Developing and trialling a Climate-based Section Guideline for Chipseal Binders

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An important note for the reader

The NZ Transport Agency is a Crown entity established under the Land Transport Management Act 2003. The objective of the NZ Transport Agency is to undertake its functions in a way that contributes to an affordable, integrated, safe, responsive, and sustainable land transport system. Each year, the NZ Transport Agency invests a portion of its funds on research that contributes to this objective.

This report is the final stage of a project commissioned by Transfund New Zealand before 2004 and is published by the NZ Transport Agency.

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ADDITIONAL NOTE

The NZ Transport Agency (NZTA) was formally established on 1 August 2008, combining the functions and expertise of Land Transport NZ and Transit New Zealand.

The new organisation will provide an integrated approach to transport planning, funding and delivery.

This research report was prepared prior to the establishment of the NZTA and may refer to Land Transport NZ and Transit.

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Terms and Abbreviations

AGO	Automotive Gas Oil – a petroleum distillate used to flux bituminous materials
BBR	Bending Beam Rheometer
Bleeding	The extrusion of a bituminous binder onto the road surface, generally in hot weather
Chip rollover	Sealing chip is rolled out of its original position
Cohesion	The ability of a material to resist, by means of internal forces, the separation of its constituent particles
Cutback	To temporarily reduce the viscosity of a bituminous material by blending it with a volatile material
DSR	Dynamic Shear Rheometer
DTT	Direct Tension Test
Flushing	Loss of texture through the presence of binder around or over the top of the top layer of sealing chip in a chipseal
LTNZ	Land Transport New Zealand
MPD	Mean Profile Depth – A measure of the surface texture of the chipseal, usually measured by laser
NIWA	The National Institute of Water and Atmospheric Research
PAV	Pressure Aging Vessel
SHRP	Strategic Highway Research Program
SPG	Surface Performance Grade
TTI	Texas Transportation Institute
TxDOT	Texas Department of Transportation
TNZ	Transit New Zealand

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Executive summary

Chipseal design and construction is a combination of science and experience. Historically, the experienced practitioner has been able to make a seal work by altering spray rates based on how the new seal looks during construction.

Nowadays, on New Zealand’s heavily trafficked roads, the binder application rates are lower than the practitioner would like, but higher application rates, when used, have consistently resulted in early loss of texture. Transit New Zealand’s focus on road safety in recent times has resulted in a focus by the road surfacing industry on producing chipseals with good texture, driving binder application rates downwards.

These light application rates have to be calculated and they are particularly sensitive to the traffic levels, and especially to heavy commercial vehicles and their transverse location on the road, where the chip is retained in the wheelpaths but not elsewhere solely because of the compaction and orientation.

Advances in the transport industry have resulted in increases in vehicle horsepower, loading and stress on the aggregate/binder interface, which mean that the correct selection of the binder properties is more important than ever. This research found that where the binder was too brittle at low temperatures, or too soft at high temperatures, this factor combined with other construction defects and lead to some degree of seal failure.

The objective of this research project was to identify whether binder properties influenced the performance of chipseals within varying climatic conditions.

The methodology for the research was to construct seals using the customary binders and then monitor their field performance at 30 sites throughout New Zealand. The binders were tested using a performance specification developed in the United States at temperatures specific to the site where they were applied. The 30 New Zealand sites were monitored for two years (2005–2007) to establish whether or not the properties of the binders did have an influence on the performance of the chipseals.

This research was carried out on generally straight, flat sections of pavement to ascertain whether the guideline for selecting binder based on the climate where they will be applied improves the binder selection process.

Most seal failures were the result of a combination of factors, including the binder properties and construction. However, field monitoring showed that on the low-stress sites used in this research, the low-temperature properties of the binders that were used influenced the performance of the chipseal more than the high-temperature properties.

The outcome of the research is the identification of climatic zones for New Zealand, and some binder guidelines that should help the sealing practitioner select a more appropriate binder for each sealing site, reducing the risk of chip loss and early texture loss related to the binder properties.

While this project does not answer all of the questions related to chipseal binder selection, it does provide a good starting point for the novice seal designer. Furthermore, the guidelines do provide a potentially promising specification for optimal binder selection, construction and performance. In particular, the climate maps that were generated provide an ideal starting point for binder design/selection, and the results of the testing give an indication of the binders that are the most suitable for specific climates.

Abstract

In recent years, the standard practice in New Zealand regarding binder selection for state highways has been to use harder penetration grade binders and reduced diluents, after some research indicated that the use of harder binders slowed the onset of flushing.

However, the use of harder binders and less diluents increases the risk of early failure of chipseals, because the higher viscosity of the binders causes chipseal construction issues and increased brittleness at low temperatures, both of which can lead to chip loss.

This report discusses the development and trial of a guideline based on the performance of a binder at the high and low temperatures likely to be encountered at the chipseal construction site. The research follows on from initial work in developing and trialling a ‘Surface Performance Grade (SPG) Specification’ by the Texas Transportation Institute (TTI) for the Texas Department of Transportation (TxDOT).

Our research, conducted between 2005 and 2007, involved developing climatic zones for New Zealand and testing binders against the SPG specification, and then comparing the actual field performance of the seals with the expected/predicted performance from the binder test results (measured in the laboratory).

1. Introduction

Ever since the first chipseals were constructed, selecting a binder with the most appropriate properties for specific site conditions has been problematic.

The binder used in a sprayed seal system must meet three primary performance requirements:

1. After being sprayed, the viscosity of the binder must be within a range that allows the sealing chips that are applied to penetrate into the binder film and reorient themselves under trafficking into a stable mosaic of interlocked aggregates.
2. Once the chip is reoriented, the binder must not remain so soft that it allows the chip to be rolled or dislodged, or flush/bleed during high temperatures and/or high-stress conditions where there is high energy input.
3. Once the chipseal is formed, the binder must not become so brittle that it cracks and breaks under stress in freezing temperatures.

In New Zealand, the industry’s only documented guideline for binder selection was an imaginary line through Taumarunui and Te Puke in the North Island – 80/100 bitumen was to be used north of the line, and 180/200 bitumen to the south (National Roads Board 1969). This map is shown in section 3 (figure 3.1).

Sealing practitioners only used this guideline as the starting point of the binder selection process, and developed their own methods of seal treatment by adding fluxing agent (Automotive Gas Oil – AGO) and cutting agent (kerosene) to the binder, according to local conditions.

In recent years, as Land Transport New Zealand (LTNZ) and Transit New Zealand (TNZ) have increased their focus on improved road safety, the selection of binders has become more critical. TNZ conducts an annual survey of the surface texture and skid resistance of the state highway network and identifies areas with insufficient texture – i.e. <0.5mm Mean Profile Depth (MPD) – that require investigation and then prioritisation for treatment. Currently, more than 50 percent of the annual resurfacing work on the TNZ state highway network is carried out because of low texture caused by flushing, with the excess binder from previous seals rising to the surface and filling the surface texture voids.

The focus on texture has also driven the chip seal binder application rates downwards – the trend in recent times is to have less binder and some chip loss, rather than flushing. Hence, chip loss is another reason given by engineers for the need to resurface the state highway network.

It is recognised in the industry that seal failures (such as chip loss and flushing) occur when several factors (e.g. inappropriate treatment selection, inappropriate binder selection, incorrect binder application rate, incorrect chip application rate, and inclement weather) all occur at the same time. Also, if any of those individual factors are significantly wrong, they can cause seal failure on their own.

Arnold and Pidwerbesky (1996) showed that using harder binder slowed the onset of premature flushing on forestry roads that carry heavily loaded traffic. However, subsequent investigation by Ball (2005) could not find any evidence to support this – their research indicated that the use of harder, more viscous binders would show increased oxidation and reduced long-term performance of the binder. Using a harder, more viscous binder would also reduce the constructability of the chipseal, resulting in chip loss.

Rather than developing and using a standard industry guideline, experienced chipsealing practitioners in New Zealand have been selecting binders based on what was perceived to have worked in the past in the different situations in their networks. This leaves the next generation of chipsealing practitioners to find out what works, and what doesn’t, by trial and error.

The primary objective of this project was to develop a practical guideline that will enable chipseal practitioners to select a binder appropriate to each chipsealing site, based on the site’s specific climate and conditions, rather than on their past experience. This will inevitably extend the lifecycle of chipseals by reducing the risk and cost of premature failure caused by the use of an inappropriate binder.

2. Scope of work

This project is an extension of research that was carried out for the Texas Department of Transportation (TxDOT) by the Texas Transportation Institute (TTI) of the Texas A&M University System (Walubita et al. 2003). That project included the development of a chipsealing binder performance specification using the test methods and equipment that were developed by the Strategic Highway Research Program (SHRP) binder research project in the early 1990s. The intention of our multi-year research was to develop a practical guideline based on the Walubita et al. 2003 binder performance specification that links high and low pavement temperatures with binder performance properties measured at these temperatures.

We used New Zealand climate data to develop distinct climatic zones, with calculations and assumptions based on New Zealand's unique geographical position. Binder samples from 30 chipseals constructed throughout New Zealand were tested according to a draft guideline, and the seals were monitored (after construction, and thereafter, at six-monthly intervals at the end of each summer and winter) to assess failure modes and texture change. All sites were assessed and the texture measured, using the sand circle test Transit New Zealand T/3, until the project ended or the seal failed.

The initial scope of the project included developing a guideline for selecting binders for the stress environment as well as the climatic inputs. After substantial debate and consideration by the steering group, it was agreed that this would add too many variables to the research, and it was better to have the initial focus on developing a guideline based on climate.

The project contained these four major tasks:

1. Developing test temperature climatic zones for New Zealand.
2. Developing a performance-graded binder selection guideline.
3. Trialling the guideline on chipseal test sites around New Zealand.
4. Developing a climatic-based binder selection guideline.

2.1 Steering group

To ensure that the completed research would be accepted by the industry, a steering group, consisting of representatives from the road industry, had regular meetings to discuss the research direction and methodology. Members were:

- Dr Greg Arnold – Transit Policy Manager (now Pavespec Ltd)
- John Patrick – Opus Central Laboratories
- Peter Mumm – Hutt City Council (now GHD Consultants)
- Walter Holtrop – Australian Asphalt Pavement Association (AAPA)
- Alan Stevens – Roading New Zealand
- Sean Bearsley – Higgins Contractors
- Phillip Muir – Works Infrastructure.

3. Developing climate guideline test temperatures

3.1 Hypothesis

The hypothesis of this research project is that chipseals fail because of the binder becoming too soft when hot and/or too brittle when cold. A guideline is required to assist with the selection of appropriate binders that will perform better in the specific high and low temperatures for chipsealing sites within their own climatic regions. Maximum and minimum air temperature maps for New Zealand have been produced by NIWA to identify the various temperature zones that are prevalent in New Zealand. However, to establish meaningful binder performance property guidelines, these zones and their temperatures need to be related to the chipseal surface temperatures.

3.2 High temperature

The SHRP program developed a formula for calculating the maximum 7-day average pavement temperature from air temperature, location, aspect, and so on (Solaimanian 1993). However, this method was based on the surface characteristics of asphaltic concrete in the US, which is not pertinent to the surface characteristics of chipseals in New Zealand.

Because the climate in New Zealand is less stable than that of continental North America, the 7-day maximum average temperature was reduced to a 3-day maximum average temperature, taking heed of the substantial body of anecdotal evidence that it is usually on the third day of three consecutive hot days that the seals fail. There was a concern that this change might produce extremely high temperatures and cause the guideline to be too conservative. However, the temperatures calculated seem moderate, with the highest 50 percentile temperature being only 31.5°C, and the 98 percentile temperature only 34.7°C.

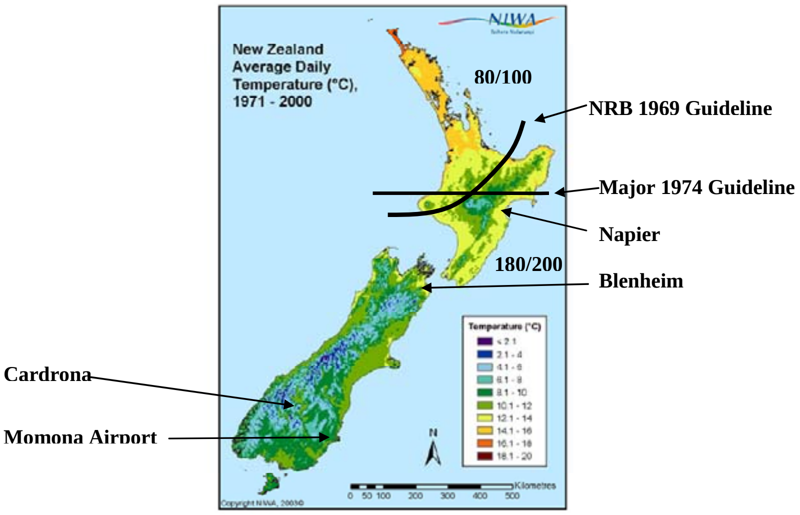

Figure 3.1
Temperature map of New Zealand.

Wood (1998) compared air temperature and the surface temperature of chipseals at four locations around New Zealand – Cardrona, Dunedin, Napier and Blenheim (see figure 3.1). A correlation between the monthly mean of the maximum daily pavement and air temperatures for the surface of the chipseal on the four sites gave a coefficient of correlation of 92 percent (i.e. $R^2 = 0.92$) for the linear relationship Tsurf = 2.074Tair – 7.210 where Tsurf is the surface temperature and Tair is the air temperature. However, Major (1965) reported data that had a linear relationship as follows:
Tsurf = 1.79Tair – 8.10 (see figure 3.2).

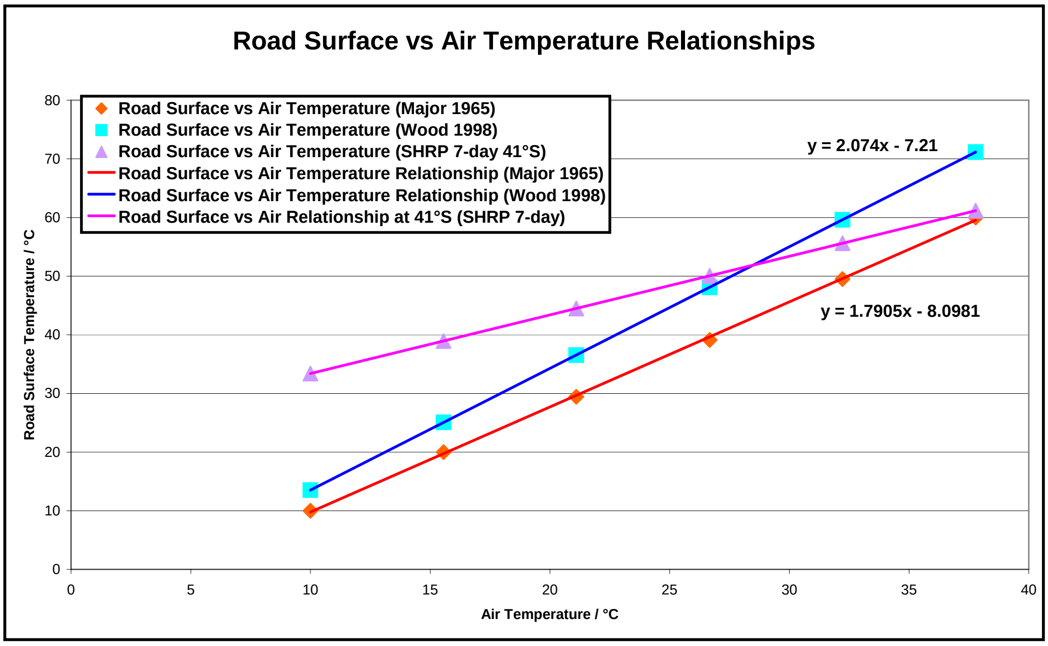

Figure 3.2 Road surface versus air temperature relationships.

To moderate the values and produce a reasonably conservative basis for testing, the median 3-day maximum air temperature value was used for the calculation, instead of the 98 percentile value (using the 98 percentile air temperatures produced road surface temperatures exceeding maximum chipseal surface temperatures recorded in New Zealand).

Bands of 5°C (see table 3.1) were chosen for the 3-day average maximum chipseal surface temperature map (figure 3.3). This produced six maximum chipseal temperature areas, reduced to five for the guideline by including the areas >55°C, which were small, isolated areas, within an all-encompassing >50°C temperature level.

Table 3.1 Maximum chipseal temperature guideline.

Calculated chipseal surface temperature (°C)	Guideline (°C)
< 35.1	35
35.1-40.0	40
40.1-45.0	45
45.1-50.0	50
> 50.0	55

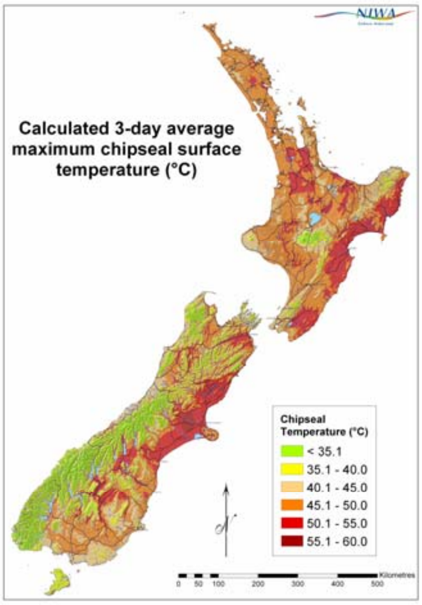

Figure 3.3 3-day maximum chipseal temperature.

A simple check (see table 3.2) on the suitability of the maximum chipseal surface temperature calculation and bands was to compare the actual air temperature and the actual surface temperature data. Wood (1998) collected chipseal surface temperature data for a full year for the four sites previously mentioned, and the maximum chipseal surface temperature map would assign the following values for these sites.

Table 3.2 Comparison of guideline with actual surface temperature data.

Site	Guideline from chipseal surface temperature map (°C)	Data[(a)] extracted from Wood (1998) – see Appendix A
Dunedin (Momona Airport)	50	0.4% year in 42–48°C range
Cardrona	50	0.8% year in 42–48°C range
Blenheim	55	0.6% year in 42–48°C range
Napier	55	1.4% year in 48–54°C range

(a) % of year that temperatures were recorded in the range

Wood's data suggests that the Napier site would require a binder with a higher stiffness at high temperatures, and the guideline surface temperature map suggests that Napier and Blenheim would require a binder with a higher stiffness at high temperatures. His data for Blenheim showed that the temperatures recorded were cooler than usual, which could explain the discrepancy between the guideline and his data.

Wood's data for Napier and Dunedin was close to the long-term average; however, the data for Cardrona was warmer than the long-term average, but there was consistency between the guideline and Wood's surface temperatures.

Wood's Dunedin data and the guideline are consistent, as would be expected since the Dunedin temperatures were close to the long-term average.

The extreme maximum temperatures ranged from 30.4°C in Dunedin to 32.0°C for Blenheim, suggesting similar high-temperature extremes for the four sites.

3.3 Low temperature

The SHRP program used the minimum temperatures recorded as the low temperature for the performance grade because the pavement could not get any colder. This makes sense particularly when determining the chipseal surface temperature, which should closely parallel the air temperature.

The National Institute of Water and Atmospheric Research (NIWA) 2nd percentile low-temperature map (figure 3.4) separated New Zealand into four low-temperature zones which were designated as bands of 5°C (see table 3.3). The lowest air temperature on the 2nd percentile map was −14.5°C, and the lowest air temperature on the 50th percentile map was −13.5°C.

Table 3.3 Minimum temperature guideline.

Temperature band (°C)	Guideline temperature (°C)
-14.9 to -10.0	-15
-9.9 to -5.0	-10
-4.9 to 0.0	-5
0.1 to 5.0	0

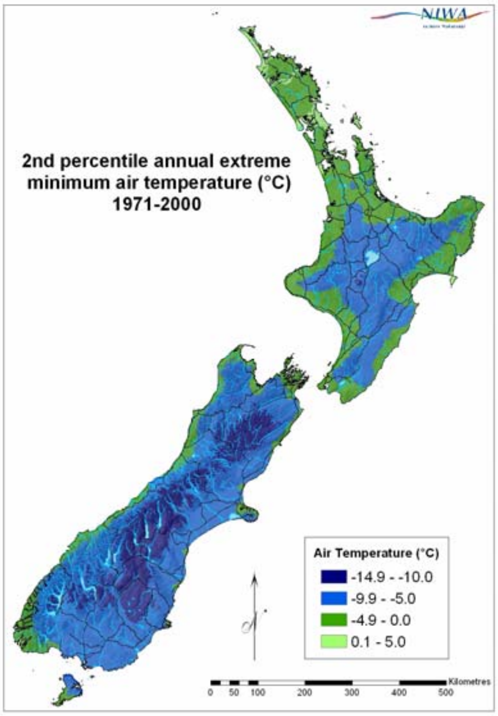

Figure 3.4 Minimum temperature.

The air and surface temperature data collected by Wood (1998) showed temperatures similar to the minima reported by NIWA (see table 3.4 on the next page).

Table 3.4. Comparison of guideline with actual surface temperature data.

Site	Guideline from 2nd percentile map (°C)	Guideline from 50th percentile map (°C)	Wood (1998) chipseal surface temp data (see Appendix A)
Cardrona	-10	-10	13.7% year in -6 to 0°C range
Dunedin (Momona Airport)	-10	-5	7.1% year in -6 to 0°C range
Blenheim	-5	-5	2.4% year in -6 to 0°C range
Napier	-5	-5	0% year in -6 to 0°C range

Wood's (1998) data shows all sites as having different low-temperature climates:

- Cardrona is colder than Dunedin, but they have the same guideline.
- Both Dunedin and Cardrona are colder than Blenheim and Napier.
- Blenheim is colder than Napier, but they have the same guideline.

Wood's data included cold-air temperatures that are consistent with the NIWA 2nd percentile temperature map, and as the low-temperature effect is more pronounced on chipseal failure, it was decided to use the 2nd percentile minimum temperature that would remove the 2 percent extreme low-temperature events, but maintain a conservative low-temperature level.

3.4 Temperature reliability

The SHRP temperature calculations utilise the standard deviation of the temperature measurements to produce temperatures for each area that have a 50 percent reliability and a 98 percent reliability factor built in as default values. For this project, the 2nd percentile, 50th percentile, and 98th percentile from 1971–2000 data were used. This removed the influence of the extreme temperatures at each end of the spectrum and identified the median high temperature.

3.5 Summary

The discussion above can be summarised into 16 possible chipseal binder performance grades (table 3.5). Both the 98th percentile maximum 3-day average, recalculated into a surface temperature, and the 2nd percentile minimum temperatures are used to form the grades in the performance-grade guideline.

Table 3.5 Summary of chipseal binder performance grade guidelines.

	Average 3-day maximum chipseal surface temperature (°C)			
Minimum surface temperature (°C)	**40**	**45**	**50**	**55**
0	**40+0**	**45+0**	**50+0**	**55+0**
-5	**40-5**	**45-5**	50-5	55-5
-10	**40-10**	**45-10**	50-10	55-10
-15	**40-15**	**45-15**	**50-15**	**55-15**

Dark shading – no locations or minimal
Light shading – climate zones with limited coverage
Unshaded – main climate zones

The four unshaded areas in table 3.5 are the climate zones that cover most of New Zealand (50-5°C, 55-5°C, 50-10°C, and 55-10°C). The plan was to find three or more sites in each of these zones to trial the binder specification guideline.

The eight light-shaded areas designate climate zones that exist but contain only a limited number of roads. These eight performance grades cover most of the rest of New Zealand with limited coverage (50+0°C, 45-5°C, 40-10°C, 45-10°C, 40-15°C, 45-15°C, 50-15°C and 55-15°C). We aimed to find trial sites within each of these climate zones, if possible.

The four dark-shaded areas in table 3.5 designate climate zones that cover either very small areas, or remote areas such as Fiordland and the Southern Alps, which do not contain significant roads.

The aim was to find 30 trial sites (the number budgeted for in the original proposal) distributed throughout the 12 main climate zones New Zealand – this was achieved.

Once these climate zones were developed, a map showing the location of each climate zone was produced by NIWA, then the location of the trial sites was added (see figure 3.5).

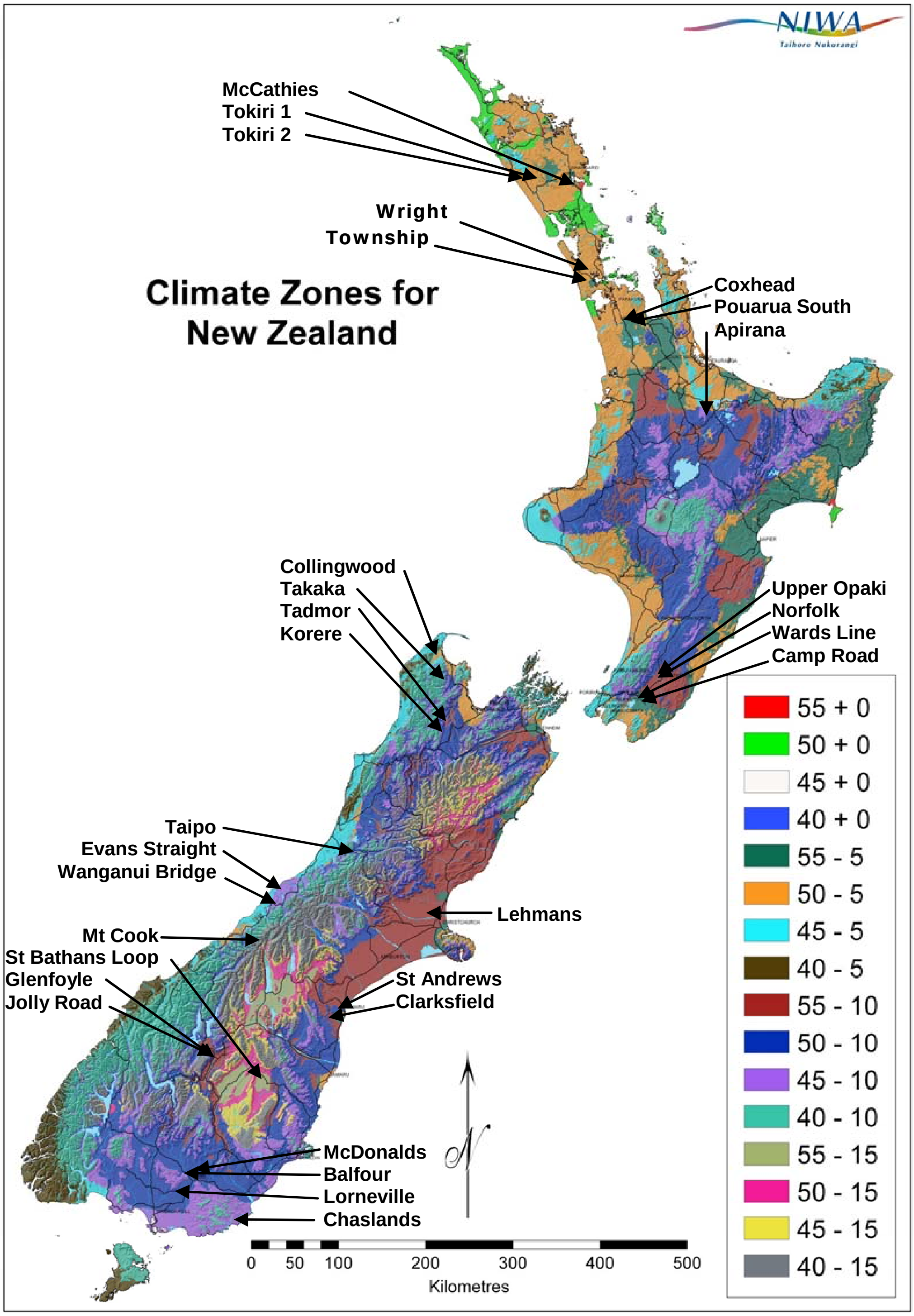

Figure 3.5 Climate zone and trial site location map.

4. Site selection

4.1 Introduction

TNZ Area Managers from throughout New Zealand were asked to provide suitable sites for the trial of the guideline. Consultants and contractors were then requested by the TNZ Area Managers to find suitable sites from their 2004–2005 resurfacing programmes.

When the list of possible sites was identified, a site inspection was carried out to ensure each had the appropriate attributes. The sites were then prioritised on the basis of suitability and location.

This research project identified 4 main climate zones covering most of New Zealand and 8 other zones that are limited to small, isolated microclimates.

The initial aim was to have 4 or 5 different trial sites for each of the main climate zones, plus 1 or 2 different trial sites for the 8 limited climate zones, making a total of 30 trial sites. Unfortunately, only 30 sites were found in total and hence not all of the zones are represented. In addition, of the 30 sites, 5 were two-coat seals, 3 were racked-in seals and only 22 were single-coat seals (the preferred surfacing type for the project).

Good representation of the 4 main zones was obtained, ranging from 5 to 8 sites per zone, with at least 4 single-coat seals in each of the 4 main zones.

4.2 Site attributes

The original aim of the project was to develop a guideline for both climate and stress; however, the industry steering group recommended that the focus of the first stage should be to develop a guideline for binder selection based solely on the climate zones. This simplified the selection criteria for trial sites, as the sites had to be relatively free of geometrical and traffic-induced stresses.

The sites (described in table 4.1) had to be on the 2004–05 resealing programme and needed to have the following attributes:

- be reasonably straight and flat
- be at least 200 m long
- if possible, require a treatment of a single-coat Grade 2 (20 mm), Grade 3 (16 mm) or Grade 4 (13 mm) seal
- have accurate traffic data, including classification information, if available
- have competent (structurally sound) pavement so that the seal would be likely to remain in place for the next 15 years before requiring treatment.

Table 4.1 Summary of sites and attributes.

Site name	Climate zone (°C)	Province	Seal type [(a)]	Geometry	Pavement condition
Chaslands	45-10	South Otago	SC3	Bend & flat	Good
Lorneville	50-10	Southland	SC3	Straight & slope	Average
Balfour	50-10	Southland	SC3	Straight & flat	Good
McDonalds Rd	50-10	Southland	SC3	Straight & flat	Good
St Bathans Loop	55-15	Central Otago	SC4	Straight & flat	Good
Glenfoyle	55-10	Central Otago	SC3	Straight & slope	Average
Jolly Road	55-10	Central Otago	SC3	Straight & flat	Good
Clarksfield Rd	55-10	South Canterbury	TC35	Straight & flat	Average
St Andrews	50-5	South Canterbury	TC35	Straight & flat	Good
Mt Cook	50-15	Mackenzie Country	TC35	Bend & flat	Good
Lehmans Rd	55-10	Canterbury	SC3	Straight & flat	Good
Wanganui Bridge	45-10	Westland	RI35	Straight & flat	Good
Evans Straight	45-10	Westland	RI46	Straight & flat	Good
Taipo	50-10	Westland	RI35	Straight & flat	Average
Korere	55-10	Nelson	SC3	Straight & flat	Average
Tadmor	55-10	Nelson	SC3	Straight & flat	Average
Wards line	55-5	Wairarapa	SC3	Straight & slope	Average
Camp Rd	55-5	Wairarapa	TC35	Straight & flat	Average
Norfolk Rd	55-10	Wairarapa	SC3	Straight & flat	Good
Takaka	50-10	Nelson	SS35	Bend & flat	Poor
Upper Opaki	55-10	Wairarapa	SS35	Straight & flat	Poor
Collingwood	50-5	Nelson	SC3	Bend & flat	Good
Pouarua South Rd	55-5	Waikato	SC2	Bend & flat	Good
Coxhead Rd	55-5	Waikato	SC2	Straight & slope	Good
Aparima Rd	50-10	Bay of Plenty	TC24	Straight & flat	Average
Township Rd	55-5	North Harbour	TC35	Straight & slope	Average
Wright Rd	50-5	North Harbour	SC3	Bend & slope	Good
McCathie Rd	55-0	Northland	RI35	Straight & flat	Poor
Tokiri Rd 2	50-5	Northland	SC3	Straight & flat	Good
Tokiri Rd 1	50-5	Northland	SC3	Straight & flat	Good

SC3 = Single-coat seal Grade 3
TC35 = Two-coat seal Grade 3/Grade 5
SS35 = Sandwich-seal Grade 3/Grade 5
RI46 = Racked-in Grade 4/Grade 6

4.3 Logistics

The original proposal was to trial the traditional binder used in the locale back-to-back with a binder complying with the guideline. However, the reluctance of the industry to carry out the trials in this manner (because of disruption to productivity) meant that the trial procedures had to be simplified further.

The final agreed procedure was to take four extra samples of binder on a site during normal sealing operations, and mark the location where the binder was sprayed so that the only disruption to normal production would be the extra binder sampling.

4.4 Risk

Transit New Zealand and its network consultants were unwilling to take the risk of seal failure if non-traditional binders were used, and there was no funding for the project to cover this risk. Thus, the seal trials were limited to using the traditional binders, keeping the risk within the resurfacing contract.

4.5 Sites

A matrix of the climate zones (Section 3.5, table 3.5) shows that there are 16 climatic zones, with four of these zones representing a large proportion of New Zealand’s land area. Contractors from throughout New Zealand offered a total of 30 reseal sites for the research from the 2004–2005 chipsealing seasons. figure 4.1 shows their geographical location. The names and the climate zones within which they are located are shown in table 4.2 below.

Table 4.2 Climate binder trial site names and climate zones.

Main zones

50-5	Collingwood (Nelson) Wright Rd (North Harbour) St Andrews (South Canterbury)	Tokiri 1 (Northland) Tokiri 2 (Northland)
50-10	Lorneville (Southland) Balfour (Southland) Takaka (Nelson)	McDonalds Rd (Southland) Taipo (Westland) Aparima Rd (Bay of Plenty)
55-5	Wards Line (Wairarapa) Camp Rd (Wairarapa) Township Rd (North Harbour)	Pouarua South Rd (Waikato) Coxhead Rd (Waikato)
55-10	Glenfoyle (Central Otago) Jolly Rd (Central Otago) Norfolk Rd (Wairarapa) Upper Opaki (Wairarapa)	Clarksfield (South Canterbury) Lehmans (Canterbury) Korere (Nelson) Tadmor (Nelson)

Limited zones

45-10	Wanganui Bridge Westland) Evans Straight (Westland)	Chaslands (South Otago)
50-15	Mt Cook (Mackenzie Country)	
55-15	St Bathans Loop (Central Otago)	

Minimal zone

55-0	McCathie Rd (Northland)

5. Performance-graded binder guideline

5.1 Background

Performance-based binder specifications were developed by the Strategic Highway Research Program (SHRP) for hot-mix asphalt as part of the asphalt research program that began in 1987. However, the binder specification development work did not include seal-coat binders. The performance-graded binder specification was adopted in 1997.

Elmore (1997) reported on work carried out to establish a procedure to enable the selection of the binder appropriate to the particular environmental and traffic conditions. Barcena et al. (2002) reported on the work carried out at Texas A&M University on changing the test procedures and conditions for the SHRP binder testing devices, in order to make the tests more closely represent what happens to the binder in a chipseal. Walubita et al. (2004) reported on the successful initial validation of the new Surface Performance-Graded (SPG) Binder Specification for chipseal in the State of Texas. Our research project utilised the test methods from this last paper as the basis for developing performance-graded guidelines for New Zealand conditions, as all of the test equipment was readily available.

5.2 Discussion

Walubita et al. (2004) reported that there was generally good agreement between the binder SPG grade predictions and actual field performance for 78 percent of the sites. Since the sites in their trial were chosen at random and the researchers had no control over the design, binder selection and construction, this was a very good result. The causes of many of the disagreements between the SPG and actual performance were construction-related failures, so in a controlled project, the agreement should be much higher. Walubita et al. (2004) also suggested that the Direct Tension Test (DTT) should be explored for a comparison with the Pressure Aging Vessel (PAV) and Bending Beam Rheometer (BBR) tests. However, because the paper did not give the reasoning for this and we do not have access to this apparatus in New Zealand, our research did not include the DTT in the test programme.

After some discussions regarding the PAV temperatures, we decided to use the existing conditions for the PAV ageing of the binder. This decision was based in part on the fact that after 12 months of environmental exposure, the properties of the binders from the site compared well with the PAV aged binder. There was also some doubt that ageing of cutback binders in the PAV would be relevant, as the system is airtight during ageing, thus inhibiting the loss of volatile diluents (cutters). Consequently, we decided to trial the test and aim to construct the seals in February (midsummer) so that the cutter content in the binders was minimal.

Some doubts were also raised regarding the relationship between BBR testing and chip loss. We decided to include the Low-Temperature Cohesion Test, using the Vialit Plate apparatus, and the Vialit Pendulum test as ranking tools for the binders at low temperature. Earlier in-house testing using the Low-Temperature Cohesion Test method with unaged modified binders ranked the binders in similar temperature zones as in this study.

The viscosity specification in the TTI Surface-Performance Grade Specification (SPG) was set solely to ensure that the binder was of a viscosity suitable for spraying. Because it is almost irrelevant to the performance of the binder in the chipseal, it was left out for this research. The specification for phase angle was also left out, because it was only relevant to temperature zones < -16°C, which are not found in New Zealand.

Discussion regarding the use and meaningfulness of the DSR test led to the inclusion of an additional test, using the Vialit Pendulum test apparatus and unaged binder, to provide a fundamental measurement of the cohesion of the binder at the appropriate high-pavement temperatures.

An example of the proposed New Zealand SPG Binder Guideline that was used for the trials is provided in table 5.1 below. All binder samples collected from the trial sites were tested according to the temperature guideline depending on the climate of the site.

Table 5.1 Proposed surface performance-graded binder guideline.

Performance grade	**SPG 40**				**SPG 45**				**SPG 50**				**SPG 55**			
	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0
Av. 3-day max. calc. Surface temperature °C	< 40				< 45				< 50				< 55			
Min. surface pavement Design temperature °C	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0
Original binder after construction (bitumen, cutback bitumen residue or emulsion residue)																
Low-temperature Cohesion test °C < 20% chips lost	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0
Vialit Pendulum	40				45				50				55			
DSR Dynamic Shear, AASHTO T315 G*/sinδ Min: 0.65kPa Test temperature @ 10 rad/s, °C	40				45				50				55			
Pressure Aged Vessel (PAV) residue (AASHTO PPI)																
PAV Aging Temperature, °C	90				90				90				90			
BBR Flexural stiffness, AASHTO T313 S, Max: 500 Mpa m-value, min: 0.240 Test temp. @ 8s,°C	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0	-15	-10	-5	0

Notes:

- Table 5.1 presents these 16 SPG grades as an example, but the grades are unlimited and can be extended in both directions of the temperature spectrum.
- Binders samples tested are either those sampled from the sprayer and tested as received, or binder samples from the sprayer that have been treated in the Pressure Aging Vessel (PAV).

6. Binder

6.1 Binder selection process

For the trial research sites, the base binder selection and cutback and adhesion agent levels were whatever the chipseal designer selected for the site as part of the normal reseal contract. The seal designer also calculated the chipseal application rates for the site as normal within the bounds of the reseal contract.

On most of the sites, four one-litre samples of binder were taken between spray runs while sealing the trial section and sent to the laboratories for testing.

Unfortunately, test results for the Township Road and Wright Road samples showed that the samples might have been contaminated. Further testing showed that the Township Road sample contained more than 20 pph solvent, and the Wright Road sample contained 11 pph solvent. The binder sprayed on the road did not seem to be contaminated, and it is likely that flushing material in the sampling nozzle contaminated the samples.

Table 6.1 outlines the recipes of the binders used on the test sites.

Table 6.1 Summary of binder additives used in the trial sites.

Number of sites	Base binder	AGO range (pph, v/v)	Kerosene range (pph, v/v)	Adhesion agent range (pph, v/v)
14	180/200	0–2	1–4	0.5–0.7
11	130/150	0	1–5	0.5–0.7
5	2% PMB 130/150	0	3–6	0.5–0.8

6.2 Rheological binder test result discussion

6.2.1 Dynamic shear rheometer test

Binders were tested as received, using the Dynamic Shear Rheometer (DSR) at the appropriate high temperature of the climate zone where the site was located, because:

> *High temperature properties are critical in specifying surface treatment binders to preclude aggregate loss and to minimise bleeding at high service temperatures due to low shear resistance and the inability of the binder to hold the aggregate in place under traffic forces.* (Walubita et al. 2003).

The $G^*/\sin\delta$ parameter on the unaged binder is a measure of the resistance of the binder to shear in new chipseals. This would ensure that the binder had sufficient initial strength to avoid sealing chip rollover when construction was during the hottest part of the season.

There were no recorded problems with chip rollover on any of the test sites. Most of the chipseals (23) were constructed during the traditionally hot part of the season between January and March (see figure 6.1). Four seals were constructed late in the season in April and May. Three seals were constructed before Christmas.

Six binders did not meet the proposed criterion for the DSR test – they had lower than the minimum stiffness requirement at the high-pavement temperature.

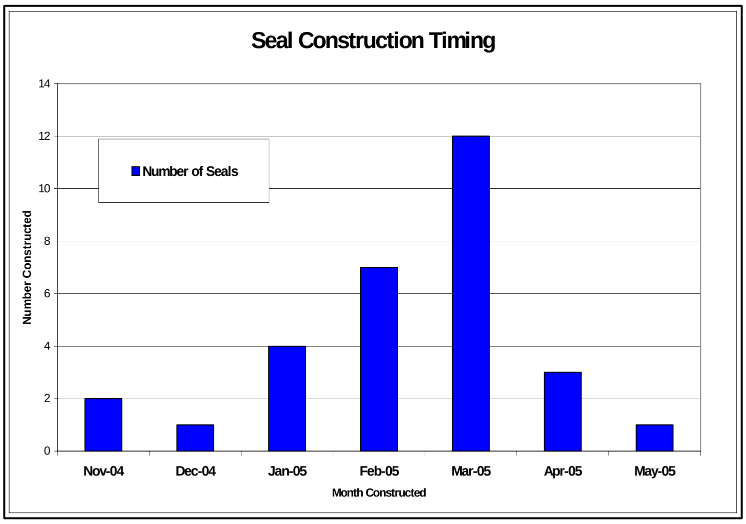

Figure 6.1 Seal construction timing.

6.2.2 Bending Beam Rheometer (BBR) test on Pressure Aging Vessel (PAV) aged binders

All binders were pretreated in the PAV, which ages the binder to a state similar to one that has been exposed to the field environment for a year. (Note: There is some divergence of opinion regarding this ageing process in general, and whether the equipment and procedure are suitable for ageing cutback binders, as the binders tested in the TxDOT project were either bitumen with added adhesion agent, or the residuum extracted from bitumen emulsions.

The aged binders were then tested in the Bending Beam Rheometer at the appropriate low temperature for the climate zone where the site was located because:

> *Low temperature properties are also critical in specifying surface treatment binders to preclude aggregate loss at low temperatures when the binder stiffness is high, causing fracture under loading.* (Walubita et al. 2003, p12).

The BBR test provides a measure of the flexural stiffness and log stiffness-log time slope (m-value) at a loading duration of eight seconds when tested at the low temperature appropriate to the site location for each sample.

The flexural stiffness tells us how stiff the binder is. A high flexural stiffness means the binder is more susceptible to chip loss at low temperatures, and a flexural stiffness greater than 500 MPa means that the seal is likely to fail by chip loss at low temperatures.

The ‘m value’ is the slope of the log stiffness versus log time curve at the test temperature. ‘It reflects the ability of the bituminous binder to relax the stresses.’ (Largeaud and Brule 2000).

The m-value tells us the rate of change of the flexural stiffness at the test temperature: the lower the rate of change, the more susceptible the binder may be to stress. Thus, binders with m-values lower than 0.240 are likely to suffer from chip loss at low temperatures.

Fifteen binders failed the proposed criteria for the BBR test by having an m-value slope less than the specified minimum, and six binders were too soft to test in the BBR apparatus (see table 6.2). None of the binders failed by having flexural stiffness larger than the 500 MPa maximum that was specified, and six binders were too soft to test in the apparatus, and so complied by default (see table 6.2 on the next page).

Table 6.2 Rheological Binder test results.

	SPG test results	Dynamic Shear Rheometer (DSR) results		Bending Beam Rheometer (BBR) results		
			(min 650 Pa) unaged		(min 0.240) aged	(max 500,000 Pa) aged
Site no	Site name	Test temp (°C)	G*/Sinδ (Pa)	Test temp (°C)	m-value	Stiffness (Pa)
1	Chaslands	45.0	910	-10	0.125	15405
2	Lorneville	50.0	900	-10	0.210	26045
3	Balfour	50.0	498	-10	0.254	28340
4	McDonalds Rd	50.0	881	-10	0.165	23270
5	St Bathans Loop Rd	55.0	570	-15	0.562	38630
6	Glenfoyle	55.0	467	-10	0.051	20147
7	Jolly Rd	55.0	479	-10	0.340	19007
8	Clarksfield Rd	55.0	767	-10	0.022	17648
9	St Andrews	50.0	768	-5	No Result	No Result
10	Mt Cook	50.0	713	-15	0.462	34565
11	Lehmans Rd	55.0	645	-10	0.094	18178
12	Wanganui Bridge	45.0	1436	-10	0.218	30160
13	Evans Straight	45.0	2574	-10	0.012	22137
14	Taipo	50.0	1473	-10	0.021	16723
15	Korere	55.0	768	-10	0.071	25000
16	Tadmor	55.0	899	-10	0.566	52130
17	Takaka	50.0	1042	-10	0.519	38167
18	Collingwood	50.0	1484	-5	0.084	19003
19	Wards Line	55.0	1047	-5	0.123	18940
20	Camp Rd	55.0	1257	-5	0.092	16817
21	Norfolk Rd	55.0	943	-10	0.446	39250
22	Upper Opaki	55.0	1156	-10	0.359	24900
23	Aparima Rd	50.0	1526	-10	0.381	25190
24	Pouarua South Rd	55.0	682	-5	No Result	No Result
25	Coxhead Rd	55.0	736	-5	No Result	No Result
26	Township Rd	55.0	149	-5	No Result	No Result
27	Wright Rd	50.0	365	-5	No Result	No Result
28	McCathie Rd	55.0	1359	0	No Result	No Result
29	Tokiri Rd 2	50.0	2668	-5	0.148	14947
30	Tokiri Rd 1	50.0	2905	-5	0.117	18123

Yellow shading – Samples too soft to test at the appropriate test temperature.
Red shading – Denotes non compliance with the specification.

6.3 Physical binder test result discussion

Table 6.3 Physical binder test results

					Vialit Pendulum results			Vialit Plate results
Site no.	**Site name**	**Binder**	**Climate high temp**	**Climate low temp**	**Cohesion value (J/cm^2) unaged at high temp**	**Cohesion value (J/cm^2) unaged at low temp**	**Cohesion value (J/cm^2) aged PAV@100°C at low temp**	**Cohesion (min 80% ret) at low temp**
1	Chaslands	180/2/3/0.8	45	-10	0.1268	0.1545	0.1545	2
2	Lorneville	180/0/3/0.7	50	-10	0.1268	0.2386	0.2869	0
3	Balfour	180/0/3/0.7	50	-10	0.1268	0.1545	0.2020	0
4	McDonalds Rd	180/2/4/0.8	50	-10	0.0830	0.1751	0.1987	0
5	St Bathans Loop Rd	180/2/4/0.5	55	-15	0.0206	0.2188	0.2428	0
6	Glenfoyle	180/1/3/0.5	55	-10	0.0415	0.2151	0.1919	1
7	Jolly Rd	180/1/3/0.5	55	-10	0.0415	0.1919	0.1919	0
8	Clarksfield Rd	PMB2/130/6	55	-10	0.1751	0.2469	0.2226	53
9	St Andrews	PMB2/130/6	50	-5	0.2671	0.2263	0.2760	84
10	Mt Cook	PMB2/130/3	50	-15	0.4204	0.2188	0.2671	8
11	Lehmans Rd	180/1/3/0.5	55	-10	0.0408	0.2188	0.2188	0
12	Wanganui Bridge	130/0/5/0.7	45	-10	0.1953	0.2188	0.1953	0
13	Evans Straight	PMB2/130/3	45	-10	0.7037	0.2715	0.2226	0
14	SH73 Taipo	PMB2/130/3	50	-10	0.4941	0.2226	0.2469	18
15	Korere	130/0/3/0.7	55	-10	0.0628	0.2188	0.2428	0
16	Tadmor	130/0/4/0.7	55	-10	0.0845	0.2869	0.2626	0
17	Takaka	130/0/4/0.7	50	-10	0.1691	0.2626	0.2626	0
18	Collingwood	130/0/4/0.7	50	-5	0.2386	0.2188	0.2428	0
19	Wards Line	180/0/1/0.7	55	-5	0.1268	0.2188	0.2917	0
20	Camp Rd	180/0/1/0.7	55	-5	0.1721	0.2428	0.2671	0
21	Norfolk Rd	180/0/1/0.7	55	-10	0.0830	0.2869	0.2626	0
22	Upper Opaki	180/0/1/0.7	55	-10	0.1268	0.2626	0.2386	0
23	Apirima Rd	130/0/2/0.7	50	-10	0.2626	0.2626	0.2869	0
24	Pouarua Sth Rd	180/0/3/0.7	55	-5	0.0617	0.2820	0.2345	0
25	Coxhead Rd	180/0/3/0.7	55	-5	0.0408	0.2263	0.2263	0
26	Township Rd	130/0/2/0.5	55	-5	0.0000	0.5410	0.7429	100
27	Wright Rd	130/0/3/0.5	50	-5	0.0400	0.2188	0.2188	47
28	McCathie Rd	130/0/1/0.7	55	0	**Sample depleted**	0.1953	0.2917	0
29	Tokiri Rd 2	130/0/2/0.7	50	-5	0.3365	0.2581	0.2820	0
30	Tokiri Rd 1	130/0/2/0.7	50	-5	0.3365	0.2820	0.3063	0

Green shading shows compliance with the Vialit Plate test specification.
Red shading shows samples that were contaminated, not indicative of binder on the road.

6.3.1 Vialit Plate Cohesion test

Figure 6.2 Vialit Plate after testing (53% retained).

A New Zealand version of the Vialit Plate test was used to test the adequacy of adhesion agents in improving the adhesion of binder to sealing chip. This test is carried out in damp conditions, and sealing chip with binder attached is counted as adhered.

The test method was modified to test the cohesion of the binder by ensuring 100 percent adhesion. Clean, dry sealing chip was applied to a millimetre thick layer of binder on 4 steel plates. The test plates were conditioned at 25°C for 2.5 hours to ensure 100 percent adhesion. The plates were then cooled to the appropriate site-specific cold test temperature for 2 hours and tested.

Binder cohesion is quantified by the number of chips debonding because of cohesive failure of the binder film. The minimum standard set for this test was 80 percent of the chips retained. Using a similar test procedure, Davis et al. (1991) found that 'Aggregate retention of the sample cured at 0°F (-17.8°C) is a good indicator of overall chip-seal performance.'

Most tests on unaged samples resulted in 0 percent of the chips being retained, compared with the target of a minimum of 80 percent.

Two binders performed better than expected:

1. The sample from the Township Road site appeared to have been contaminated and was extremely soft. Viscosity testing suggested that the sample may have contained up to 20 percent AGO. This soft binder performed very well, retaining 100 percent of the chips, where the results from tests on similar binders had lost 100 percent of the chips at -5°C.
2. The result from the Wright Road site also performed well, retaining 47 percent of the chips, where the results from tests on similar binders had lost 100 percent of the chips at -5°C. Viscosity testing suggested that the sample may have contained 11 percent kerosene.

The requirement for this test was that 80 percent of chips were retained. Only one of the binders achieved this – that used on the St Andrews site. These results suggest that all of the seals should fail by chip loss during low temperatures, which is in line with the recent push to use harder binders and less cutback to avoid flushing. However most of the binders tested have been used in previous seasons with minimal problems of chip loss in low temperatures. The other more likely possibility is that the Vialit Plate Cohesion test method may produce a higher stress on the binder than is encountered in the field. All samples that produced zero retention could not be ranked.

6.3.2 Vialit Pendulum testing

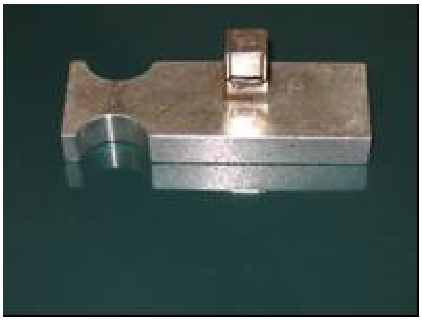

Figure 6.3 Brass cube, sample and base.

In this test, a film of sealing binder is used to attach a small brass cube to a base plate and this entire set-up is conditioned at the appropriate test temperature before testing. The brass cube is then dislodged by a swinging pendulum and the energy used to dislodge the cube is calculated. This energy is a fundamental measurement of the cohesive strength of the binder.

The Vialit Pendulum test was carried out at both the high and low pavement temperatures. The results at the low pavement temperature ranged from 0.1545 to 0.2869 Joules for the unaged cutback and modified binders, and from 0.1545 to 0.3063 Joules for the aged cutback and modified binders (Township Road and Wright Road results were not included). These results were as expected when compared with standardised graphs from international testing where the low-temperature cohesive strength of most types of binders approaches 0.2 Joules below 0°C.

The results at the high pavement temperature ranged from 0.0206 to 0.3365 Joules for the unaged cutback binder, and 0.1751 to 0.7037 for the unaged modified binder (Township Road and Wright Road results were not included).

The results for the cutback binders were as expected when compared with the standardised international data where the cohesive strength of cutback binders approaches 0.2 Joules at 40°C.

The results for the modified binders containing cutters (diluents) were better than expected when compared with the standardised international data where the cohesive strength of cutback modified binders approaches 0.2 Joules at 45°C.

6.3.3 Pressure Aging Vessel (PAV) test

The PAV test was used to age the binder, using test conditions that age the binder to a state similar to that of a binder that has been exposed to the field environment for one year. There is some doubt about ageing cutback binders in these conditions, as the test requires the system to be airtight, which will prevent the cutters from evaporating during the process and probably reduce the ageing effect. This is likely to make the low temperature BBR results better than expected. Further research on cutback binder ageing using this test will be required to ascertain the ageing effects of the specified conditions.

Future testing will be carried out on the unaged binders to remove the doubt over the PAV test.

7. Comparing guideline prediction with field performance

7.1 DSR unaged binder – high temperature

7.1.1 Test performance vs field performance

The binder from six sites failed this test, which means that they might have been susceptible to chip rollover during construction, or flushing/bleeding during the hotter parts of the season. These six sites were St Bathans*, Glenfoyle, Jolly Road, Lehmans Road, Township Road* and Wright Road. (* These sites also had some minor areas of flushing.)

There was no chip rollover on these or any of the sites in the research project. The binder from these sites all complied with the DSR Unaged Binder High-temperature Guideline, so flushing or chip rollover would not be expected on these sites.

7.1.2 Flushing

The testing predicted that 6 sites would have issues with flushing or chip rollover, and 4 of these sites did have some minor flushing. However, there were 7 sites out of the remaining 24 that had minor flushing even though the binder that was used passed the test. In summary:

- 4 out of 6 sites flushed when the test results predicted that they would
- 17 out of 24 didn’t flush when the test results predicted that they wouldn’t flush
- that is, the testing correctly predicted the flushing performance of 21 out of 30 sites – a 70 percent correlation.

These results are a little misleading, as the likelihood of flushing was reduced considerably on most sites by several factors:

- the relatively low binder application rates used in the seal construction
- the low to moderate traffic on the sites
- the reasonably good state of the existing surface that was being resealed.

Most sites that had some flushing were reflecting the condition of the surface underneath, particularly the Upper Opaki site where there was significant excess binder on the existing surface. A two-coat grade 3/5 sandwich seal was used to try to reduce the binder/aggregate ratio, but this has failed after two years.

7.1.3 Chip rollover

The guideline predicted that there would be chip rollover on 6 of the 30 sites (i.e. no rollover on 24 sites). There was no chip rollover on any of the sites – an 80 percent correlation.

However, these results are a little misleading, as the sites selected for this trial were deliberately kept flat and straight to simplify the initial research. The lack of scrubbing stress on the sites (because they were generally straight and flat) meant there was very little energy applied by traffic that would dislodge chips and/or cause chip rollover – so it is possible that any normal binder would have held the chip in place.

Figure 7.1 Upper Opaki site – Flushing, May 2007.

7.2 BBR aged – low temperature

7.2.1 Test performance vs field performance

No binder from any site tested as being too stiff after ageing, with all of the test results below the maximum 500,000 Pa.

The binders from 15 sites failed to meet the m-value minimum criterion, predicting that those sites could have chiploss at low temperatures. Of these, 13 (Chaslands, Lorneville, McDonald Road, Glenfoyle, Lehmans Road, Wanganui Bridge, Evans Straight, Taipo, Korere, Collingwood, Wards Line, Tokiri Road 1, and Tokiri Road 2) had chip loss. The two that did not (Clarksfield Road and Camp Road) were both two-coat seals.

Four sites had some chip loss even though their binder complied with the m-value minimum criterion. These were St Bathans, Jolly Road, Tadmor, and Apirana Road. Four other sites also had chip loss, but the binder samples from these sites were too soft to test. These were Pouarua South Rd, Coxhead Road, Wright Road and McCathie Road.

7.2.2 Chip loss

The issue of binder softness was a problem here. The testing predicted that 15 sites would have chip loss (correct for 13 sites), and it also predicted that 9 would not have chip loss (correct for 5 sites). However, 6 binders could not be tested because they were too soft, and of these, 5 had chip loss. In summary, the testing correctly predicted 18 out of 24 sites – a 75 percent correlation.

If we assume that the softness of the 6 binders that we could not test meant there would be problems with the seal, and 5 of these sites did actually have chip loss, then the guideline's successful prediction rate rises to 23 out of the 30 sites – a 77 percent correlation. However, if being too soft to test meant that the test result is predicting no chip loss on the sites (more likely), and only 1 of these 6 sites had no chip loss, then the guideline correctly predicted the performance on 19 out of the 30 sites – a 63 percent correlation.

The issue for these binder test results was the temperature at which they were tested. For 5 of the binders that were too soft, the test temperature was –5°C, and for McCathie Road, it was 0°C.

However, as other similar binders tested at the same temperatures were stiff enough to produce a result, it is likely that these results are related to the proportion of kerosene remaining in the binder after the Pressure Aging.

7.3 Vialit Pendulum – low temperature

7.3.1 Test performance vs field performance

Low-temperature testing using the Vialit Pendulum produced results that are all similarly low, whether the binder was aged or unaged. This may be reflecting that at the low temperature end, a high-velocity short-duration impact will cause brittle failure in the binder, resulting in chip loss.

Twenty-one out of the 30 sites had some degree of chip loss, but only 1 site had to be resurfaced because of substantial chip loss.

7.3.2 Chip loss

The test result predicted that there would be chip loss from all 30 sites, and 21 of these sites had chip loss – a 70 percent correlation.

7.4 Vialit Pendulum – high temperature

7.4.1 Test performance vs field performance

High-temperature testing using the Vialit Pendulum produced a wider variation in the results. The 7 lowest results measured (< 0.05J/m²) and included the 6 binders that failed the DSR unaged test – a good correlation between the two tests.

7.4.2 Flushing

If we use this criterion result (< 0.05J/m²), then the test results predicted that 7 sites would have flushing, but only 2 of these sites had flushing. The results also predicted that the other 23 sites would not have flushing, but 6 of them did. In summary, the test predicted correctly for 19 out of the 30 sites – a 63 percent correlation.

The action of the Vialit Pendulum tester does not mimic the processes in the field, such as compaction, that would relate to flushing.

7.4.3 Chip rollover

Chip rollover was not identified on any of the 30 sites. If the result < 0.05J/m² is accepted as the criterion because it relates well to the DSR unaged results, then this test is predicting that 23 of the 30 sites will not fail by chip rollover – a 77 percent correlation between the test and the field.

The action of the Vialit Pendulum is more likely to measure the resistance of the binder to the chip being dislodged, rolled over or lost.

7.5 Vialit Plate Cohesion results – low temperature

7.5.1 Test performance vs field performance

The Vialit Plate Cohesion low-temperature test results showed that only 1 sample passed the criterion (> 80 percent retained) and that that seal was performing well. The polymer-modified binders performed better in this test than the cutback bitumens, with 4 out of the 5 samples (80 percent) retaining chip, and only 2 out of the remaining 23 cutback samples (9 percent) retaining 1–2 chips.

This test, which is run at the climate low temperature for each site, is intended to predict the likelihood of chip loss due to the binder fracturing under load.

7.5.2 Chip loss

All single-coat seals were constructed with cutback binder; all 18 of these binders failed the criterion. Seventeen of these sites (94 percent) had more than 1 percent chip loss.

Figure 7.2 Wright Road monitoring circles.

7.6 Summary of comparison between test results and field performance

7.6.1 Test performance prediction vs field performance

The results above show that all of the tests in the guideline predicted field performance correctly more than 60 percent of the time. If predicting correctly 50 percent of the time is arbitrarily assumed as a reasonable benchmark for performance prediction, then these results suggest that the guideline should be considered valid.

8. Cause and effect tables

8.1 Description

Cause and effect tables (Appendix B) were constructed by comparing each of the failure modes with construction issues, and with each of the other failure modes for each of the 45 monitoring circles (see figure 7.2).

The measure of the strength of the relationship was calculated by summing the products formed by multiplying the assessments of the performance of each of the failure modes and measurements within each circle with each other.

8.2 Single-coat seal cause and effect table discussion

The cause and effect tables showed that there was a relationship between some single-coat chipseal construction issues and most failure modes. Some of the relationships that were identified were:

- over-chipping or under-chipping – some aggregate loss
- texture decrease – aggregate breakdown and bleeding/flushing
- no binder rise – some aggregate loss
- high binder m-value – aggregate loss and no binder rise
- high binder stiffness – aggregate loss and no binder rise
- low DSR – aggregate loss and no binder rise
- low cohesion – aggregate loss and no binder rise.

As 'no binder rise' and 'aggregate loss' were the predominant modes of failure, it is no surprise to find relationships between most of the issues bullet-listed above.

8.3 Two-coat seal cause and effect table discussion

The cause and effect table shows that there were no significant relationships between two-coat seal construction issues and the failure modes examined. This lack of relationship is mostly because of the treatment selection being two-coat seals on straight, flat sections of road – this is a very conservative treatment and unlikely to fail in these conditions.

Three of the two-coat seal sites have significant flushing that is reflecting through from the surface below and is not related to construction issues or the binder used.

9. Summary of findings of the test sections

Four sites in Southland (Chaslands, Lorneville, Balfour and McDonalds)
All of these were sealed with Grade 3 single-coat seals. All suffered from some chip loss, with a relationship between lack of binder rise and chip loss. Also, the binder from three of these sites failed the m-value criterion and the fourth only just passed, confirming that the low-temperature properties may have contributed to the chip loss from these seals.

Three sites in Central Otago (St Bathans, Glenfoyle and Jolly)
All were sealed with single-coat seals – St Bathans with single-coat Grade 4, and the other two with single-coat Grade 3. All seals had chip loss that had a strong relationship with lack of binder rise, and only the Glenfoyle binder failed the m-value criterion, which showed a relationship between binder properties and chip loss.

Three sites in Westland (Wanganui Bridge, Evans Straight and Taipo)
All were sealed with racked-in seals with cutback polymer-modified binder. Their binders all failed the m-value criterion, and all had chip loss from low-trafficked areas and where there was a lack of binder rise.

Four sites in Canterbury (Hermitage, Clarksfield, St Andrews and Lehmans)
Lehmans Road was sealed with a Grade 3 single-coat seal that had a lack of binder rise – the binder failed the m-value criterion, and the seal had chip loss.

The other three sites were surfaced with two-coat Grade 3/5 seals using cutback polymer-modified binder. This binder failed the m-value criterion when tested at the warmer temperatures, but there was very little chip loss from these seals. Two-coat seals were selected for these sites because of the variability of the existing surface texture and the local climates – the two-coat seals all performed very well.

Four sites in Nelson (Korere, Tadmor, Takaka and Collingwood)
These were all constructed with conventional binders: Takaka was sealed with a sandwich seal Grade 3/5, and single-coat Grade 3 seals were used for the other three. The Takaka seal had no chip loss but had some reflection flushing from beneath. The Tadmor seal performed well, while the binders on the other two seals failed the m-value criterion and had chip loss from low-trafficked areas with low binder rise.

Four sites in Wairarapa (Norfolk, Camp Road, Upper Opaki and Wards Line)
Upper Opaki was sealed with a Grade 3/5 sandwich seal using a conventional binder – it failed because of excess binder reflecting through from the surface below. The other three were all Grade 3 single-coat seals with a conventional binder.

The Norfolk seal failed by chip loss in the first month after construction because of lack of binder rise, traffic stress, and stiff binder properties (the second highest of the 30 samples). Camp Road had early chip loss caused by rain, and had a wet lock applied a month after construction. The binder used on Camp Road failed the m-value test. The Wards Line seal had chip loss due to a lack of binder rise and the binder failed the m-value test. The binder used for all four of these seals had the same recipe, but was tested at different temperatures appropriate to their different climate zones.

Two sites in Waikato (Coxhead and Pouarua South)

These were sealed with a Grade 2 single-coat seal and conventional binder. The binder was too soft to test at the test temperature appropriate to their climate zone, so it should not have been too stiff. There was some chip loss, but only in untrafficked areas with lack of binder rise.

One site in Bay of Plenty (Apirana)

This was sealed with a two-coat Grade 2/4 seal using a conventional binder. The binder application rate was reduced because of the binder-rich surface, and there was chip loss in the low-trafficked areas due to the lack of binder rise.

Two sites in Auckland (Township and Wright)

The binder samples from these sites were probably contaminated, as the results are not consistent with the binder recipe. The results therefore should not relate to what is seen in the field. The Township Road two-coat Grade 3/5 seal had no chip loss, and the significant flushing and binder rise on the seal was probably caused by the binder-rich surface beneath and not a soft binder in the new seal. By contrast, the Wright Road single-coat Grade 3 seal had chip loss related to the lack of binder rise in low-trafficked areas.

Three sites in Northland (Tokiri 1, Tokiri 2 and McCathies)

McCathie was a single-coat Grade 3 seal with a Grade 5 dry lock with a conventional binder. The binder was too soft to test for the m-value. The seal had chip loss due to lack of binder rise in low-trafficked areas and on preseal repairs. The two sites on Tokiri Road were single-coat Grade 3 seal with a conventional binder that failed the m-value test. Both sites had chip loss related to lack of binder rise and the binder properties.

In summary

There was generally a lack of binder rise, especially in the low-trafficked areas, and there was chip loss in these areas, especially where the binder was stiff or failed the m-value test. As the sites were generally flat and straight with low stress, there were no issues with chip rollover at high temperatures, suggesting that in this type of site, the binder properties could be designed for the low temperatures on the site without fear of seal failure at high temperatures. There was very little evidence to suggest that the softer binders contributed to binder rise in the seals, and most of the flushing was directly related to the surface beneath. In fact, for most seals, the softer binders probably facilitated the development of the chip mosaic that contributes to the durability of the chipseals.

These results show that even on these low-stress sites, there is a relationship between the binder properties tested according to the guideline that can be related to the actual seal performance. In general, there was some good correlation between the laboratory test results (specification guideline predictions) and the actual observed field performance – thus substantiating the validity of the specification.

The next stage of the research will require monitoring the construction of chipseal performance on sites with higher stress, where the binder properties should contribute more to the durability of the seal than seems to be the case on low-stress sites.

10. Conclusions

1. The results show that the tests are identifying the binders that are susceptible to the high or low temperatures of the climate where they have been applied. Most chipseal failures were located where a combination of detrimental construction factors (including incorrect binder) occurred. The use of the susceptible binder served to amplify the other construction deficiencies, almost guaranteeing that there would be a failure.

2. The structure of the TxDOT specification provides a rational basis for a chipsealing binder selection guideline by requiring testing of the binders at the actual extremes of the temperatures that they will be exposed to in service under environmental conditions.

3. The SPG suite of tests used in this guideline are fundamental tests designed to measure binder rheological behaviour at the temperature extremes. However, the relationship between the SPG test results and what actually happened on the road is considered only reasonable at best.

4. The Low-temperature Plate Cohesion test is a ranking test that compares the cohesion of the binders and involves some interaction with the aggregate. It seems that the test at the extreme temperatures that are encountered in the field is too severe for most binders in this study. The test could be modified to obtain more useful results by reducing the severity of the applied stress, increasing the temperature environment of the test, and applying the stress to the chip – this would produce more realistic test results.

5. The Vialit Pendulum Tester results showed that it is not a suitable ranking tool for binders at low temperatures, but it is a suitable indicator for performance at high pavement surface temperatures.

6. The PAV procedure is probably not appropriate for ageing cutback binders – a different ageing test protocol for cutback binders needs to be explored.

7. The DSR results for the unaged binders at high temperatures identified binders that may contribute to bleeding/flushing. Therefore, the DSR results should be considered a good indicator of the potential of a binder to bleed or flush at high service temperatures.

8. The m-value parameter identified binders that would be likely to have chip loss. Therefore, the m-value should be considered a good indicator of a binder’s potential for chip loss at low pavement surface temperatures.

9. Field monitoring has generally shown that the single-coat seals performed well. However, the low binder application rates contributed as much or more to the aggregate loss than the properties of the binder.

10. Two-coat seals performed very well on these straight, flat sites, showing that they are a useful treatment for sites with varied or minimal texture. The interaction of the two layers of aggregate seems to overshadow the effects of the various binders used.

11. Generally, the two-coat seals performed better than the single-coat seals with respect to both chip loss and bleeding and flushing, especially where polymer-modified binders were used.

12. With respect to the seasons, it was generally observed that the majority of the chip loss occurred during the cold season (winter), whilst most of the bleeding/flushing predominantly occurred during the hot season (spring–summer).

13. Overall, the developed specification guideline is functional and offers a promising framework for selecting chipseal binders that takes into account binder rheological properties and climate. The correlation between the guideline’s prediction of performance and the actual (observed) field performance of the binder was greater than 60 percent, which is reasonable, considering the binders and sites utilised in this study.

14. Based on the findings, and consistent with the developed specification guideline (for chipseal binder selection), a list of laboratory tests were recommended for characterising the binder rheological properties to optimise chipseal design and performance. These binder tests are listed in Appendix D and include the test conditions, the binder property measured and the associated failure criteria.

15. The successful application of binder selected according to the developed guideline is also dependent on good construction practices, appropriate treatment selection and an appropriate seal design.

11. Recommendations

1. Further investigation is required on the performance of chipseals under a similar monitoring programme on sites with stress from bends and inclines. This would differentiate between binders where the straight, flat sections used in this initial research did not. A study of this nature should also incorporate a detailed traffic evaluation or analysis, to aid in the development of stress-based binder selection criteria and guidelines.

2. Further work is required to identify the penetration binder recipes that fit within each of the climatic zones, to help the practitioner select the appropriate binder for each site.

3. Some of the tests used in the guideline do not accurately prescribe the required properties of the binder – better tests should be examined or developed to further improve the guideline. For example, the Vialit Pendulum Tester produced unsatisfactory results at low temperatures, while the PAV did not perform well with cutback binders. Also, review of the failure criteria and laboratory test conditions is recommended, as some of the threshold values may have been too conservative.

4. Binder selection for chipseals for straight, flat, low-stress sections of a road should focus on the low-temperature properties for binder selection for single-coat reseals. All of the chip loss during the monitoring programme was due to cohesive failure at low temperatures.

5. Guidance for binder recipes can be found in Appendix E, which summarises both the low-temperature and high-temperature performance of the binders in their respective climate zone.

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Appendix A Temperature data from Woods 1998

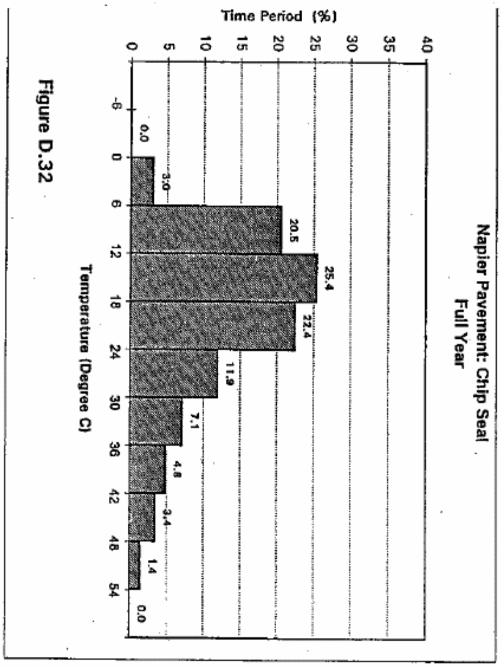


Figure D.32

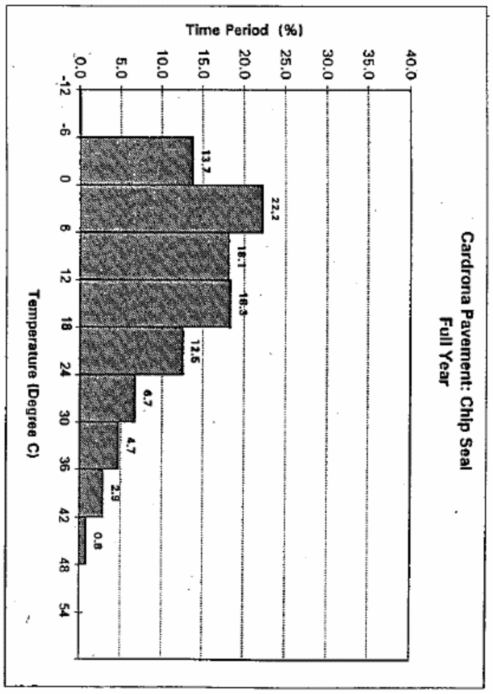
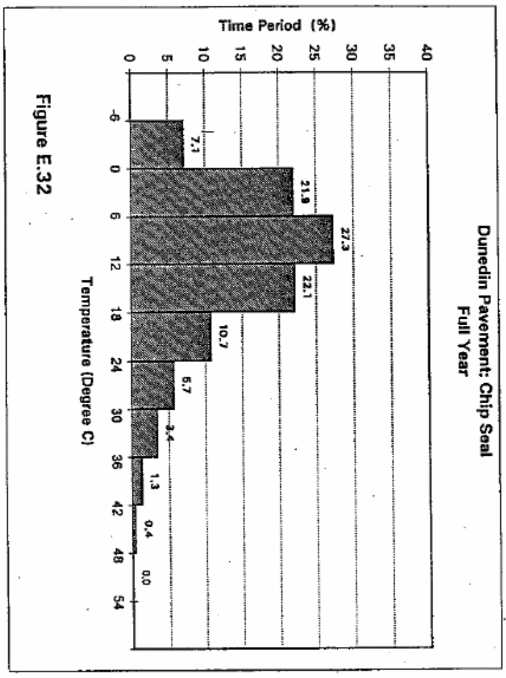


Figure C.30



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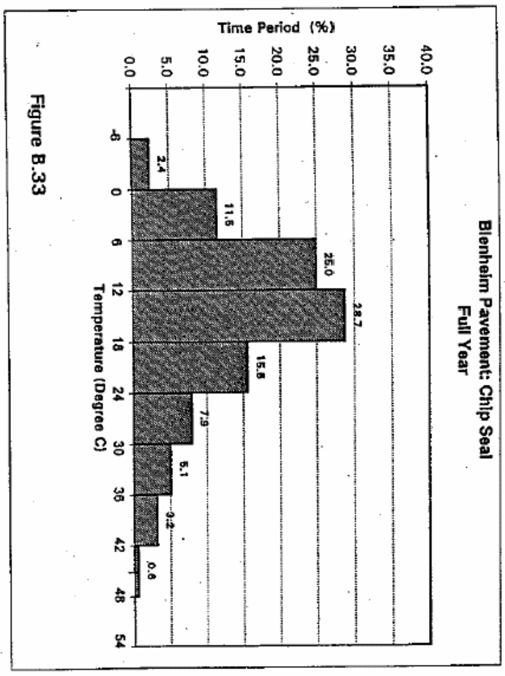

Figure B.33

Appendix B Single-coat seal performance cause and effect *(page 1)*

	Under-chipping	Over-chipping	Texture decrease	Texture increase	Construction timing	No binder rise	Binder rise	Binder m-value low temp	Binder stiffness low temp	DSR high temp	Cohesion high temp
Chaslands											
Aggregate breakdown		O	O		O						
Aggregate loss	✓	O	·		O	✓		✓	O	O	O
No binder rise	✓	✓	✓✓		✓			✓✓	**O**	✓	✓
Lorneville											
Aggregate breakdown			✓								
Aggregate loss	✓				O	✓		✓✓	✓	✓	✓
No binder rise	O		✓		O			✓	✓	✓	✓
Bleeding/Flushing			O		O		✓✓	✓	O	O	O
Balfour											
Aggregate breakdown	O										
Aggregate loss	✓			✓✓	·	✓✓		O	✓	✓	✓✓
Binder rise		O							O	O	O
No binder rise	✓	O	O	O				O	✓	✓	✓✓
Bleeding/Flushing		O	O				✓		O	O	O
McDonald Road											
Aggregate breakdown	✓	✓	✓✓		✓✓	·	O	·	·	·	·
Aggregate loss	✓✓	O	·		✓✓	✓✓		✓✓	✓	✓	✓✓
Binder rise	O		✓		O	·		O	O	O	O
No binder rise	✓	✓	✓✓		✓✓	·		✓✓	✓	✓	✓✓
Bleeding/Flushing	O		✓✓		✓			✓	O	O	O
St Bathans											
Aggregate breakdown	✓	✓✓	✓✓		✓✓	·	✓		·	·	·
Aggregate loss	✓✓	✓	·		✓✓	✓✓			✓✓	✓✓	✓✓
Binder rise	O		✓✓		O				O	O	O
No binder rise	O	✓	✓✓		✓✓				✓	✓✓	✓✓
Bleeding/Flushing	O	O	✓✓		✓✓		✓		✓	✓✓	✓✓
Glenfoyle											
Aggregate breakdown	✓	✓	✓✓	·	O	·	✓	·	·	·	·
Aggregate loss	O	✓	·	O	O	✓✓		✓✓	✓✓	✓✓	✓✓
Binder rise			✓								
No binder rise		✓	✓✓		O			✓✓	✓✓	✓✓	✓✓
Bleeding/Flushing			O				O				

Single-coat seal performance cause and effect (continued, p2)

	Under-chipping	Over-chipping	Texture decrease	Texture increase	Construction timing	No binder rise	Binder rise	Binder m-value low temp	Binder stiffness low temp	DSR high temp	Cohesion high temp
Jolly Road											
Aggregate breakdown	✓✓	✓✓	✓✓		O	▪	✓			▪	▪
Aggregate loss	✓✓	✓		✓✓	O	✓✓		O	O	✓✓	✓✓
No binder rise	✓	✓	O		O			O	O	✓✓	✓✓
Bleeding/Flushing							O				
Lehmans Road											
Aggregate breakdown		✓	✓✓		✓	▪		▪		▪	▪
Aggregate loss		O			✓	✓		✓✓	O	✓✓	✓✓
No binder rise		O	✓✓		✓			✓✓	O	✓✓	✓✓
Korere											
Aggregate breakdown	O	✓	✓	▪	O	▪	O	▪	▪	▪	▪
Aggregate loss	✓✓	✓			O	✓✓		✓✓	✓	✓	✓✓
Binder rise	O	O	O					O	O	O	O
No binder rise	O	✓	✓		O			✓✓	✓	✓	✓✓
Bleeding/Flushing	✓	O	✓		O		✓	✓	O	O	O
Tadmor											
Aggregate breakdown		✓✓	✓✓		✓✓	▪	✓✓		▪	▪	▪
Aggregate loss		O	▪		O	✓			O	O	O
Binder rise		✓✓	✓✓		✓				✓✓	✓	✓✓
No binder rise		O	✓		✓				✓✓	✓	✓
Bleeding/Flushing		✓✓	✓✓		✓✓		✓✓		✓✓	✓✓	✓✓
Collingwood											
Aggregate breakdown		✓✓	✓✓		✓✓	▪	✓✓	▪	▪	▪	▪
Aggregate loss		O			O	O		✓	O	O	O
No binder rise		O	✓		O			O			O
Bleeding/Flushing		O	O				O	O			
Wards Line											
Aggregate breakdown		O	O		O		O				
Aggregate loss		O			✓✓	✓✓		✓✓	O	O	✓✓
Binder rise		✓✓	✓✓		✓			✓	O	O	✓
No binder rise			✓		✓			✓	O	O	✓
Bleeding/Flushing		✓✓	✓✓		✓		✓✓	✓✓	O	O	✓

Single-coat seal performance cause and effect (continued, p3)

	Under-chipping	Over-chipping	Texture decrease	Texture increase	Construction timing	No binder rise	Binder rise	Binder m-value low temp	Binder stiffness low temp	DSR high temp	Cohesion high temp
Norfolk*											
Aggregate breakdown	O	O	O		O						
Aggregate loss	O	✓✓			✓✓	✓✓			✓✓	✓✓	✓✓
No binder rise	O	✓✓	✓		✓✓				✓✓	✓✓	✓✓
Pouarua South Rd											
Aggregate breakdown	✓	✓	O		O						·
Aggregate loss	O	O			O	✓		O		O	✓
No binder rise	✓	✓	✓		✓			O		✓	✓
Coxhead Road											
Aggregate breakdown	O	O	O		O						
Aggregate loss	O	O		✓	✓	✓✓		O		✓	✓
No binder rise	O	✓	O		✓			O		✓	✓✓
Wright Road											
Aggregate breakdown		✓	✓		✓✓		O			·	·
Aggregate loss		O			✓	O				O	O
Binder rise			O		O					O	O
No binder rise		✓	✓✓		✓✓			O		✓✓	✓✓
Bleeding/Flushing		O	✓		✓		✓✓			O	O
Tokiri 1											
Aggregate breakdown		✓	O		O			·			
Aggregate loss		✓		O	O	✓		✓	O		O
No binder rise		✓	O		O			✓✓	O		O
Tokiri 2											
Aggregate breakdown		✓	O		✓			·			
Aggregate loss		O			O	O		✓	O		O
No binder rise		O			O			O			

✓✓	Strong relationship
✓	Some relationship
O	Possible relationship
	No relationship

Appendix C Two-coat seal performance cause and effect

	Binder m-value low temp	Binder stiffness low temp	DSR high temp	Cohesion high temp	Chip loss
Clarksfield					
Aggregate loss	O			O	
Binder rise	O				
No binder rise	✓✓	O	✓✓	✓✓	O
Bleeding/Flushing	O		O	O	
Texture decrease	✓	O	✓	✓	
St Andrews					
Aggregate loss	O		O	O	
No binder rise	✓✓		✓✓	✓✓	O
Texture decrease	✓		✓	O	
Mt Cook					
No Binder Rise		✓	✓	O	
Texture Decrease		O	O	O	
Wanganui Bridge					
Aggregate loss	✓	O	O	O	
No binder rise	✓	O	O	O	
Texture decrease	✓	O	O	O	
Evans Straight					
Aggregate loss	✓	O			
No binder rise	✓	O			
Texture decrease	✓	O			
Taipo Bridge					
Aggregate loss	✓✓	O	O		
No binder rise	✓✓	O	O		
Texture decrease	✓	O	O		
Takaka					
Binder rise		O		O	
No binder rise		✓	O	✓	
Bleeding/Flushing		O		O	
Texture decrease		✓	O	✓	
Camp Road					
Aggregate loss	O				
Binder rise	✓✓	O	O	✓	
No binder rise	O			O	
Bleeding/Flushing	✓✓	O	O	✓	
Texture decrease	✓✓	O	O	✓	
Upper Opaki					
Aggregate loss		O		O	
Binder rise	O	✓	O	✓✓	
No binder rise		O		O	
Bleeding/Flushing	O	✓✓	O	✓✓	
Texture decrease	✓	✓✓	✓	✓✓	
Apirana Road					
Aggregate loss	O	✓		O	
Texture decrease	O	✓		O	
Township Road					
Binder rise	O			O	
No binder rise	✓✓		O	O	
Bleeding/Flushing	✓		O	O	
Texture decrease	✓✓		O	O	
McCathie Road					
Aggregate loss	✓✓		O	O	
No binder rise	✓✓		O	O	✓
Texture decrease	✓		O	O	

✓✓	Strong relationship	O	Possible relationship
✓	Some relationship		No relationship

Appendix D Binder Test description

Test	Test conditions	Property measured
DSR Dynamic Shear	High temperature, binder unaged G*/sin δ, Min 0.65k Pa@10rad/s	For characterising unaged binder rheological properties at the high service temperature to identify the potential for bleeding/flushing.
Vialit Pendulum test	High temperature	For measuring the energy required to break the binder bond at the high service temperature to identify the potential for chip rollover.
Low-Temperature Cohesion test	Low temperature, binder unaged <20% chips lost	For identifying the unaged binders' performance at the low service temperature to identify the potential of brittle binder failure and subsequent chip loss.
PAV	@ 90°C – Aging conditions	Designed to age the binder to a state as if it had been exposed in the field for 12 months.
BBR Flexural Stiffness	Low temperature, binder aged Max 500,000 Pa@8s	Measures the stiffness of the binder – the higher the stiffness, the more susceptible the binder may be to chip loss at the low service temperature.
m-value	Measured as per BBR Min 0.240	Tells us the rate of change of the stiffness at the low service temperature – the lower the rate of change, the more susceptible the binder may be to stress, with the potential for chip loss.

Appendix E Binder performance

The research project tested various binders and monitored how they performed over the two-year monitoring period on flat, straight sections of selected roads. Listed below are the binders, their recipes and climatic zones. The table below is a summary of the binders and their performance on the respective sites and climatic zones.

Site name	**Base binder**	**Additives**	**Climate zone**	**Binder performance in the field**	
				Low temp	**High temp**
Chaslands	180/200	2/3/0.8	45-10	Okay	Good
Lorneville	180/200	0/3/0.7	50–10	Poor	Okay
Balfour	180/200	0/3/0.7	50–10	Good	Good
McDonalds Rd	180/200	2/4/0.8	50–10	Poor	Good
St Bathans Loop Rd	180/200	2/4/0.5	55–15	Okay	Poor
Glenfoyle	180/200	1/3/0.5	55–10	Poor	Good
Jolly Rd	180/200	1/3/0.5	55–10	Good	Good
Clarksfield Rd	130/150 2%PMB	0/6/0.7	55–10	Good	Good
St Andrews	130/150 2%PMB	0/6/0.7	50–5	Good	Good
Mt Cook	130/150 2%PMB	0/3/0.7	50–15	Good	Good
Lehmans Rd	180/200	1/3/0.5	55–10	Poor	Good
Wanganui Bridge	130/150	0/5/0.7	45–10	Okay	Okay
Evans Straight	130/150 2%PMB	0/3/0.7	45–10	Okay	Okay
SH73 Taipo	130/150 2%PMB	0/3/0.7	50–10	Poor	Okay
Korere	130/150	0/3/0.7	55–10	Poor	Okay
Tadmor	130/150	0/4/0.7	55–10	Okay	Poor
Takaka	130/150	0/4/0.7	50–10	Good	Okay
Collingwood	130/150	0/4/0.7	50–5	Good	Good
Wards Line	180/200	0/1/0.7	55–5	Poor	Good
Camp Rd	180/200	0/1/0.7	55 –5	Good	Poor
Norfolk Rd	180/200	0/1/0.7	55–10	Poor	Good
Upper Opaki	180/200	0/1/0.7	55–10	Good	Poor
Apirana Rd	130/150	0/2/0.7	50–10	Good	Good
Pouarua South Rd	180/200	0/3/0.7	55–5	Good	Good
Coxhead Rd	180/200	0/3/0.7	55–5	Good	Good
Township Rd	130/150	0/3/0.7	55–5	Good	Okay
Wright Rd	130/150	0/3/0.7	55–5	Good	Good
McCathie Rd	130/150	0/1/0.7	55–0	Poor	Okay
Tokiri Rd 2	130/150	0/2/0.7	50–5	Good	Good
Tokiri Rd 1	130/150	0/2/0.7	50–5	Good	Good