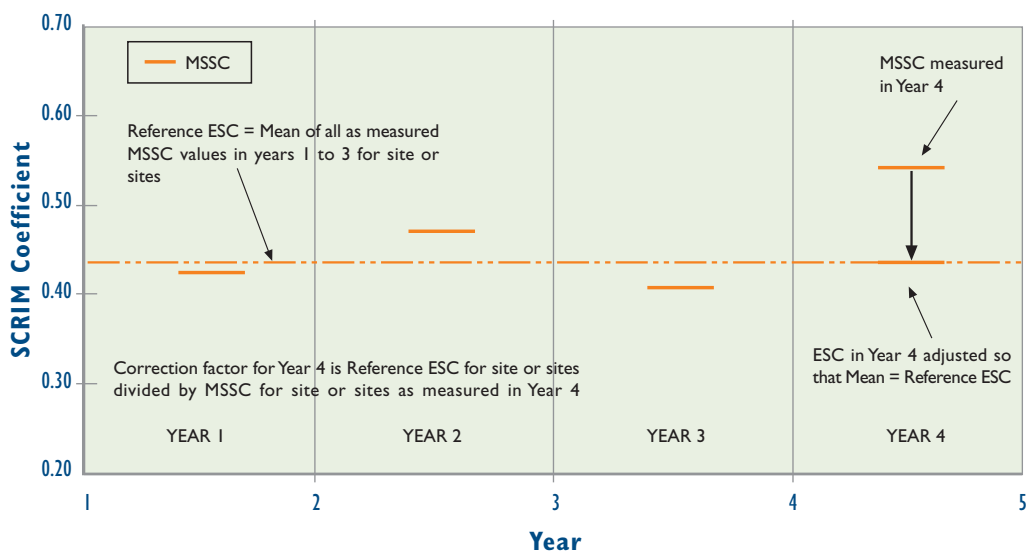


Figure 4-29 Strategy for obtaining Equilibrium SCRIM Coefficient (ESC), which is the NZ MSSC value multiplied by an Equilibrium Correction Factor. The equilibrium correction factor is calculated for each seasonal site and is applied to individual 10 m sections.

4.9.3.6 Chip Properties

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

Polished Stone Value

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

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

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

where: SFC = required skid resistance
 Q = commercial vehicles/lane/day (>3.5 tonnes)

4.9.3.7 Traffic Volume and Type

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

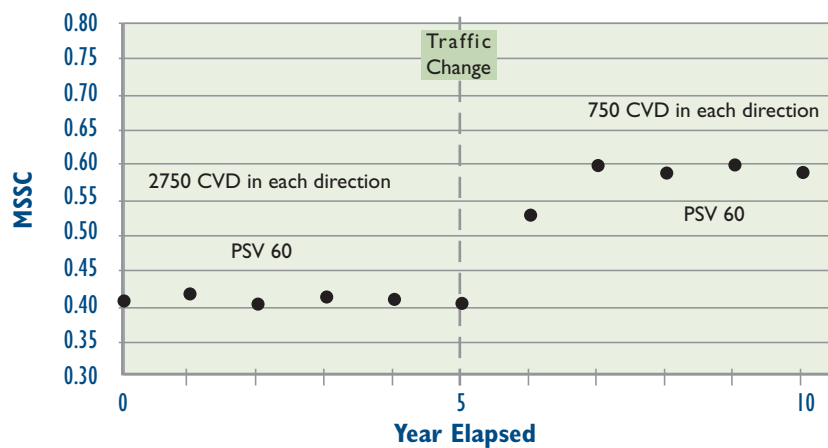


Figure 4-30 Improved skid resistance with decreased traffic volume (CVD).

4.9.3.8 Other Road Factors Affecting Skid Resistance

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

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

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

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

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

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

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

4.10 References

- Austrroads. 2005. Guidelines for the management of road surface skid resistance. *Austrroads Publication No. AP-G83/05*. 116pp. Austrroads, Sydney, NSW.
- Ball, G.F.A. 1992. Weathering of New Zealand chipseal binders – investigations from June 1991 to May 1992. *Central Laboratories Report 92-26323.06*. Opus International Consultants Ltd, Wellington, New Zealand.
- Ball, G.F.A. 1997. End of life chipseal conditions – stage 2, progress report: chipseal lifetimes in New Zealand. Transfund New Zealand Research Project. *PR3-0126*. 59pp.
- Ball, G.F.A. 1999. Chipseal bitumen hardening trials in New Zealand. *Transfund New Zealand Research Report No. 137*. 43pp.
- Ball, G.F.A., Owen, M.T. 1998. Chipseal lifetimes in New Zealand. *Proceedings of 9th Road Engineering Association of Asia and Australasia Conference (REAAA), Vol.1*: 453-458. Wellington, New Zealand, 3-8 May, 1998.
- Ball, G.F.A., Patrick, J.E., Stevenson, R.B., Herrington, P.R. 1999. Assessment of a temperature-sensitive bitumen for chipsealing on New Zealand roads. *Transfund New Zealand Research Report No. 154*.
- Herrington, P. 2000. Development of a durability test for bitumens used on New Zealand roads. *Transfund New Zealand Research Report No. 158*.
- Herrington, P.R., Forbes, M.C., Ball, G.F.A., Hamilton, P.G., Patrick, J.E. 1998. Cohesion of chipseal surfacings. *Proceedings of the 19th Australian Road Research Board Conference*: 260-275. ARRB, Sydney, Australia.
- Houghton, L.D., Hallett, J.E. 1987. An analysis of single coat seal designs. *Proceedings 1987 NZ Roading Symposium 2*: 249-263.
- Hudson, K.C., Saunders, L.R., Nicholls, K.F., Hambleton, P.H. 1986. Rolling of chip seals. *Proceedings 13th ARRB/5th REAAA Conference: Pavements and Construction 13(4)*: 173-186.
- Major, N. 1972. Letter [concerning vapour venting in New Zealand roads]. *NZ National Roads Board Road Research Unit Newsletter No. 36*: 3.
- National Roads Board (NRB) Road Research Unit (RRU). 1989. Chip seal rolling investigation. Report on Stages 1 and 2. *RRU Project AB/13*, May 1989.
- Oliver, J. 1999. The performance of sprayed seals. *ARRB Research Report ARR 326*. 45pp. ARRB Transport Research.

Patrick, J.E. 1987. Diluent loss from chipseals. *Proceedings NZ Roading Symposium 1987*: 1017.

Patrick, J.E. 1998. Bitumen emulsion sealing: New Zealand field trials. *Transfund New Zealand Research Report No. 99*. 27pp.

Patrick, J.E. 1999. Background to the development of the Transit New Zealand Performance-based Chipseal Specification P/17 Requirements. *Opus Central Laboratories Report 99-526242.04*.

Potter, J.L., Church, M. 1976. The design of sprayed single seals. *ARRB Proceedings 8*: 16-24.

Szatkowski, W.S., Hosking, J.R. 1972. The effect of traffic and aggregate on the skidding resistance of bituminous surfacings. *TRRL Report LR 504*. TRRL, Crowthorne, UK.

Transit New Zealand. 2002. Performance-based specification for bituminous reseals. *TNZ P/17: 2002*.

Transit New Zealand. 2002. Specification for skid resistance investigation and treatment selection. *TNZ T/10: 2002*.

