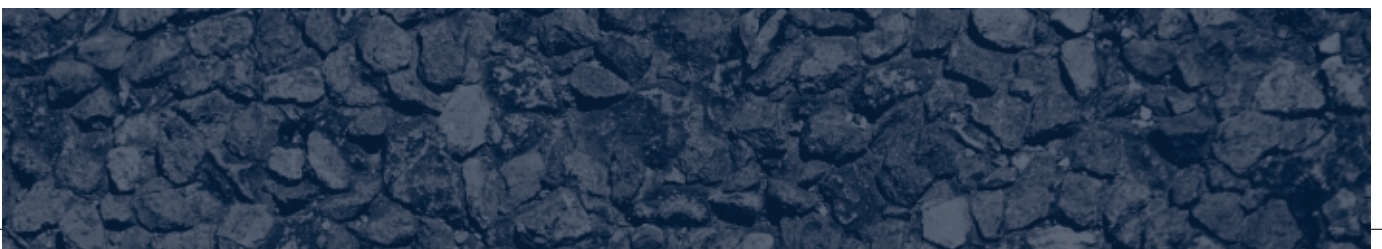CHAPTER
NINE

Chipseal Design

Previous page: The road north of Punakaiki takes the traveller through spectacular West Coast scenery and as a result has to carry high traffic volumes and requires good chipseal design.

Chapter 9   Chipseal Design

9

Chapter 9   Chipseal Design (continued)

Chapter 9   Chipseal Design

9.1   Introduction

This chapter describes the design for a seal coat once the pavement investigation has confirmed that the pavement needs resealing, that it is suitable for sealing, and that any necessary repairs have been made. For reseals and second coats, the design also assumes that a preliminary decision has been made on whether to use a small chip for a voidfilling chipseal or a larger chip for a conventional design. The detailed investigations discussed here may confirm the original treatment but in some cases the selected design for treatment may need to be changed.

9.2   Origin of Chipseal Design in New Zealand

9.2.1   Hanson's 1935 Developments

The first published work describing any kind of rational design of single coat seals was the paper by F.M. Hanson, presented to the New Zealand Society of Civil Engineers in 1935 (Hanson 1935; see also Chapter 1).

In his paper, Hanson introduced the concept that a successful seal required the partial filling of the voids in the covering aggregate, and that the volume of these voids was controlled by the Average Least Dimension (ALD) of the sealing chips being used.

Hanson found that chips when first placed on the binder had a percentage of voids of 50%, which reduced to 30% by construction rolling, and to 20% by traffic compaction. This resulted in a single layer of chips that bedded with shoulder-to-shoulder contact after trafficking.

In his research, Hanson graded the sealing chips recovered from a sample after trafficking, and it showed that considerable breakdown of the chips had occurred during service. This breakdown is presumed to have been caused by the crushing effect of steel drum rollers and the predominance of solid rubber-tyred trucks, steel-tyred horse-drawn drays and traction engines that were using the pavements in the 1930s.

He also found that in any seal coat, and with any size of sealing chip, the average compacted depth of the seal coat after trafficking was approximately equal to the ALD of the sealing chips, irrespective of the volume of traffic. He further stated:

> *Although sufficient binder to fill only 50% or 70% of the voids or air spaces between the stones is applied, nevertheless the road will be thoroughly sealed and waterproofed while the stone chips are held securely in position.*

Hanson's conclusion was that, for a successful seal on a smooth surface, the rate of binder application should be such that the 20% of voids volume after trafficking became 70% filled with binder. He expressed this as a simple formula:

Residual application rate R = ALD x 0.20 x 0.70   (Hanson's Equation)
or R = 0.14 ALD

where: R   =   residual binder application rate (ℓ/m^2)
         ALD =   Average Least Dimension of the chip (mm)

9.2.2   1960s Development Work

Thirty years later, in the 1965–66 sealing season, trial lengths of sealing were laid on a number of state highways to investigate the effect of traffic and existing surface texture on Hanson's basic application rates. At each site a set of three different rates was applied:

1. the design rate (as estimated by the local sealing practitioners),

2. a lower rate, and

3. a higher rate.

The trials were visually monitored for three years. Then in August 1969, experienced sealing practitioners made inspections of each site, and they were asked to predict the future service performance of each of the three sections of seal.

The combination of these subjective observations with the known traffic volumes, pre-seal surface texture, chip ALD and application rates, enabled the production of a spray rate chart. This, in turn, led to the Transit New Zealand Design Algorithm known as RD286 (NRB 1971):

$$R = (0.138\,ALD + e)\,T_f$$ RD 286

where: R   =   residual binder application rate (ℓ/m^2)
         ALD =   Average Least Dimension of the chip (mm)
         e   =   a surface texture correction factor (ℓ/m^2)
         T_f =   an adjustment factor for traffic

This equation is very similar to Hanson's but includes an allowance for the existing texture and a varying application rate for traffic volume.

9.2.2.1   Effect of Texture

If the existing surface has significant texture depth (i.e. macrotexture), this first needs to be filled with binder before enough binder is left available to secure the new chip. Allowance for this is made by increasing the binder application rate.

The texture depth is determined by using the sand circle test in which the diameter of the circle that a standard volume of sand makes when spread on the substrate surface is measured (Figure 9-1). The test is described in TNZ T/3:1981 specification. The relationship between 'e' and texture depth was determined during the 1965–66 state highway trials and was defined as:

$$e = 0.21\,Td - 0.05 \qquad \text{(T/3 equation)}$$

where: Td = texture depth (mm) derived from the sand circle test
e = the surface correction factor (ℓ/m^2)

Figure 9-1   Sand circle test is used to determine the texture depth. Comparison of sand circles before (left) and after (right) a Grade 2/4 sandwich seal has been laid.

Photo courtesy of Lindsay Roundhill, Opus

9.2.2.2   Traffic Factor

The binder application adjusted for the surface texture depth was then further modified by a traffic factor 'T_f'. This factor takes into account the differences in chip orientation that occur under different traffic volumes, and that some embedment into the substrate will occur under high traffic loadings. The basic assumption that Hanson made about chips lying on their ALD was found not to occur, especially under light traffic, and therefore, as the chip layer is still thicker, it requires more binder to fill the larger volume of voids.

The traffic factor 'T_f' is related to the traffic volumes measured in vehicles/lane/day (v/l/d). The relationship determined during the 1965–66 trials reflected the practice that was satisfactory for the traffic volumes of the time.

9.2.3   1980s and 1990s Developments

The basic RD286 algorithm has essentially remained the same since its development in the 1960s. Modifications however were made in 1986, and again in 1993, associated with the traffic factor to reflect the experience at that time. At both times the effect was to increase the binder application rate at lower traffic volumes (less than 1000 v/l/d) but keeping the rate the same at higher traffic volumes (>1000 v/l/d).

The 1986 change increased the traffic factor by 17% for traffic volumes of 100 v/l/d and, in the 1993 Transit NZ *Bituminous Sealing Manual*, the factor for roads with traffic of 100 v/l/d was increased by another 15% (i.e. additional to the 17% in 1986). Also introduced in the 1993 *Manual* was the concept of equivalent light vehicles (elv). This was based on South African experience where a heavy commercial vehicle (HCV) was considered to be equivalent to 10 light vehicles or cars.

9.2.4   Two Coat Seals

Before the 1993 *Manual* was published there was no standard method for designing two coat seals. Practitioners had developed their own relationships such as adding the single coat binder application rates for the two chip sizes and then taking 75% of this rate.

In the 1993 *Manual* a design method was given for two coat seals. This method was adapted from French practice and developed for New Zealand conditions. Observations and trials were carried out in Dunedin and Lower Hutt (Houghton 1987).

9.3   Latest Developments

When developing performance-related chipseal specifications in the 1990s, considerable data was gained on the rate of change of texture with time. This information has allowed the basic Hanson criteria to be expanded to assist in obtaining a satisfactory seal.

9.3.1   Basic Voids Concept

The concept of voids in a single coat seal is illustrated in Figure 9-2, taken from Potter & Church (1976).
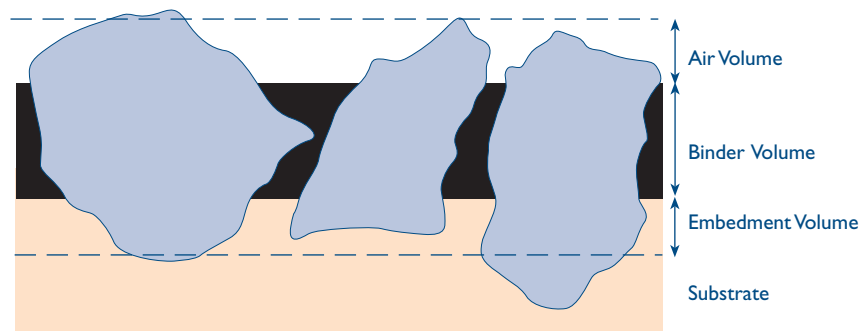

Figure 9-2   The voids concept as it applies to a single coat seal: spaces between chips are taken up by air, binder or embedment in the underlying substrate (from Potter & Church 1976).

The spaces (voids) between the sealing chips can be regarded as consisting of air, binder, and substrate (which is related to the amount of chip embedment).

Under traffic, the voids decrease in volume as the chip becomes re-oriented and embedded in the substrate and leads to reduced texture. On heavier trafficked roads this loss of texture, which ultimately leads to flushing, is the most common failure mechanism.

The extent that the chip embeds into the substrate is a function of the substrate hardness (i.e. of the existing seal). In New Zealand the hardness of existing seals is relatively constant and hardness has not been specifically taken into account in all previous design methods.

> Care does need to be exercised when constructing first coat seals on unbound granular basecourse, or when sealing over asphaltic mixes, to ensure that the hardness of the underlying pavement is not significantly different from that of normal chipseals. If it is different, adjustments to the binder application rate may be required, and guidance is given in Section 9.4

Hanson's research indicated that the total volume of voids reduced under traffic to approximately 20%, and that the chip tended to lie on its ALD. Contrary to his research, later investigations (Potter & Church 1976, Patrick 1999) indicated that the total volume of voids is significantly higher than 20% in a compacted seal, and that the voids continue to decrease with further compaction under traffic.

9.3.2   Volume of Voids v Traffic Volume

The change in voids in a seal on New Zealand pavements is discussed in Chapter 4. The most comprehensive set of results was from research carried out on Lower Hutt (New Zealand) roads (Patrick 1999), and the best-fit line through the data is given in Equation 9-1. This equation is derived in Section 4.4.1.

$$\frac{V_v}{ALD} = 0.83 - 0.07 \log_{10} (elv) \qquad \text{Equation 9-1}$$

where: V_v = volume of voids

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

elv = cumulative equivalent light vehicles based on assumption that one HCV is equivalent to 10 cars

Using this equation the change in the volume of voids under cumulative traffic is shown in Figure 9-3. The changes in the volume of voids as they are affected over time under different traffic conditions are given in Figure 9-4. The rate of change of voids, and therefore rate of change in texture, is very rapid after initial construction but then tends to slow.
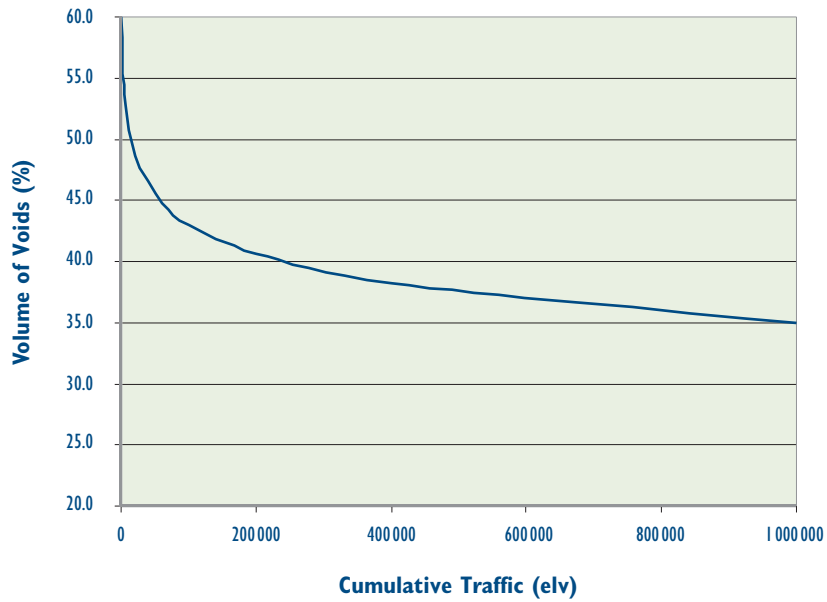
Figure 9-3   Rate of change in volume of voids (%) in a chipseal under different traffic volumes. The traffic volumes are shown as a cumulative total (in elv).
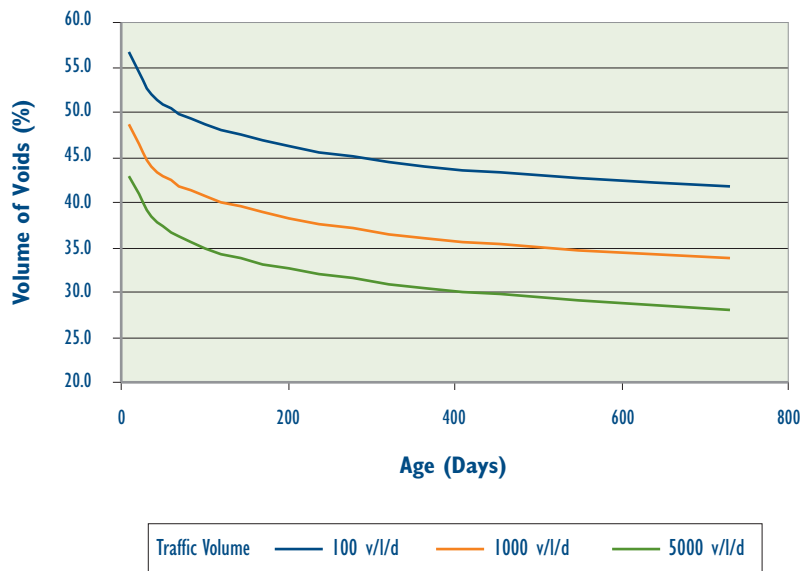
Figure 9-4   Change in volume of voids (%) with increasing time (in days from sealing for about 3 years), for low (100 v/l/d), medium (1000 v/l/d) to high (5000 v/l/d) volumes of traffic.

9.3.3   Derivation of the 2004 Chipseal Design Algorithm

Most international chipseal design methods use the void concept on the basis that in a durable seal the voids are filled to between 60–70%. The assumption is that the seal settles into a stable state after approximately one year.

The 2004 Seal Design Algorithm has been based on the philosophy of the performance-based chipseal specification (TNZ P/17:2002) which is in turn based on the premise that, if the chips do not dislodge during the first winter, there is a low risk that premature low-temperature chip loss will occur later. Likewise TNZ P/17 discourages excessive binder use as that could lead to premature flushing. This concept is illustrated in Figure 9-5.
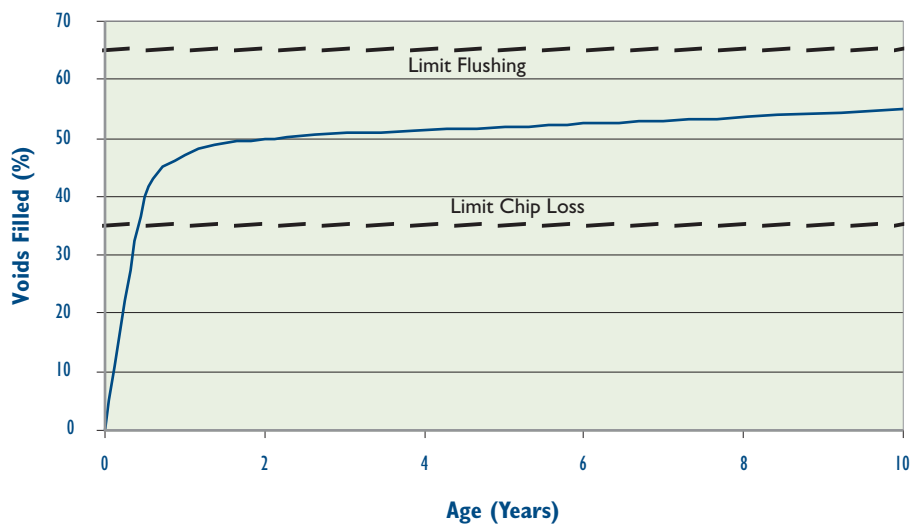
Figure 9-5   The binder application is a balance between too much binder which would cause flushing, and too little which would cause chip loss.

The effect of winter on chip retention was researched by Houghton & Hallett (1987). They found with single coat seals on roads in both Dunedin and Lower Hutt that, if the binder had not risen up the chip by 35% to fill the voids, chip loss would occur when the first cold snap occurred (and, as discussed in Section 4.2.3, this 35% value is not absolute for all conditions). The 2004 algorithm also requires that the voids must be at least 35% filled by the beginning of winter. If the seal is constructed so late in the sealing season that the binder has not had time to rise, then a softer binder will be required to reduce the risk of cohesive failure and chip loss.

The derivation of the 2004 chipseal design algorithm is as follows.

$$\frac{V_v}{ALD} = 0.83 - 0.07 \log_{10} (elv) \qquad \text{Equation 9-1}$$

where: V_v = volume of voids

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

elv = cumulative equivalent light vehicles based on assumption that one HCV is equivalent to 10 cars

The volume of voids consists of:

$$V_v = V_b + V_{air} + V_e \qquad \text{Equation 9-2}$$

where: V_b = volume of binder

V_{air} = volume of air or texture depth

V_e = volume of chip embedment

Based therefore on the requirement to have 35% of the voids filled at the beginning of winter and the assumption that seals constructed in the middle of the sealing season have 100 days until the first major frost occurs, Equation 9-1 can be modified to form Equation 9-3 as follows:

$$V_v = ALD (0.83 - 0.07 \log_{10} (T \times 100)) \qquad \text{Equation 9-3}$$

$$V_b = 0.35 \times V_v \qquad \text{Equation 9-4}$$

$$= 0.35 \times ALD (0.83 - 0.07 \log_{10} (T \times 100)) \qquad \text{Equation 9-5}$$

$$= ALD (0.291 - 0.025 \times \log_{10} (T \times 100)) \qquad \text{Equation 9-6}$$

where: V_b = residual binder volume (ℓ/m^2)

T = elv per lane per day

The relationship in brackets can be regarded as similar to the 'Traffic Factor' in previous algorithms.

9.3.4 Impact of HCVs on Binder Application Rates

In practice the percentage of HCVs on most highways is approximately 10-11% and therefore the equation can be expressed in terms of v/l/d as follows:

$$elv = v/l/d \times (1 + 0.09 \times m) \qquad \text{Equation 9-7}$$

where: m = percentage of HCVs

v/l/d = vehicles per lane per day

If the typical % HCVs is taken as 11% then:

$$elv = 2.0 \times v/l/d \qquad \text{Equation 9-8}$$

in which the factor of 2.0 can be considered to be a heavy vehicle factor 'T_f'.

In terms of v/l/d, Equation 9-6 can be expressed as:

$$V_b \quad = \quad ALD\ (0.291 - 0.025 \times \log_{10}\ (2.0 \times v/l/d \times 100)) \qquad \text{Equation 9-9}$$

If the HCV volume 'm' was very high, e.g. 40%, then the Heavy Traffic Factor 'T_f' would be:

$$T_f \quad = \quad (1 + 0.09 \times 40) \quad = \quad 4.6 \qquad \text{Equation 9-10}$$

and this would replace the value of 2.0 in the algorithm.

9.3.5   Adjustment for Texture

In the derivation of the relationships for the Lower Hutt research, the amount of binder used to compensate for the existing surface texture was excluded, i.e. the binder required to fill the existing texture was subtracted from the total volume of bitumen used.

However the road trials in the 1960s made a specific allowance for additional binder to compensate for the texture of the substrate. The adjustment developed in those trials was equivalent to increasing the ALD of the chip. As well it has been recognised that the chip does not sit proud of the existing texture and instead it interlocks with the existing texture.

In the 2004 algorithm the interlock embedment has been assumed at 30% and thus the ALD of the chip is increased by $0.7 \times Td$, where 'Td' is the texture depth measured by the sand circle test (as specified in TNZ T/3:1981).

The amount that the chip interlocks is a function of the chip sizes being used. On very coarse textured surfaces with a sand circle of <170 mm and a Grade 3 existing chip, then if a large Grade 2 chip is used, it will tend to bridge the existing texture of the underlying seal. This may need a larger adjustment for texture. On the other hand where the existing seal is already a Grade 2, and a Grade 4 is being used as a reseal, the finer chip may sit within the texture, and a lower adjustment for texture would then be required.

The basic equation that can be used for determining application rates (V_b) assuming 11% HCVs is:

$$V_b \quad = \quad (ALD + 0.7\,Td)\ (0.291 - 0.025 \times \log_{10}\ (2.0 \times v/l/d \times 100)) \\ \text{Equation 9-11}$$

where: Td = texture depth (mm) derived from the sand circle test

This rate gives the volume of residual binder at 15°C. As was the case for the 1993 *Bituminous Sealing Manual*, this application rate should be regarded as a guide only, and adjustments need to be made for other variables, as discussed in Sections 9.4 and 9.8.5.

9.3.6 Comparison with Other Algorithms

As discussed in Section 9.2, a number of changes have been made to the original algorithm known as RD286 since it was published in 1968, and the effects of the algorithms on application rates are discussed here.

Figure 9-6   Comparison of bitumen application rates, R (ℓ/m²), for a range of traffic volumes and a Grade 2 seal, calculated using three Transit NZ algorithms and the Austroads algorithm.
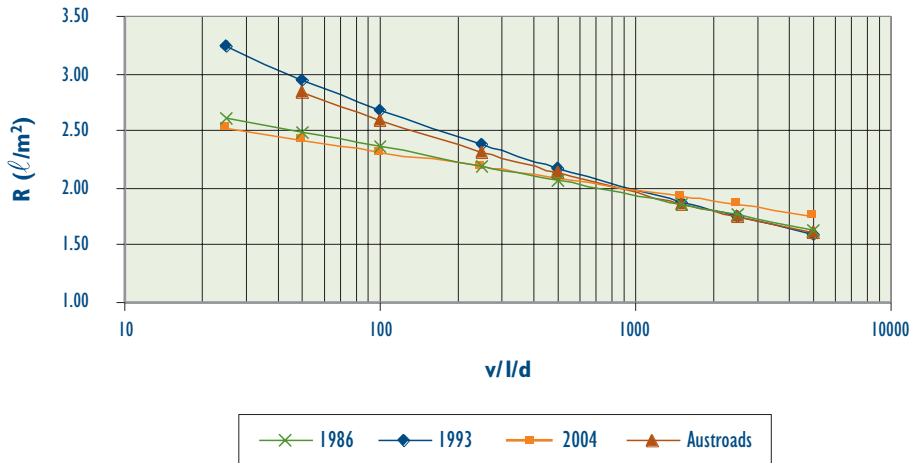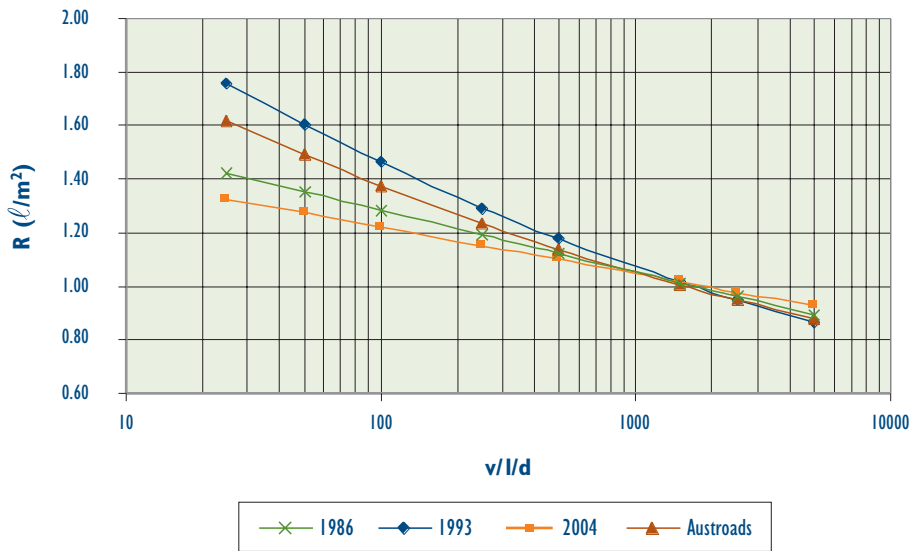

Figure 9-7   Comparison of bitumen application rates, R (ℓ/m²), for a range of traffic volumes and a Grade 4 seal, calculated using three Transit NZ algorithms and the Austroads algorithm.

Application rates calculated from the different algorithms over a range of traffic volumes are compared in Figures 9-6 and 9-7, for Grades 2 and 4 chips respectively on a relatively smooth texture. The figures show that all the algorithms are similar at higher traffic volumes but diverge at low traffic volumes.

At low traffic volumes the Austroads 2004 and the Transit NZ 1993 algorithms give similar results. The practitioners who were surveyed for this present book advocated variations in application rates greater than those in Figures 9-6 and 9-7 for low traffic volume roads.

For low traffic volumes, flushing would not be expected to occur and therefore the higher application rates can be seen as a safety factor in reducing the chance of chip loss in winter. Also the higher application rates would mean the binder may harden more slowly and, coupled with the higher binder rise around the chip, the higher application rate could assist in achieving a longer life.

On low-traffic urban roads, higher binder application rates can also assist in initially holding the chip in higher stress areas. Again with lower traffic volumes, the higher rates can be regarded as a safety factor for holding the chip and reducing the chance of chip loss, but care is required to avoid premature flushing.

In the site-specific adjustment discussed in Section 9.4, provision is made for an adjustment for low traffic areas.

9.4   Site-Specific Adjustments

The following describes other variables used in the 2004 Chipseal Design Algorithm to make site-specific adjustments.

9.4.1   Soft Substrate (Ss)

Soft substrates are occurring more often in New Zealand pavements which consist of multiple chipseals. They can also occur when resealing over asphalt or pavement repairs that have not fully cured or hardened. At present (2005), any allowance that is made in the application rate design for the extra embedment likely to occur over a soft substrate is derived simply from experience. The art is to apply sufficient binder to initially hold the chip and not lose it during the following winter before it is fully cured, yet not apply too much that will cause premature flushing to occur as embedment takes place.

In terms of the design algorithm the effect of a soft substrate can be modelled by increasing the traffic factor or decreasing the chip size.

TNZ P/17:2002 specifies the Ball Penetration Test apparatus for measuring substrate hardness. This test, which originated in South Africa and is also used in Australia, consists of measuring the penetration that a 19-mm ball bearing makes in a sample of the substrate when it is struck by one blow of a Marshall hot mix-compaction hammer (Asphalt Institute 1997). Typical ball penetration values for reseal surfacings in New Zealand are in the range of 2 to 3 mm.

Based on the South African seal design method, an adjustment for substrate hardness can be made by changing the ALD of the chip in the algorithm as follows.

If ball penetration values are:

•   1 mm or lower, increase ALD by 1 mm;

•   3-4 mm, decrease ALD by 1 mm;

•   >5 mm, substrate is too soft for a normal chipseal; pavement repairs are required.

As discussed later in Section 9.6, the sensitivity analysis shows that such a change of 1 mm in ALD would be equivalent to:

•   decreasing the binder rate by about 0.15 ℓ/m^2;

•   for a 10 mm ALD chip;

•   for a traffic volume of <1000 v/l/d.

9.4.2   Absorptive Surfaces (As)

On some surfaces binder can be absorbed, meaning that the binder 'disappears' into the surface and in effect results in a low application rate. Surfaces that may exhibit this condition are open graded porous asphalt (OGPA), an open-graded emulsion mix (OGEM), or a grader-laid asphalt. A similar absorptive effect occurs when first coat sealing over a unbound granular base.

As no method is available for assessing the degree of absorption, the preferred procedure is to seal the surface first with a small chip (see Section 7.3.4.4). If this is not possible, the basic application rate could be increased in the order of 0.1 to 0.2 ℓ/m^2.

9.4.3   Steep Grades (Gs)

On steep uphill grades, slow moving heavy vehicles can cause premature flushing of the surface. The Heavy Traffic Factor adjustment can be used for the application rates for crawler lanes (when these are provided), so the pavement can cope with the slow heavy vehicles.

A reduction of 0.1 to 0.15 ℓ/m^2 in binder application rate for these areas is commonly used to minimise the chance of binder pick-up from the truck tyres, which causes tracking and potential for flushing.

9.4.4 Chip Shape (Cs)

Chip shape is controlled by a maximum ratio of ALD:AGD of 1:2.25, although typical ratios of 1:2 have been found in practice. These shapes are preferred as they pack in with maximum shoulder-to-shoulder contact.

Some aggregate crushing systems can result in more cubical chip with ratios less than 1:2.0. The volume of voids, with this more cubical shape of chip, is higher than the voids between chips having the 1:2 cubical shape. Subsequently the binder application rate needs to be increased. Typically, the application requires up to 10% extra binder for chips with more cubical shape.

9.4.5 Urban and Low Traffic Volume Reseals (Us)

A significant number of urban Road Controlling Authorities (RCAs) and contractors are of the opinion that urban streets sealed with normal application rates suffer from chip loss along centrelines and in parking lanes.

A number of ways are available for dealing with this problem.

Generally, chip loss will be solved by increasing binder application rates from 10% up to 20%. However, apply this solution with caution especially in areas with higher traffic volumes, otherwise shortened seal life caused by flushing in the wheelpaths may result.

To reduce this risk of flushing using high binder application rates, two further options can be considered:

1. Dry-lock or wet-lock the centreline and parking lanes; and
2. Spray higher binder application rates on the centreline and parking lanes on their own. This option is more easily used on very wide streets.

As was discussed in Section 9.3.6, the 2004 Seal Design Algorithm gives lower application rates than the 1993 algorithm (Transit NZ 1993) at low traffic volumes. As the 2004 algorithm gives the minimum that should be applied, then there is scope for practitioners to increase the application rate at low traffic volumes. With traffic volumes around 100 v/l/d, then increases of 15% would give similar rates to that proposed in the 1993 algorithm.

A traffic factor that gives similar binder application rates to the 1993 algorithm is:

$$V_b \quad = \quad (ALD + 0.7\,Td\,)\,(0.42 - 0.0485 \times \log_{10}(2.0 \times v/l/d))$$

Equation 9-12

9.5 2004 Chipseal Design Algorithm

The 2004 chipseal design algorithm is therefore:

| | R | = | $V_b + As + Ss + Gs + Cs + Us$ | Equation 9-13 |

where: R = Final residual binder application rate in ℓ/m^2 at 15°C

V_b = Basic application rate from Equation 9-11 with a heavy traffic adjustment if required:

i.e. V_b = $(ALD + 0.7Td)\,(0.291 - 0.025 \times \log_{10}(2.0 \times v/l/d \times 100))$

Equation 9-11

As = Allowance for an absorptive surface

Ss = Allowance for a soft substrate

Gs = Allowance for a steep grade

Cs = Allowance for chip shape

Us = Allowance for urban and/or low traffic volumes

The 2004 seal design algorithm provides a basic design only. Site conditions and other site-specific reasons will dictate whether or not the application rate may need to be adjusted.

The RAMM database, which will contain data on application rates used locally, should be used to determine typical local application rates and therefore assist in determining the allowances that should be used.

9.6 Sensitivity of the 2004 Chipseal Design Algorithm

9.6.1 Introduction

The variables used in the main part of the 2004 Algorithm are discussed in this section. They are: ALD, texture, %HCV, traffic volume, and time before winter. The sensitivity of the algorithm to changes in these variables is discussed.

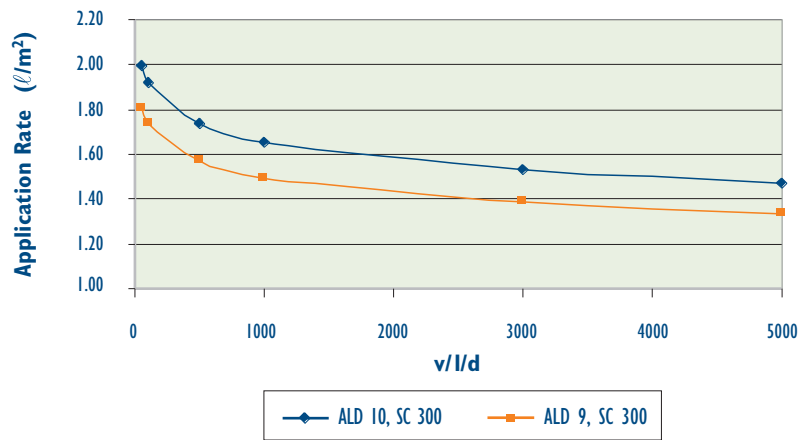Figure 9-8   Effect of changing the ALD of chip from 10 mm (coarse) to 9 mm (fine).
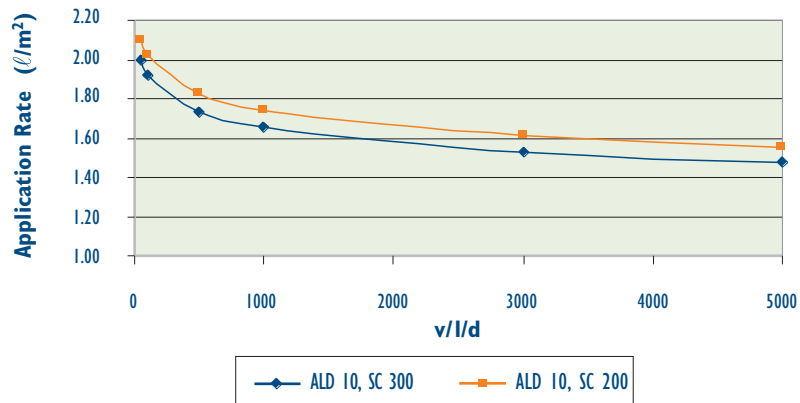

Figure 9-9   Effect of changing the texture depth of the substrate measured by a decrease in sand circle diameter from 300 mm (smoother) to 200 mm (rougher texture).
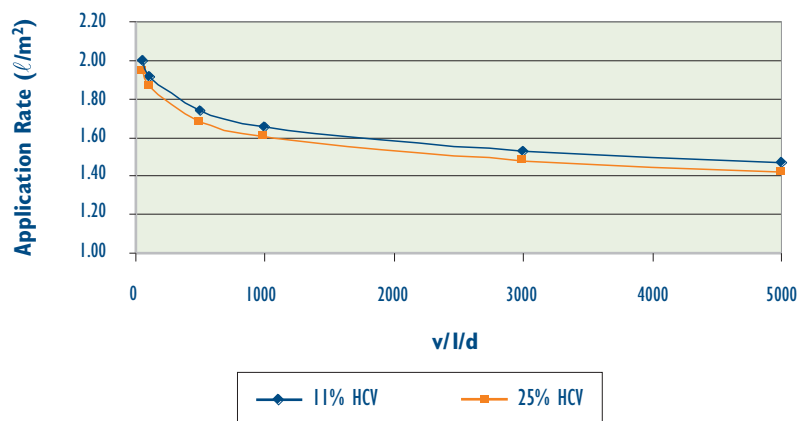

Figure 9-10   Effect of an increase in heavy vehicle traffic volume from 11% up to 25% for a pavement with chip ALD of 10 mm and sand circle diameters of 300 mm.

9.6.2   Sensitivity of Algorithm to Changes in Variables

A sensitivity analysis of the algorithm can give an indication of the accuracy required of the input. Figures 9-8, 9-9 and 9-10 illustrate the effect of changing the ALD of the chip, the texture depth of the substrate, and the % heavy vehicles respectively. The effects of changing these three inputs on the application rate of binder (V_b) are listed in Table 9-1.

Table 9-1   The effects of changes of chip ALD, texture and %HCV on application rate (V_b) for a typical road having 1000 v/l/d traffic volume.

v/l/d	Chip ALD (mm)	SC diameter (mm)	%HCV	V_b
1000	10	300	11	1.66
1000	9	300	11	1.50
1000	10	200	11	1.74
1000	10	300	25	1.60

The differences in traffic volume and texture are relatively easy to visualise. Figure 9-9 illustrates a difference between texture as measured by 300-mm and 200-mm sand circles, and Figure 9-10 a difference between 11% and 25% HCV, both of which have effects on the binder application rate that are very significant. However the difference between a chip ALD of 10 mm and 9 mm (a change of 1 mm), which is difficult to see in the field, has had the greatest effect on the application rate (i.e. 1.66 ℓ/m^2 decreases to 1.50 ℓ/m^2). Such a change in ALD of 1 mm can be considered to have the same effect on the application rate as halving the traffic volume from 1000 v/l/d to 500 v/l/d.

From a practical sense, the chip ALD is the most critical component although variations or changes in application rate of the order of 0.2 ℓ/m^2 will be made for other conditions at the site. Experienced practitioners may also make greater adjustments for HCVs than the algorithm suggests.

The rationale of the algorithm, i.e. that the volume of voids must be filled to 35% by the beginning of winter, can be used to demonstrate the importance of not sealing late in the season. Figure 9-11 illustrates that, if only 30 days remained before significant cold weather occurs, in theory the application rate would need to be increased.

To help prevent chip loss, the application rate for the 1000 v/l/d pavement would need to be increased from 1.65 ℓ/m^2 to 1.79 ℓ/m^2. This change in application rate is just as significant as that required for a change in ALD of 1 mm.
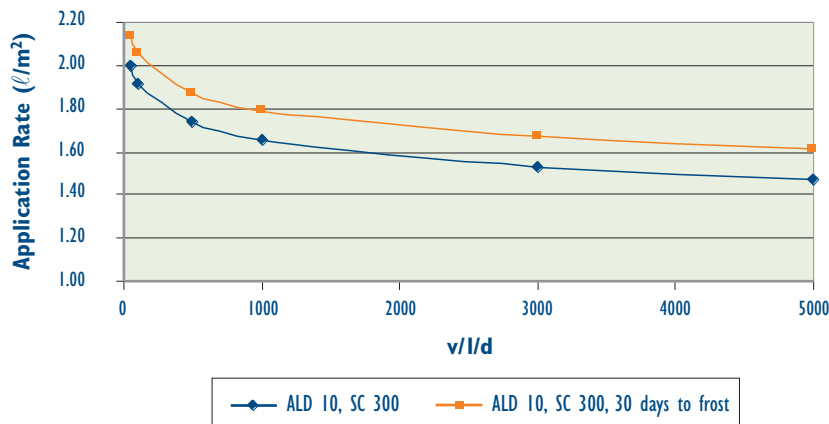
Figure 9-11   The theoretical increase in binder application rates related to traffic volume if sealing has to be done within 30 days of onset of winter conditions.

In practice such an increased application rate should not be applied as this could lead to early flushing, e.g. in the first summer. Instead a higher diluent content should be used to temporarily soften the binder so that it is not so hard at low temperatures.

On low volume roads (<1000 v/l/d) which are not expected to flush before cracking (see Chapter 4), some practitioners would argue that the increase in application rate would not affect the seal life and should be used rather than increasing the diluent content. This has been discussed in Section 9.4.5.

9.7   Design of Residual Binder Application Rates for Other Seal Types

9.7.1   Modified Binder Application Rate for Multiple Seal Coats

As discussed in Chapter 4 the volume of voids to traffic relationship for two coat seals is the same as for single coat seals.

This implies that the residual volume of bitumen that should be used in two coat seals is the same as for single coat seals. Therefore the formula used for application rate for two coat seals is calculated as for a single coat seal, with the ALD of the larger chips used in the formula.

As these seals are stronger than single coat seals, the increase in application rate for urban and low traffic seals (Us) is not as critical.

Two coat seals are considered to be more tolerant of surface texture variation than single coat seals, so the limitations given for single coats do not apply. However, extreme variations in surface texture should be avoided and, as for single coat seals, the recommendation is that a voidfilling seal should be used if the section has more than 10% of its area with a coarser texture than a 170 mm sand circle.

This binder application design is only applicable to two coat seals where the ratio of the ALDs of the two chip sizes fall within the shaded area of the graph in Figure 9-15 (see Section 9.11).

In the case of the racked-in or dry lock type of multiple seal, the binder is applied as a single application before any chip is added.

For two coat seals, the total amount of binder is applied in two applications immediately before the application of each chip layer. This split is normally at a 60:40 ratio, i.e. 0.6R is one binder application rate and 0.4R is the other (where R is the residual application rate). Some practitioners consider that the split should be 50:50 while others prefer a 40:60 split. When deciding what the split should be, it is wise to consider how the low rate will distribute through the chip. If the second rate is very low, most of the binder is applied to only one side of the large chip. Alternatively streaking could occur.

Where small chip sizes are being used, the first and/or second binder application rates may be too low for them to be accurately applied by the sprayer. If this is the case, then one or both of the applications will have to be applied as emulsions.

The above procedure is based on both coats of the two coat seal being constructed in succession on the same day. Where a gap in time of a day or more occurs between the construction of the first coat and the second, it is usually called a wet lock. In this case the first coat is designed as a single coat seal and the second as a voidfill.

9.7.2   Cape Seals

The sprayed binder rate for a cape seal should be as for a single coat seal.

9.7.3   Sandwich Seals

A sandwich seal is used to absorb excess binder on a flushed seal. The objective is therefore to use a binder application rate that is as low as possible.

The determination of the appropriate application depends on the quantity of excess binder but can be approximated by using the ALD of the small chip rather than that of the large chip when applying the application rate calculations shown in Section 9.5.

As sandwich seals are used only on flushed surfaces, no texture depth correction is required.

The binder is applied at the total application rate after the first layer of chip has been spread and before the second layer of chip is applied.

9.7.4   Geotextile Seals

The sequence of construction for a geotextile seal (see Figure 3-25) is to apply the first layer of binder at a rate sufficient to saturate the fabric mat, and as specified by the geotextile manufacturer. This depends on the fabric but is in the order of 1 ℓ/m^2. The fabric is then applied on top of the first layer of binder, and a conventional seal coat with application rates as calculated normally (Section 9.5) is placed over the fabric.

While 1 ℓ/m^2 may be required to saturate the fabric, care is required not to apply all of this in the base tack coat because, if the tack coat is too heavy, the saturated fabric will stick to tyres and lift off during the second application of binder.

9.7.5   Precoating

Precoating of sealing chip is a technique that produces good adhesion between binder and chip in the early stages of chipseal construction. It allows the cutter content of the binder to be reduced, can enable the use of stiffer binders, and lowers the risk of stripping and chip loss.

The coating should be as thin as possible to prevent the chips from sticking together as they then become difficult to handle and distribute.

Precoating materials should have an adhesion agent added to ensure that the bond between the precoating layer and the chip is adequate.

For cold-applied precoats consisting mainly of diesel oil, 6 to 8 ℓ/m^3 of precoat are required for a clean Grade 2 chip. As chip size decreases, the amount of precoat will need to be increased accordingly to compensate for the greater surface area and will be up to 10 to 12 ℓ/m^3 for Grade 6 chip.

If dust is present on the chip, and depending on how much there is, the amount of precoat may need to be increased by up to a further 2 ℓ/m^3. The aim is to produce a complete coating that cannot be washed off with water. If the dust is excessive, it should be removed before precoating by washing or pre-screening.

For hot-applied precoats with straight-run bitumen, the quantity of precoat may need to be increased from 10 to 12 ℓ/m^3 or more) to get adequate coverage. Up to 2% by weight may be required and even then the higher viscosity may not give a continuous film over each chip, presenting a speckled brown appearance. This is acceptable and will produce satisfactory results provided that this chip is used within a short period, is not too dusty and the bitumen cannot be washed off with water or rain.

Note that precoating can add up to 0.1 ℓ/m^3 residual binder to the chipseal. As discussed above in connection with Figure 9-11, this increase in application rate can be enough to lead to premature flushing. Therefore a reduction in binder application rate by 0.1 ℓ/m^3 may be required when using precoated materials.

9.8   Practical Aspects for Seal Design

9.8.1   Spray Runs

The start and end positions, widths and tapers of the spray runs need to be planned and documented in advance in all but the very simplest situations. It is essential that the appropriate application rates are designed in advance for different parts of the pavement, and that the field construction personnel are absolutely in no doubt where each change in rate is to occur.

Details of spray run planning for longitudinal laps, at intersections and in wheelpaths are in Chapter 11. It is a two-stage process: to gain first an approximate layout for spraying, then to develop the detailed design requirements specific to sections.

9.8.2   Homogeneous Sections

The seal design is applied to a homogeneous section of pavement.

In assessing the homogeneity the following variables need to be considered:
- Traffic;
- Texture;
- Pavement hardness;
- Stress.

Wherever the surface condition changes, a new or modified seal design or seal type for the different condition in that segment needs to be considered.

In the surfacing selection process made at the first stage, detailed in Chapters 5 and 6, a preliminary assessment will have been made. In the specific design undertaken at the second stage in readiness for the operation, the available chip sizes, traffic volume, etc. will be used to determine the final design that will be used on the site.

9.8.3 Segmentation by Traffic

If the road has sections that carry different volumes of traffic, each of those sections must be investigated and designed separately. A 'one size fits all' approach will not result in the optimum design for any of the sections.

Examples of situations where it is always necessary to investigate breaking the road up into separate design sections are as follows:

- Wide shoulders and through-lanes;
- The fast and slow lanes of a multi-lane road;
- Turn bays and slip lanes at intersections;
- Parking lanes in urban areas;
- Uphill and downhill lanes on steep gradients that significantly affect truck speeds.

In some cases the sections may be too small or awkward to allow for separate spray runs. In those sections the design should still be checked to see how far the ideal design is likely to differ from the one chosen. The chosen design should be that which suits the section carrying the most traffic. If the designs differ a lot, the need for pretreatment to make the surfaces more uniform should be investigated, so that the binder application rate can be more efficiently designed.

9.8.4 Traffic Volume

In most locations, most of the heavy vehicle traffic will use the left hand of multiple lanes, except at right-turn bays.

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This may not be the case in situations where the volumes of traffic are high and include high numbers of trucks. Light vehicle traffic will also use the left lane except when the traffic is heavy and/or significant numbers of slow-moving vehicles are in the flow. In these cases special traffic counts are warranted to ascertain the split of heavy vehicles, especially if they form more than about 20% of the total traffic flow.

9.8.5   Texture Variation

In most cases the texture depth will differ along the length to be resealed. The results of the sand circle tests are studied to determine how the surface should be divided up to achieve the optimum matching of application rate to surface texture, without requiring an excessive number of short spray runs.

Each type of seal differs in its sensitivity to texture variation and excessive texture. Voidfilling seals which are not sensitive to texture are specifically intended to be used on pavements where the texture is deep and variable. At the other end of the scale, conventional large- or medium-sized single chipseals are quite sensitive to texture and can tolerate only slight variation in texture.

If the section has more than 10% of its area with a coarser texture than 170 mm (estimated by sand circle), a voidfilling seal is the desirable seal type to select rather than a conventional reseal. This requirement should normally be picked up during the seal selection investigation but needs to be re-checked at the detailed design stage.

Application rate design has to steer a path between applying too much binder and applying not enough, as stated before. Enough binder is needed to securely hold chips on the lesser trafficked centreline between wheelpaths and road edge areas.

The situation can occur where the difference between the centreline texture and wheelpath texture is so great that the binder application rate required to hold chip in the wheelpaths will not be enough to hold chips either on the centreline or between the wheelpaths.

To cope with this variation, the designer checks the texture variation between sections with coarsest and finest chip size to determine if the seal can perform reasonably with the chosen application rate.

As a rule of thumb for deciding whether the difference between wheelpath and centreline textures is excessive, apply the following so-called 'ALD/16 rule' for single coat seals:

$$Td_{(coarse)} - Td_{(average)} \text{ shall be} < Min\ ALD/16 \qquad \text{Equation 9-14}$$

$$Td_{(average)} - Td_{(fine)} \text{ shall be} < Min\ ALD/16 \qquad \text{Equation 9-15}$$

where: $Td_{(average)}$ =   average texture depth (mm) from all the sand circle measurements taken for each spray run section

$Td_{(coarse)}$ =   largest texture depth (mm) from sand circle measurements

$Td_{(fine)}$ =   smallest texture depth (mm) from sand circle measurements

If the difference between either $Td_{(average)}$ and $Td_{(coarse)}$ or $Td_{(fine)}$ is greater than ALD/16, then a texturising seal should be used. This rule is not applied to first coat seals.

For first coat seals, $Td_{(average)}$ should be limited to less than, or equal to, 1.5 mm.

If a pavement with a texture variation greater than ALD/16 is sealed, and the binder application rate is determined from the average texture depth, then sufficient binder rise may not have occurred by winter to ensure good chip retention. Multiple coat seals can tolerate a larger texture variation as they have increased strength through chip interlock that will assist them under normal traffic loading to resist winter chip loss, even if binder rise is less.

Care should be taken to ensure that the application rate being used is not so high that premature flushing results on low texture areas. The practice of using the wheelpath texture for two coat design rather than using the average between centreline and wheelpath assists in minimising the binder application rate, and in this way preventing flushing yet utilising the increased strength of this seal to resist early chip loss.

Traditionally the texture depth derived from average sand circles has been used in the calculations, although more recently some practitioners have been using the wheelpath texture depth. This can result in a lower application rate being applied, which is thought to help prevent premature flushing.

If the texture variation is excessive, the following measures should be considered:

• Determine if the area can be subdivided practically;

• If different application rates can be applied to each area;

• Try the effect of using a larger chip;

- Correct the extreme texture areas if they do not cover too much of the total area;
- Change design to a voidfilling type reseal or, if texture is not too variable, to another type of chipseal.

9.8.6   Pavement Hardness

The hardness of the existing pavement should have been considered in the treatment selection process.

For example, if the existing surface had been a hot mix asphalt, then provision should have been made to use an appropriate size chip or to ensure that the mix had hardened sufficiently to allow the construction of a seal. See also Section 9.4.1 to allow for the effects of soft substrate.

In the more detailed investigation for the final design, the hardness of preseal repairs and variations in the existing surface need to be considered in order to plan homogeneous spray runs.

A similar process to that used for a variable texture in attempting to obtain consistent spray runs should be considered to cope with softer areas. Also if a bridge deck is part of the chipsealing site, adjusting the spray rate for the harder substrate will have to be considered.

9.8.7   High Stress Sites

Although a site may appear to be suitable overall for, say, a single coat seal, it may include areas where turning traffic, driveways or sharp bends could impose high levels of stress.

In these areas a different seal system, e.g. racked-in or dry lock, may be more appropriate. These high stress areas are often small and can be accommodated in the spray run, and separate designs are not required.

9.9   Design of Residual Binder

Three bitumen grades are commonly used for chipsealing: 180/200, 130/150 and 80/100 penetration grades and they are used in First coat seals and Reseals.

9.9.1   Binder for First Coat Seals

In the past, first coats always used 180/200 grade bitumen but in recent years 130/150 grade has been used, and even 80/100 grade in some situations.

Assessment of the unbound surface cannot be done until the compaction rolling is complete. However, testing may be needed before the final brooming of the surface in preparation for sealing. If sand circle testing is required, several representative small areas of the trafficked surface are vigorously hand broomed to produce a surface that would be similar to the surface prepared for sealing.

In most cases after brooming, the texture of the surface will be appreciable and this may have to be allowed for in the design of the first coat application rate.

If the first coat chip to be used is fine and the texture of the surface is made up by large (20 mm plus) aggregate (which is the ideal case), the first coat will essentially be acting as a voidfiller for the basecourse texture.

If the texture is significant but made up of finer chip, the texture will need to be measured so that its effect on the application rate can be calculated.

9.9.2   Cutting Back for First Coat Seals

9.9.2.1   Developing a Good Bond

For first coat seals on an unbound granular base, a good bond must be developed that penetrates the dust layer which inevitably forms on a basecourse surface. It is advantageous if the binder can also penetrate into the top of the basecourse. For this reason the normal cutter content for a first coat seal is 6-8 pph of total diluent. In many places the diluent is all kerosene, although for some areas it may also include some AGO (Automotive Gas Oil).

The critical importance of establishing a good bond to the basecourse in order to achieve a waterproof seal has been discussed in Chapters 3, 6 and 7. The difference between a first coat seal and a second coat or reseal is that, with a first coat seal, the underlying base is inevitably dusty and somewhat porous. Hence total diluents in a cutback binder

must be adjusted to compensate. For bases prepared with aggregates meeting the TNZ B/2:1997 specification, i.e. they are reasonably clean, the cutback content is about 3 pph higher than for a reseal which has a minimum of approximately 3 pph.

9.9.2.2 Temperature

The total diluents are not reduced to zero for higher air temperatures because the requirement for wetting the basecourse takes priority over the danger of bleeding. An adhesion agent should always be used in these situations.

9.9.2.3 Influence of Cutter

A primer used to penetrate dust and fine material on an unsealed basecourse has a high cutter content and low viscosity. A first coat binder must hold the sealing chip firmly and must therefore be less fluid than a primer. Because a first coat seal has more cutter, it should never be sealed with a second coat or overlaid with asphalt until the cutter has cured out. Otherwise the remaining cutter will seriously soften the second layer laid on top.

In circumstances where early overlay is the best option, use of emulsion first-coat binders would be desirable because they have little cutter and yet are more fluid. However, unless the emulsion has been specially formulated, as discussed for prime coats, it may not provide a reliable bond to the base.

9.9.3 Binder for Second Coat Seals and Reseals

To approve the area for sealing in the first place, normally the road asset manager will have had a detailed pavement assessment carried out. In the process, some sand circle testing will have been carried out to decide whether the new seal will be of the voidfilling type or not. Those investigations may well have been made some time in advance of the sealing season, and conditions could have changed in the interval between the pavement analysis and the sealing operation.

For the final seal design, the detailed design testing should be carried out as close to the actual sealing date as logistical decisions allow.

The final testing should be combined with a check of the surface to make certain that all repaired areas are in a fit state for sealing in regard to stability, curing and texture. Where clearly a voidfilling seal type is to be used, this visual check of repairs is all that is required.

9.9.3.1　Texture Testing

For reseals or second coats the texture of the existing surface must be accurately measured by sand circle so that it is allowed for in the seal spray rate design.

Instructions to the staff who are measuring the sand circles would usually include the preliminary spray run plans described in Section 9.8. The sand circle measurements and close observation may reveal the need for further segmentation or other modification of the spray runs. The testing staff need to be able to recognise this in the field and be able to undertake additional testing as required.

The sand circle measurements are made to determine the average and the two extremes which are representative of the length of road being sealed. To achieve this, the site of each sand circle measurement position needs to be carefully chosen. Measurements should be taken at approximately 100-m intervals along the road, with a minimum of five places being tested if the length of road being sealed is less than 400 m.

Where the shoulders are wider than 0.75 m, the texture should also be measured at 200 mm inside the seal edge.

For each spray run, two sand circle measurements should be taken at each cross section: one of the smoothest and one of the coarsest textures. The occasional area of extreme variability in wheelpaths maybe ignored.

9.9.3.2　Grade of Bitumen

Although 180/200 grade bitumen has been the most common grade used in the past in New Zealand, over the last 10 years the use of the harder 130/150 and 80/100 grades has increased.

The reason for using the harder 80/100 and 130/150 grade bitumens is to prevent chip loss caused by chip rollover during the summer and to minimise the risk of bleeding and binder pick-up.

9.9.3.3　High Temperature Considerations

Only limited research has been performed on binder pick-up by tyres but Figure 9-12 illustrates modelling of a truck tyre on a chipseal. It shows how a tyre can push into a seal for more than 1.5 mm. If the binder has risen to within 1.5 mm of the tops of the chip, the tyre can pick up that binder.
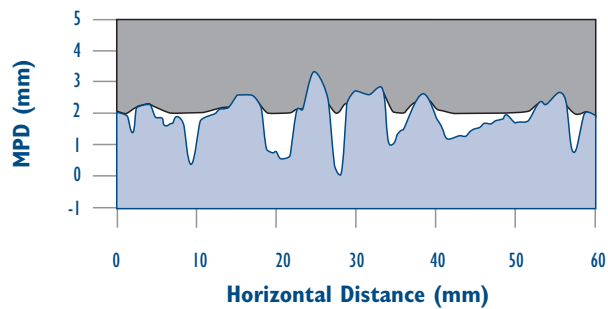
Figure 9-12   A model showing how a tyre can push into a seal and pick up binder. Tracking will occur if the binder is high enough up the sides of the chips.

The viscosity of the binder at which tyre pick-up under slow moving traffic will occur is about 200 Pa.s. Figure 9-13 shows the viscosity–temperature relationship for New Zealand bitumen, and that this viscosity is reached at 47°C for 180/200 and at 57°C for 80/100 grades. (This viscosity for a 130/150 grade would be at 52°C, but is not shown on the figure.) In practice the addition of kerosene as a cutter means that binder pick-up occurs at significantly lower temperatures in the first year after construction.
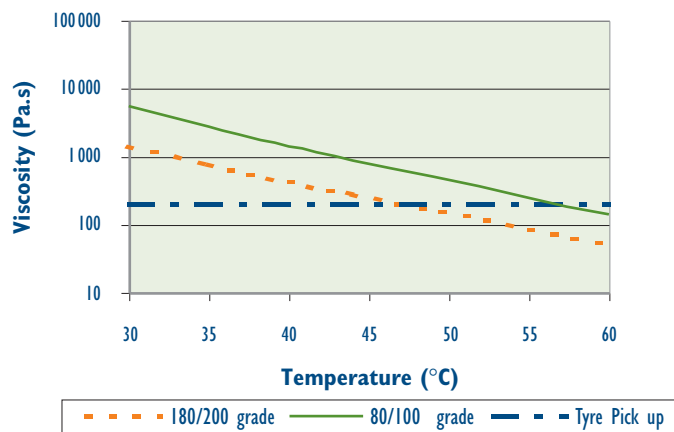
Figure 9-13   Viscosity (Pa.s) of binder for two grades of bitumen and its relationship to the temperature at which tyres pick up binder.

In deciding which grade bitumen to use, the temperature range for the location needs to be considered, and not just at the regional climate level but more at microclimate level because high or low extremes of temperature may occur near the pavement surface (see Section 4.2.3).

From the bitumen durability trial data (Ball 1998), a 180/200 grade bitumen will have hardened to approximately the penetration of a 80/100 grade bitumen within one year. However residual kerosene used in chipseal construction would tend to keep it softer for a longer time.

If the site is subjected to high temperature, slow traffic and/or heavy traffic, then the use of a PMB with higher softening points can be considered for resisting tyre pick-up.

The risk of bleeding and tyre pick-up decreases as the binder hardens and the seal ages, especially if harder binders and lower diluent contents are used (so the binder is harder to start with), and if traffic is faster (because slow-moving heavy traffic which aggravates bleeding is minimised).

Recent research by Ball (in press) has shown that under typical New Zealand conditions the binder grade does not have any effect on the rate of change in texture. This means that harder binder grades will not delay the onset of flushing.

9.9.3.4   Low Temperature Considerations

At the other end of the temperature spectrum, the need is to ensure that the binder is not so hard in winter that premature cracking or chip loss occurs. This concern has prompted the use of 180/200 bitumen and, in some areas, the use of a flux (e.g. AGO) to attempt to permanently soften the binder. As was noted in Section 4.2.1, 70% of the added AGO has evaporated after 5 years when, in the past, it had been assumed that the AGO did not evaporate. Therefore AGO is not now regarded as a permanent flux. If permanent softening is required, other materials (e.g. furnace oils) could be used.

The present manufacturing process being used to produce bitumen from the Marsden Point Refinery results in a reduction in temperature susceptibility as the bitumen goes from soft to hard grades of bitumen. This means that, although at 25°C the difference in hardness is significant, this difference decreases at lower temperatures so that at 0°C and below, the three grades are very similar in properties (see Figure 8-7). This relationship applies only to bitumen currently produced at Marsden Point.

The combination of the decreasing temperature susceptibility with control of durability has encouraged the use of harder grades of binder in colder regions. Although trials of harder grades in cold regions of New Zealand are only about 5 years old, no apparent increase has occurred in low temperature cracking.

9.10   Selection of Binder Type and Additives

9.10.1   Binder Type, Emulsion or Cutback

The basic characteristics of emulsions and cutbacks are discussed in detail in Chapter 8.

Emulsions are used less frequently than cutbacks for most seal types, principally because of cost. As design of emulsions to reduce their early tenderness or slow curing is not yet a science, it requires experience with the local aggregates and conditions.

> A claimed advantage of emulsions is that they allow good adhesion in cool damp conditions. Although good adhesion does occur, breaking time of conventional emulsions is usually delayed in cold humid conditions. The emulsion chipseal is then vulnerable if rain falls before the break occurs. This can result in a higher risk of failure than if a cutback binder had been used. In colder weather the tender 'cheesy' phase also lasts longer.

Emulsions can be formulated to cope with and reduce this risk. If it is too risky for even a well-made emulsion, then a cutback binder would also be a high risk treatment.

Fine Grade 6 chip is usually used with emulsions for voidfilling. The tenderness of emulsions in this case does not usually matter because fine chip is held within the voids of the larger chip. Almost any cationic emulsion complying with TNZ M/1:1995 specification will hold such small chip in reasonable weather conditions. Grade 6 seals require very low binder application rates that may be outside the application rate range of the distributors used for hot cutback bitumen binders. The higher water content of emulsions will boost the application rate, which then falls within the distributor's application rate range.

9.10.2   Binder Additives

9.10.2.1   Fluxes

AGO can be blended with the base bitumen to produce a softer residual binder by a process called fluxing. The addition of 2 pph of flux to 80/100 bitumen will produce a bitumen of approximately 130/150 grade, and an addition of 4 pph will result in a bitumen of approximately 180/200 grade.

The use of AGO is decreasing in New Zealand. Even for first coat seals where up to 4 pph has been added in the past, the realisation that the evaporation rate of AGO is faster than originally believed has lead to the use of kerosene rather than AGO as flux.

9.10.2.2 Adhesion Agents

The adhesion between bitumen and chips is a surface chemistry phenomenon. Given a low enough viscosity, a bituminous binder will usually spread across the surface of a dry chip 'wetting' it and thereby initiating a bond.

However, if a film of free water exists on the chip surface, the bitumen cannot adhere without first displacing the water (see Figure 8-9), as the chip–water bond is much stronger.

It is therefore good practice to use an adhesion agent (Section 8.2.2) to increase the ability of the hot bitumen binder to set up a good bond between the substrate, the binder and the chips in the presence of water. Tests can be used to determine the dosage rate of the agent, and typical dosage rates are between 0.5 and 1.0 pph of binder.

Adhesion agents are not required in emulsion binders as the emulsifiers used to produce the emulsion provide the same function.

Precoated chips often have an adhesion agent incorporated in the precoating agent, so that if precoated chips are used an adhesion agent is not needed in the binder (see Section 8.2.3).

9.10.2.3 Polymers

The use of polymers has been discussed in Section 8.4. If they are used, then care is needed when determining the correct percentage to be used for the binder application rate, taking into account all variables (as outlined in Section 9.4). The residual binder should have the same final application rates and properties regardless of whether the polymer-modified bitumen binder (PMB) is applied as a cutback or as an emulsion. Because of the many additives used in producing PMBs, the grade of bitumen used in their manufacture does not have as significant an effect as it does in straight bitumen sealing. Advice should be sought from the PMB manufacturer on the properties of the PMB blend.

9.10.3   Cutting Back

9.10.3.1 Objectives

Objectives in chipsealing design include obtaining:

- a binder viscosity on the road that allows the binder to adhere to the chip;
- cohesion to resist chip displacement after adhesion has occurred;
- a binder viscosity and expected % voids filled at the onset of winter that is enough to prevent chip loss;
- sufficient binder viscosity for the following season so that bleeding and pick-up on tyres will not occur.

Other factors that need to be considered when using high cutter contents include:

• binder pick-up by pedestrians;

• flow of binder into gutters and on steep pavements.

9.10.3.2 Process

The process of temporarily reducing the bitumen viscosity using diluents (as opposed to using an emulsion), termed 'cutting back', normally uses kerosene as the diluent. In calculating the binder application rate the kerosene is not included, and this is termed the 'residual binder', the assumption being that all the cutter evaporates.

When a binder is sprayed it very quickly cools to approximately the pavement temperature. Pollard (1967) found that the binder cooled within approximately two minutes to just above (5°C) the existing pavement temperature. Pollard pointed out that even in a relatively dry area of New Zealand (Canterbury) the humidity in stockpile was 100% and thus the chip was damp. The chip that is applied to the binder therefore will not adhere until the water has evaporated, and this takes time.

Once the chip has been applied the roller and traffic then will re-orient it. Throughout this process faces of the chip are being pushed into the binder and this process of re-orienting can take at least 24 hours or longer. When the chip embeds in the binder, adhesion needs to occur.

The above discussion indicates that binder–chip adhesion occurs over a period of hours to days rather than minutes, and relying on obtaining an on-road binder viscosity at the time of chip application can unrealistic. Pollard demonstrated, for example, that the arrival of a cold front could cause a rapid drop in pavement temperature. Another significant factor affecting pavement temperature is shade as the difference between the pavement temperature in the shade and in the sun can be greater than 20°C.

The rate of wetting of a binder on a chip has been shown by Forbes et al. (2000) to be an inverse function of the viscosity. Using Forbes' relationships and an estimate of the change of viscosity of bitumen with temperature, the ratio of wetting time for a 180/200 bitumen at 35°C is shown in Figure 9-14. This figure illustrates that, if the wetting time at 35°C for a 180/200 grade bitumen is taken as 1, then at 20°C the bitumen will take 7 times as long to wet the same area, and 30 times as long at 10°C. An 80/100 grade bitumen at 20°C will take 30 times longer than the 180/200 grade at 35°C. This shows that the exponential nature of the change in viscosity with temperature has a very significant effect on the time for wetting and adhesion to take place.

9.10.3.3 Effect of Shade

Figure 9-14 illustrates why initial adhesion problems can occur where the pavement is in the shade. The pavement in the sun could be at 35°C, but in the shade could be below

20°C. Thus while the chip in the sun-lit areas may have adhered by the end of the working day, the area in the shade will take seven times as long to adhere and is thus vulnerable to chip loss. Active traffic control can minimise this and in some regions, 48 hours of active traffic control is required after sealing. If sealing is performed near the end of the day followed by a drop in temperature overnight, chip loss may occur. Seals constructed earlier in the day will adhere and perform well, while those constructed late in the day may loose chip.
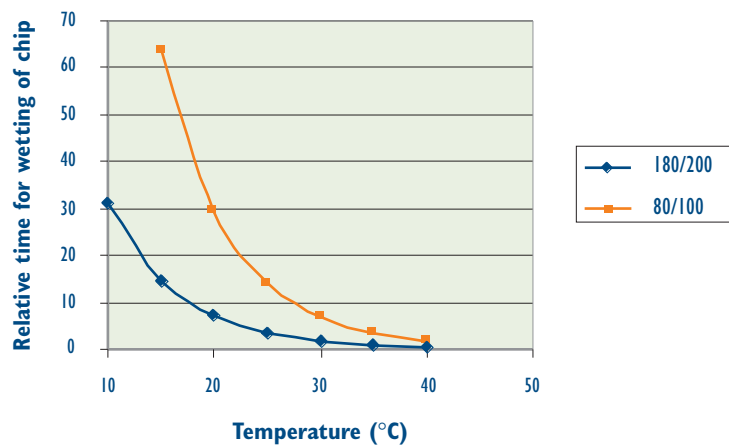

Figure 9-14   Relative increase in time required for wetting chip with decrease in temperature for two grades of bitumen.

9.10.3.4   Effect of Rolling and Traffic

The effect of rolling and traffic on the development of a good bond can be considered as similar to a pressure-sensitive adhesive. As the viscosity of bitumen is stress-dependent, the tyre stress results in the binder acting at a lower viscosity, and the stress also increases the rate of wetting. From the work of Forbes et al. (2000) the rate of wetting will be directly proportional to the stress imposed. Rolling and traffic will therefore assist the adhesion process.

9.10.3.5   Effect of an Emulsion

Even though the use of an emulsion will result in an initial coating of some of the chip with binder it does not result in mitigating all the variables associated with adhesion. After the emulsion has cured, chip re-orientation still takes place and, if sufficient wetting of the binder over the chip has not taken place before the construction crew leaves the site, then chip loss overnight can occur.

9.10.3.6   Desired Viscosity of Binder on the Road

Attempts to determine a target viscosity for the binder on the road are complicated not just by the rapid changes in temperature that can occur but also because approximately 20% of the added kerosene is lost during the construction process.

From the above discussion it is not surprising that a wide range of opinions and experiences exist in the determination of the on-road viscosity required for construction.

The decision on diluent content is therefore based on an assessment of risk. If binder has too little diluent, adhesion may not occur, but too much diluent and cohesive failure may occur. Either way the failure mode is chip loss.

Factors that affect the decision on the quantity of diluent besides the daytime temperature include:

- Time of year – in mid-summer the hours of sunlight and heat in the pavement are longer and the drop in temperature is less than in autumn, so less diluent is required.

- Time of day – if sealing in autumn or spring and low night-time temperatures are expected, then a higher diluent content is required when sealing in the afternoon.

- Settled weather – if a cold front is likely within 24 hours of sealing, then a higher diluent content could be required. If on the other hand, a cold front has just passed and temperatures are expected to increase, then a lower diluent content could be used.

- Traffic volume – where traffic volumes are higher, a lower diluent content can be used as long as traffic is controlled to track over the whole surface. Conversely where traffic volumes are very low then higher diluent contents should be used.

- Chip cleanness – if the chips are of borderline standard or do not meet the cleanness required by TNZ M/6:2004, then a higher diluent content would be required to ensure chip wetting and adhesion.

- Slow heavy traffic – a lower diluent content can be used to guard against binder pick-up caused by slow heavy vehicles pressing deeply into the seal.

- Precoated chip – if the chip is precoated, then a lower diluent content can be used.

In practice it is common for a sealing operation to use a 'recipe' approach, where a standard diluent content will be used in the beginning of the sealing season, another in the middle, and yet another at the end. For example, this maybe 4 pph of kerosene as cutter in the early and late season, and 2 pph in the middle of the season.

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A starting point for deciding the diluent content to use is given in Table 9-2. This is considered appropriate for average traffic conditions, so that at low traffic volumes the diluent contents can be increased by 2 to 3 pph and at very high traffic volumes diluent can be decreased by 2 to 3 pph.

Table 9-2   Diluent contents recommended for a reseal at 24h maximum air temperatures and three bitumen grades.

Expected 24h Maximum Shade Air Temperature (°C)	Reseal Bitumen Grade		
	180/200	130/150	80/100
	Diluents - parts per hundred		
15.0	6	8	10
17.5	4	6	8
20.0	2	4	6
22.5	0	2	4
25.0	0	0	2
27.5 and over	0	0	0

9.11   Design for Chip Application Rates

9.11.1   Design Using 2004 Algorithm

Chip application rates are traditionally specified in terms of area per volume (m^2/m^3). This allows the sealing crew to easily estimate the area (m^2) that will be covered with a truck load of chip (of a known volume in m^3).

A theoretical chip application rate can be calculated based on the total void volume and this was used in the past to estimate the 'correct' application rate.

As discussed in Section 9.3.1, the volume of voids is significantly higher than 20% in a single coat seal.

Using the relationships in the algorithm given in Section 9.5, the voids on a lightly trafficked road are likely to be approximately 40% after two years. This equates to a chip application rate of approximately 830/ALD m^2/m^3. Using the above analysis procedure, the theoretical application rate and a rate with a 10% allowance for loss by whip off is given in Table 9-3.

If the thickness of a seal is assumed to equal the ALD of the chip, then the volume required to seal a square metre is equal to:

$$V_T = 1 \times \frac{ALD}{1000} \ m^3$$ Equation 9-16

where: V_T = total volume of the seal (m^3)

The volume of chip is a proportion of the total volume:

$$V_S = (1-V_V) V_T \qquad \text{Equation 9-17}$$

where: V_S = volume of chip (m³)

V_V = proportion of voids as defined in Section 9.3.1

Combining Equations 9-16 and 9-17:

$$V_S = (1-V_V) \times \frac{ALD}{1000} \text{ m}^3 \qquad \text{Equation 9-18}$$

The chip in a truck has a void content of approximately 50%. Therefore the loose volume of chip that needs to be delivered and spread on the seal is double that of the compacted chip.

$$V_l = 2(1-V_V) \times \frac{ALD}{1000} \text{ m}^3 \qquad \text{Equation 9-19}$$

where: V_l = volume of loose chip (m³)

In terms of m²/m³ Equation 9-19 can be expressed as:

$$R_c = \frac{1000}{2 \times ALD \times (1-V_V)} \text{ m}^2/\text{m}^3 \qquad \text{Equation 9-20}$$

Hanson's research indicated that the voids in a compacted seal were approximately 20%, i.e. $V_V = 0.2$. Substituting this value into Equation 9-20:

$$R_c = \frac{1000}{1.6ALD}$$

$$= \frac{625}{ALD}$$

This is the basis of the chip application rate recommendations made in earlier publications (NRB 1971).

Table 9-3   Chip application rates for single coat seals.

V_v	V_s	$\frac{x}{ALD}$ m²/m³	+10% allowance for whip off
0.20	0.80	625	560
0.25	0.75	667	600
0.30	0.70	714	640
0.35	0.65	769	690
0.40	0.60	833	750

where: V_v = volume of voids; V_s = volume of chip; $V_v + V_s = 1$

Recent research by Alderson (2001) indicates that an application rate of 900/ALD m²/m³ appears appropriate for most chipseals, and that when excess chip is applied it quickly disappears by whip off. The Austroads research also indicated that the loss was not

associated with traffic volume. This research does not support the findings of Major (1993) who found that over-application of chip was a significant factor in poor seal performance.

The chip application rates required for single chipseals, multiple seals and special seals are the same for first coat seals, second coats or reseals.

The 1993 Sealing Manual considered that a chip application rate of $\frac{1000}{ALD}$ m²/m³

was a 'theoretical' optimum and that a numerator of 700 to 750 should be used to estimate the total amount required. This compares well with the Table 9-3 numerator of 750 for a V_V of 0.4. Although there are various options on the optimum application rate for chip, in practice it is visually assessed as discussed in Chapter 11.

9.11.2   Selection of Chip

Selection of chip size is covered below but chip properties should also be considered by the seal designer.

The chip chosen must comply with all requirements of TNZ M/6 *Specification for sealing chip* (Section 8.5.8). In particular, the PSV of the chip must be adequate to resist on-road polishing, taking into account the requirements of TNZ T/10 and the previous actual on-road performance of chips in relation to predicted on-road performance (Section 6.6.1.2).

9.11.3   Single Coat Seals and Cape Seals

For conventional single chipseals which require Grades 2 to 5 sealing chip, an estimate of the chip rate as calculated above is given by:

$$\text{Rate} = \frac{750}{ALD} \text{ m}^2/\text{m}^3 \qquad\qquad \text{Equation 9-21}$$

This allows for approximately 10% for whip off but assumes a good standard of uniformity of chip spread. See Figure 11-4 in Chapter 11.

9.11.4   Voidfilling Seals

The chip application rate for a voidfill seal is approximately 80% of the rate for a conventional seal, i.e. 950/ALD m²/m³ for Grades 4 and 5 and approximately 250 to 300 m²/m³ for Grade 6.

Selection of the correct chip size is essential so that it fits into the texture of the old seal. Taking actual samples of several chip sizes on site and physically observing how they interlock with the substrate allows the optimum chip size to be selected.

9.11.5   Racked-In Seals

In a racked-in seal the chip application rates of both layers are given as 1050/ALD m^2/m^3 for Grades 2 to 5 and 350 m^2/m^3 for Grade 6 chip. These rates are 70% of those for a conventional seal. After the optional rolling of the first layer of chip, the second chip layer is added and it should just fill the surface voids of the first.

The compatibility of sizes between the two layers of chip is important, and Figure 9-15 shows a guide that can be used, based on the second chip being approximately half the size of the first chip. The intersection of the size of the first chip and the size of the second chip should lie within the shaded area on Figure 9-15. This should be checked on-site using the chips that will be used on the job.

Chip combinations with ALD intersections above the shaded area should be used very cautiously because the binder application rates derived for these seals has been based on seals conforming to the above relationships.
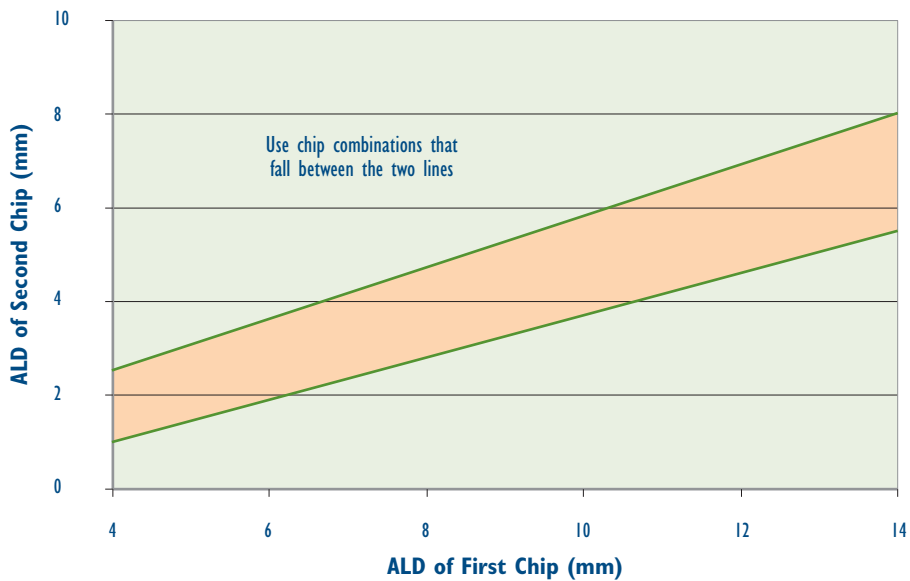

Figure 9-15   Compatibility of first chip and second chip of a two coat seal.

9.11.6   Two Coat Seals

The first application rate controls the extent of interlock with the second chip. There are differences of opinion on the extent that the second chip should fall within the interstices of the first chip. As there should be no allowance for 'whip off' for the first chip application the theoretical application rates are used. If the first chip is spread at approximately 920/ALD m^2/m^3, i.e. about 90% of the single seal rate, then the second chip will not be interlocked to the same extent that would occur with a lower application rate of 1100/ALD m^2/m^3.

The lower application rate will result in a seal that has similar chip mosaic to a racked-in seal but with two binder application rates. After the first seal has been well rolled, and after the second binder application has been made, the second chip layer is added. The second chip application rate is the same as for a racked-in seal second application.

The compatibility of sizes between the two layers of chip is checked, using Figure 9-15 in the same way to determine the recommended relationship as for the racked-in seal design.

9.11.7   Sandwich Seals

The chip application rate for the first chip of a sandwich seal (laid without binder) is as for a single coat, in that shoulder-to-shoulder contact is required but the layer of chips is to be not more than one chip thick. Opinion differs however on whether or not the first layer of chip needs to be rolled. The second chip is applied immediately after the application of the binder, as for a two coat seal.

The compatibility of sizes between the two layers of chip is checked using Figure 9-15 in the same way as for the racked-in seal design.

9.11.8   Geotextile Seals

A geotextile seal is simply a conventional seal, either a single or multiple coat, laid over the geotextile layer. The design of chip application rates therefore follows exactly that used for the equivalent conventional seal type, but binder application rates include the additional binder that is required to 'fill' the fabric.

9.12   Worked Example for a Single Coat Seal

The following worked example is for a single coat reseal. The design procedure for a single first coat seal is very similar.

Basic Design Information

Location: The road is a state highway in a small urban area, central South Island, and is subject to frost and ice.

Geometry:

Length:	1150 m	
Intersections:	3 major intersections included in the 1150 m length	
Width:	9 m (average)	
Lanes:	2	

Current surface: a 4-year-old Grade 6 chipseal.

Reason for sealing: inspection has shown 95 lineal metres of fine cracking.

Traffic: ADT: 1200 vpd
HCV: 10%

Chip Selection

Available materials: typical ALDs of local chips:

Chip ALDs:	Grade 3	=	8.0 mm
	Grade 4	=	7.0 mm
	Grade 5	=	5.0 mm

Treatment selection: A Grade 4 single coat seal was chosen as appropriate for the site using criteria from Chapter 6. In particular:

• The 4-year life for the Grade 6 seal indicated that seal stability was unlikely to be a problem.

• The fine cracking was not sufficient to warrant a specific crack treatment seal.

• The noise generated by a Grade 4 chip would be acceptable.

• As the site was not in the centre of the shopping area, the amount of loose chip and binder pick-up that a single coat seal would cause would be acceptable.

Chip Selection *(continued)*

Chip Application Rate:

The chip application rate for Grade 4 (7mm) chip (from Table 9-3) should be about

$$\frac{750}{7.0} = 107 \text{ m}^2/\text{m}^3$$

The area being sealed $= (1150 \times 9) \text{ m}^2 = 10,350 \text{ m}^2$.

Therefore the quantity of chip $= \dfrac{10,350}{107} = \mathbf{97 \text{ m}^3}$

To allow for some loss of chip through stockpiling, 10 to 20% extra chip should be ordered, i.e. **110 m³** of chip will be ordered.

Binder Selection

Binder Type:

Because the local contractor cannot yet obtain emulsified bitumen at a cost that is competitive with hot bitumen, this decision is simple. Hot bitumen will be used.

Binder Design:

Bitumen: The traditional binder used in this central South Island area has been 180/200 bitumen with 1 pph of AGO. It is decided that, as binder pick-up through the urban area needs to be avoided, the harder 130/150 grade will be used.

Flux: After considering the basic information, the decision is to use no AGO in this reseal.

Adhesion agents: The arguments for using adhesion agents to promote binder–chip adhesion are considered valid for this area where unsettled weather is common during the sealing season.

Binder Application Rate:

ALD of sealing chip: The assumed ALD of 7.0 mm will be used as the chips that are available have not yet been stockpiled or tested.

Use of multiple spray rates: An inspection of the site shows that it is not practical to use different spray rates across the job because of the traffic patterns involved. Therefore the spray run will be a full lane width.

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Texture Considerations

Texture depth: The local laboratory is asked to carry out sand circle testing so that the texture depth correction could be calculated.

The laboratory is asked therefore to take tests at 100m intervals along the road. At each interval, they are asked to take one test in the finest textured wheelpath, and another along the centreline because prior inspection has shown that the extreme texture levels are in these positions. Results of the tests are in Table 9-4.

The average Td value for a sand circle diameter is calculated (TNZ T/3) as follows:

$$\text{Td} = \frac{57{,}300}{\text{D}^2}$$

where: D = is the sand circle diameter (mm)

The $\text{Td}_{(average)}$ for both centreline and wheelpath is 1.18 mm.

The smallest and largest texture depths are taken from the table as $\text{Td}_{(fine)}$ and $\text{Td}_{(coarse)}$ as 1.04 mm and 1.26 mm respectively.

To determine whether the difference between wheelpath and centreline texture is excessive, the ALD/16 rule (Section 9.8.5) is applied:

$$\text{Td}_{(average)} - \text{Td}_{(fine)} = 1.18 - 1.04 = 0.14 \text{ mm}$$
$$\text{Td}_{(coarse)} - \text{Td}_{(average)} = 1.26 - 1.18 = 0.08 \text{ mm}$$

Table 9-4   Results of laboratory tests for texture depth using the sand circle test at 100m intervals along the sealed area.

Displacement	Texture Depth Td (mm)		Displacement	Texture Depth Td (mm)	
	Wheelpath	Centreline		Wheelpath	Centreline
0	1.24	1.26	600	1.12	1.26
100	1.10	1.23	700	1.18	1.18
200	1.18	1.24	800	1.15	1.23
300	1.12	1.25	900	1.10	1.25
400	1.15	1.18	1000	1.04	1.13
500	1.04	1.13	1100	1.24	1.24
Average = 1.18 mm					

Texture Considerations *(continued)*

From the ALD/16 rule, the greatest difference is 0.14 mm. With a 7 mm ALD chip the maximum allowable value is calculated as:

$$\frac{7}{16} = 0.44$$

The texture depth difference of 0.14 is less than this value and, therefore, the texture variation is not excessive for this sized chip.

The above check has shown that the difference in textures is acceptable if the 7.0 mm chip is used.

Re-arrangement of the ALD/16 rule shows that the ALD of Grade 4 chip would have to be less than 2.6 mm before it would become unsuitable for the range of textures concerned, i.e.

$$0.14 \times 16 = \text{Allowable ALD} = 2.24 \text{ mm}$$

This could never occur as the minimum ALD allowed for a Grade 4 chip is 5.5 mm so the $Td_{(average)}$ value of 1.18 mm is used in the design.

Traffic factor: The traffic information shows that 1200 vpd/2 lanes = 600 v/l/d use each lane, which includes 10% HCVs. As such a % HCV is not excessive, the basic equation for V_b without adjustment for high % HCV can be used.

Application rate, R:

	R	**=**	**Vb + As + Ss + Gs + Cs + Us**		Equation 9-13

where:	R	=	Final residual binder application rate in ℓ/m² at 15°C		
	V_b	=	(ALD + 0.7 Td) (0.291 – 0.025 × $\log_{10}$ (2.0 × v/l/d × 100))		
	Td	=	Texture depth (mm) from the sand circle test	=	1.18
	v/l/d	=	Vehicles per lane per day	=	600
	As	=	Allowance for an absorptive surface	=	0
	Ss	=	Allowance for a soft substrate	=	0
	Gs	=	Allowance for a steep grade	=	0
	Cs	=	Allowance for chip shape	=	0
	Us	=	Allowance for urban and/or low traffic volumes	=	0.05

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Calculation V_b = $(7.0 + 0.7 \times 1.18)(0.291 - 0.025 \times \log_{10}(2.0 \times 600 \times 100))$

                       = **1.28 ℓ/m²**

As the substrate is an existing unflushed chipseal, no allowance for absorption (As) or embedment affected by soft substrate (Ss) is required.

The site is flat and therefore no allowance is required for a steep grade (Gs).

Chip sourced in the area has a typical shape factor of 2:1 (AGD:ALD) and no allowance is required for shape (Cs).

With the intersections and relatively low traffic, the concern is that the rate of chip take may be too slow and the decision is that an urban factor (Us) of 0.05 ℓ/m² needs to be added.

When compared to traditional application rates recorded in the RAMM system the use of a higher application rate with traffic volumes less than 600 v/l/d has been used.

No other allowance is considered appropriate.

Therefore the final application rate is:

         R = V_b + Us

              = 1.28 + 0.05

              = **1.33 ℓ/m²** residual binder at 15°C

This may need to be adjusted based on the ALD of the sealing chip ultimately used, once the decision on the chip size is made.

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9.13   References

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