Resealing strategies to increase seal life and prevent seal layer instability

G. F. A. Ball and J. E. Patrick
Opus International Consultants Ltd, Lower Hutt

NZ Transport Agency research report 372

ISBN (paperback): 978-0-478-34604-6
ISBN (pdf): 978-0-478-34603-9
ISSN (paperback): 1173-3756
ISSN (pdf): 1173-3764

Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Ball, G. F. A., and Patrick J. E. Resealing strategies to increase seal life and prevent seal layer instability. *NZ Transport Agency research report* 372. 39 pp.

Keywords: aggregate, bitumen, chipseal, fines, flushing, spray rates

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 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 funds innovative and relevant research that contributes to this objective.

The views expressed in research reports are the outcomes of the independent research, and should not be regarded as being the opinion or responsibility of the NZ Transport Agency. The material contained in the reports should not be construed in any way as policy adopted by the NZ Transport Agency or indeed any agency of the NZ Government. The reports may, however, be used by NZ Government agencies as a reference in the development of policy.

While research reports are believed to be correct at the time of their preparation, the NZ Transport Agency and agents involved in their preparation and publication, do not accept any liability for use of the research. People using the research, whether directly or indirectly, should apply and rely on their own skill and judgment. They should not rely on the contents of the research reports in isolation from other sources of advice and information. If necessary, they should seek appropriate legal or other expert advice.

Terms and abbreviations

ALD	The average of the least dimension of a sample of chips. The least dimension of a chip is the distance between two parallel plates in contact with the chip, when the chip is placed so that the distance is a minimum.
ALD	The average of the greatest dimension of a sample of chips, aligned in their greatest dimension.
RAMM	Road Assessment and Maintenance Management system: a computer-based system to manage the maintenance and rehabilitation of pavements and associated roading features.
Transit NZ	The authority responsible for the construction and maintenance of the NZ State Highway system (merged with the NZ Transport Agency in August 2008).

Contents

Executive summary

The original aim of this project was to produce seal selection guidelines for the resealing of flushed seals that would eliminate or reduce the incidence of future premature failure through flushing. The working hypothesis of the project was that there is a maximum compaction level for any particular multilayer chipseal with a corresponding void content; if the total binder content is greater than this, then flushing will eventually occur.

The assumption was made that chip degradation is sufficiently low that void changes are principally due to seal compaction. This assumption has proved to be incorrect, and further investigation of the processes of chip degradation in the seal pavement is needed.

In order to determine the maximum compaction possible in multilayer seals, artificial chipseals, consisting of chips only, were constructed by placing chips on a square tray, and the void content was measured by adding weighed amounts of water and then measuring the height of the water surface above the tray floor.

Voids contents of the order of 40–50 percent were obtained. When these are compared with recommended spray rates, available voids are typically about twice the expected volume of bitumen that would be sprayed. On this basis, there should never be a problem of flushing.

Multilayer chipseals cored from road surfaces typically have binder contents around 15 percent by volume, with air voids around 5 percent. In addition, continuously graded fine material (passing a 4.75 mm sieve) fills around 15 percent of the core volume. If the fines come predominantly from breakdown of the larger chip, it follows that, typically, around a fifth of the original chip is converted to fine material under trafficking and weathering stresses.

The *total* volume of binder, air voids and fines is of the same order of total voids (around 40 percent) found in the multilayer seals constructed without binder in the laboratory. This accounts for the difference between the total void volume in the laboratory samples and the calculated sprayed volumes.

Some potential sources of fine material are:

i) traffic wear of the aggregate

ii) fine basecourse material migrating upwards

iii) wind-blown detritus, particularly soil and vegetable matter

iv) traffic-sourced materials eg material transferred from unsealed roads and tracks, brake-pad material and rubber

v) grit from iced road treatments

vi) inadequate sweeping of the road surface prior to chipsealing.

The relative contributions from different sources may vary from site to site. Chemical and petrographic testing and x-ray diffraction may assist in ascertaining the actual origins of fine material.

The study of one set of cores taken in and between the wheeltracks at a single site suggested that wheeltracked sites are likely to have a higher fines content. This supports the hypothesis that the fines largely come from aggregate degradation caused by traffic, although it would be expected that any fine material on the surface, from whatever source, would be incorporated more effectively into the seal structure at the wheeltrack location.

The production of fines, by whatever means, changes the effective void content. In any analysis it is not clear whether the fines should be counted as part of the binder content or part of the aggregate, or divided in some way between the two, and there is no guarantee that the proportion of fines would be constant for a particular combinations of seals. In fact, it would be expected to increase over time.

Because of the evidence that significant production of fines occurs over time, it is currently impossible to predict the void content of a completely compacted multilayer chipseal surface. Thus, the proposed method of predicting seal compaction and availability, under trafficking, of voids to contain bitumen is not practicable at present.

A more complete understanding of the processes that produce fines in seals is required before a means to predict compaction and liability to flushing through loss of voids in seals can be developed.

Any investigation should aim to settle the following two questions arising from the work described in this report – the answers may affect chipseal performance:

a) Are the fines amounts and gradings predictable, given initial aggregate gradings, chip source and traffic levels?

b) Does the fines content significantly affect the tendency of a seal to flush early, and if so, to what degree?

A combination of field results and testing of laboratory-constructed seals, designed to have varying quantities of fines, may assist in answering these questions.

A selection of newly sprayed seals should be monitored to observe the development of fines content. Cores should be taken immediately prior to sealing and at intervals thereafter.

In order to ascertain the sources of the fine material, a combined chemical, petrographic and x-ray diffraction analysis should be carried out on fines material in several samples from a representative selection of seal cores from around the country. Any significant regional differences should be noted and the reasons for these differences be ascertained.

Indoor trafficking of seals that are constructed in the course of other research work (eg in the CAPTIF apparatus in Christchurch) could provide samples that exclude some possible sources of fine material that are present in the field. Examination of fines in core samples from CAPTIF work would therefore provide further insight into the processes of fines generation.

Abstract

A study of cores from multilayer chipseals shows that fine solid materials (passing 4.75 mm) fill a significant proportion of the chipseal volume that would otherwise be available for bitumen. If fines are ignored, the available voids are typically about twice the expected volume of bitumen that would be sprayed. Generation of fines may therefore contribute significantly to premature flushing. The origin of these fine materials remains to be examined; at least six different processes may contribute, and the relative contributions may vary from site to site.

1 Introduction

The original aim of this project was to produce seal selection guidelines for the resealing of flushed seals that would eliminate or reduce the incidence of future premature failure through flushing. This was to be achieved by measuring the change in void volume in multilayer seals because of trafficking, and projecting those results to ultimate potential compaction. We intended to assess this by modelling seals in the laboratory as well as sampling from sites that had fully compacted seals, such as very heavily trafficked roads (principally forestry roads). The working hypothesis of the project was that there is a maximum compaction level for any particular multilayer chipseal with a corresponding void content; if the total binder content is greater than this, then flushing will eventually occur. The assumption was made that chip degradation is sufficiently low that void changes are principally due to seal compaction.

However, while some progress was made towards the project's goal, this basic assumption was found to be incorrect, and further investigation of the processes of chip degradation in the seal pavement is needed. The work leading to this conclusion is described in sections 2 and 3.

Premature flushing is an ongoing problem in New Zealand sealed roads. In a study conducted for Transit New Zealand, Ball and Patrick (2005a) found that chipseal lives were falling well below expected values. Approximately 30 percent of state highway chipseal surfaces failed through flushing before they reached half their expected lifetimes, and some 5700 km (50 percent) showed significantly reduced seal lifetimes because of flushing. Flushing was also a major cause of seal failure in urban areas.

The majority of the New Zealand road network consists of multiple-layer chipseals. In a Land Transport NZ study on flushing of multiple-layer chipseals (Ball et al 2005b), it was found that they were not unduly likely to flush if standard seal design practice was followed throughout the sealing process. In cases where early flushing of multilayer seals did occur, it appeared to be associated with an instance of resealing before adequate compaction of the underlying surface had taken place. Sealing onto a highly textured surface (using increased bitumen application rates) ultimately resulted in insufficient voids to accommodate the bitumen as compaction continued under traffic, and flushing occurred.

The research described here aimed to look at compaction within the various layers of the whole multilayer seal system, based on the proposition that compaction within these layers continues after a new seal surface is applied. Thus early resurfacing, which usually requires more bitumen to be used to deal with existing surface texture, might ultimately lead to flushing.

2 Maximum compaction study

2.1 Study design

Artificial chipseals, consisting of chips only, were constructed by placing chips on a square tray, and the void content was measured by adding weighed amounts of water and then measuring the height of the water surface above the tray floor. Each subsequent layer of chips was gently rolled with a rubber-covered hand roller to encourage movement of chips into the underlying voids. This method has previously been used by Potter and Church (1976), Houghton and Hallett (1983), Dickinson (1990) and Alderson (2001) to examine aspects of single-coat seals.

Table 2.1 lists the properties of the aggregate used for this work.

Table 2.1 Measured physical properties of sealing chip used in the laboratory study

TNZ chip grade[a]	ALD[b] mm	AGD[b] mm	AGD/ALD	Dry density kg/m³	SSD density kg/m³	Bulk density kg/m³	Bulk air voids %
2	12.5	24.1	1.93	2683	2663	1316	51
3	10.5	18.8	1.79	2687	2662	1375	49
4	8.5	15.1	1.89	2687	2662	1379	49
5	5.3	11.2	2.11	2687	2662	1347	50

a) Chip grades are as specified in Transit NZ specification M/6 (2004).

b) ALD is the average least dimension of the chip, and AGD the average greatest dimension.

The ALG/ALD ratio needs to be of the order of two or greater to minimise void content for a single-coat seal (Alderson 2001; Transit NZ 2005, section 9.4.4). Bulk density values are used along with the ALDs in estimating aggregate coverage needed for different types of seal surface.

As a starting point, Grade 2 chips were closely packed by hand on the tray. The total weight of dry Grade 2 chip (1.605 kg) corresponded to a chip placement rate of 803/ALD m^2/m^3 (as usual, the ALD is expressed in millimetres). The chip rate currently recommended for a single-coat surface is 750/ALD m^2/m^3, which, when the 10 percent of chip allowed for whip off is removed, reduces to 833/ALD m^2/m^3. (Transit NZ 2005, pp. 366–7). Therefore, the application rate for the chip in the test tray is at a similar application rate to that suggested in the textbook.

Although the majority of chipseals placed on state highways today are two-coat or sandwich or dry locked seals constructed with two grades of sealing chip, most seals constructed prior to 2000 were single-coat seals. For the initial comparative work, the multilayer laboratory seals were constructed aiming at a chip coverage of 803/ALD m^2/m^3.

The following seal combinations were studied:

1 Single-coat Grade 2 (Grade 2 surface)

2 Grade 4 over Grade 2 (Grades 2/4 surface)

3 Grade 3 over Grade 4 over Grade 2 (Grades 2/4/3 surface)

4 Grade 5 over Grade 3 over Grade 4 over Grade 2 (Grades 2/4/3/5 surface)

5 Grade 2 over Grade 2 (Grades 2/2 surface)

6 Grade 3 over Grade 3 over Grade 2 over Grade 3 (Grades 3/2/3/3 surface).

Surfaces 1 to 4 represent a reasonable sequence of seals. Surfaces 5 and 6 are not generally recommended, as sealing with the same chip size as the underlying seal is considered bad practice that is likely to lead to flushing (Ball et al 2005b).

2.2 Procedures for analysing the results

For the purposes of discussion, the results are presented in graphical format in figures 2.1 to 2.4, using the four types of graph that are shown in generic form below.

1 **Depth of water (cm) versus volume (cm3)**

These are the initially measured quantities (volume being deduced from the weight of water). Figure 2.1 illustrates this format.

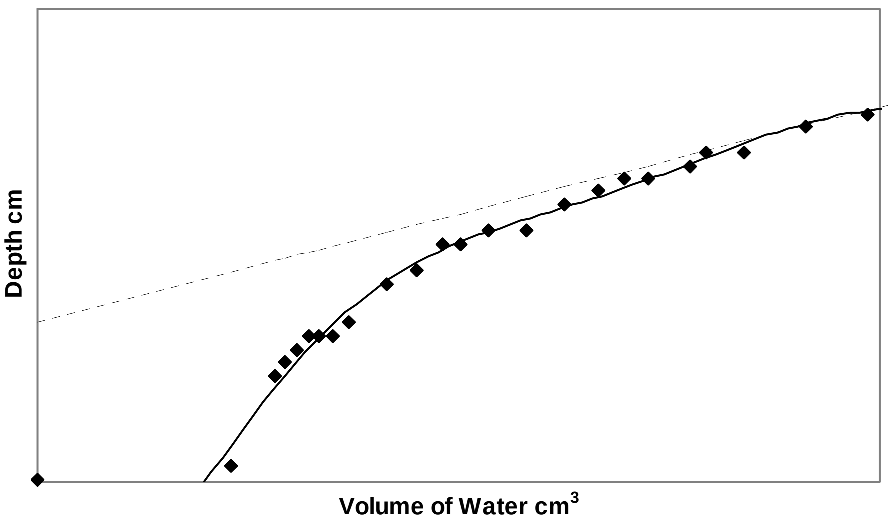


Figure 2.1 Form of depth versus volume plot

The dotted line represents the equation

$$\textit{Depth of water (cm)} = 0.0011342\ (\textit{Volume of water} + \textit{Volume of chip}) \qquad \text{(Equation 2.1)}$$

where the volumes are in cm^3 and the chip volume is calculated from chip weight and chip dry density (table 2.1). This line is expected to intercept the depth-versus-volume curve at the point where the chip is completely covered, and assist in determining the surfacing's thickness.

Note that in each case, some volume of water has been added before any measurable depth is observed, and the amount of water is too great to be accounted for by saturation of the chips. It is proposed that this effect is due to the dish base not being exactly flat, and more importantly, surface tension pulling water up onto the chip surfaces without a measurable increase in water depth between the chips. The volume displacement before any noticeable water depth is observed increases with the amount of chip. For this reason, results for the first few millimetres of depth do not give an accurate indication of the voids-versus-depth relationship.

2 **Volume of binder (L/m²) that would be required to fill a square metre of seal to a given depth (in mm)**

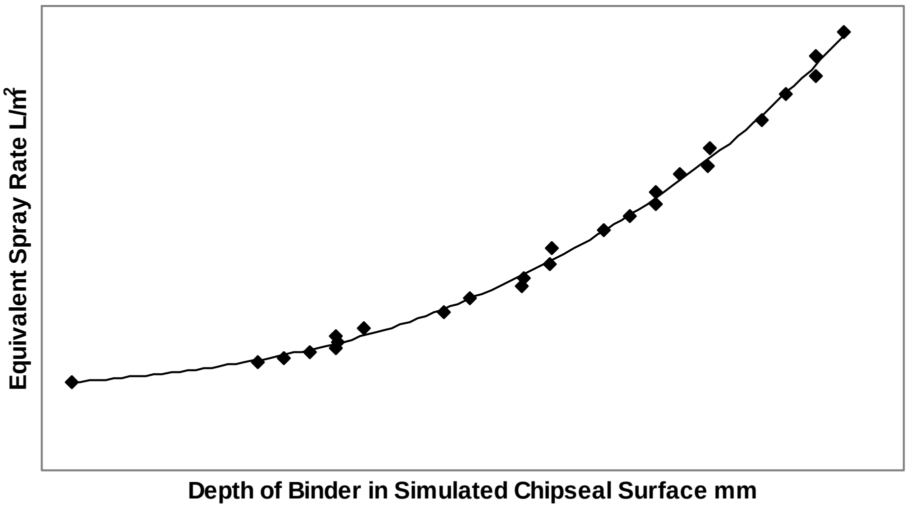


Figure 2.2 Form of volume-versus-depth plot

These volumes are obtained by dividing the volume of water at a given depth in the tray by the tray area (in m^2).

This form of graph enables comparisons to be made with void content and recommended spray rates as defined in Transit NZ (2005).

3 **Depth of water versus the percent of the total volume of chip immersed**

The total volume of chip immersed for a given water depth is

$$100 \times \frac{volume\ of\ test\ dish\ at\ water\ depth - volume\ of\ water}{total\ volume\ of\ chip}$$

(Equation 2.2)

where the total volume of chip is calculated by dividing the total chip mass by the dry density (table 2.1).

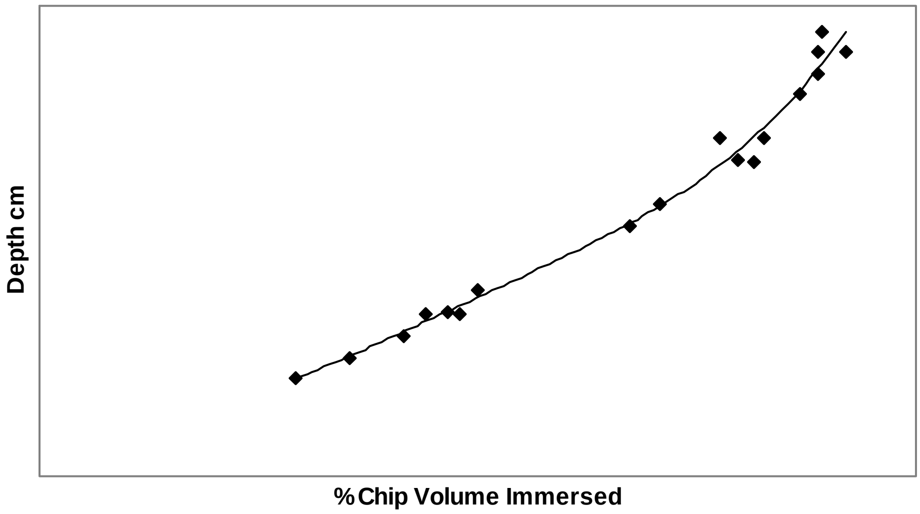


Figure 2.3 Form of plot of depth of water versus % of chip volume immersed

This curve reaches a value of 100 percent at the point where the water level reaches the thickness of the seal (ie the chips are just completely covered) and thus provides an additional means of determining the seal depth.

4 **Percent of the surface for a given depth of binder that is voids**

This is given by

$$100 \times \frac{volume\ of\ water\ at\ given\ depth}{total\ volume\ of\ test\ dish\ to\ that\ depth} \qquad \text{(Equation 2.3)}$$

and is indicative of the spray rate of a binder that is necessary to fill voids to that depth.

The percent volume voids curve typically reaches a minimum value around 80 percent of the full depth of the seal combination.

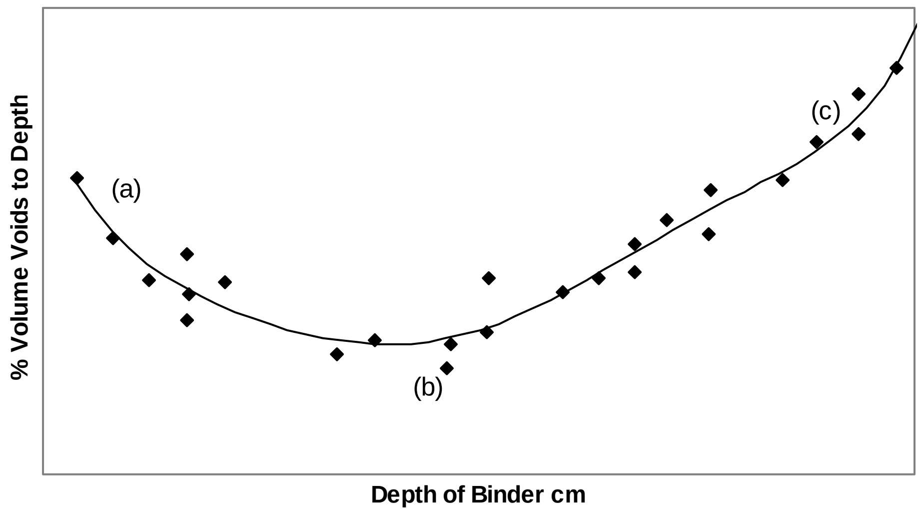
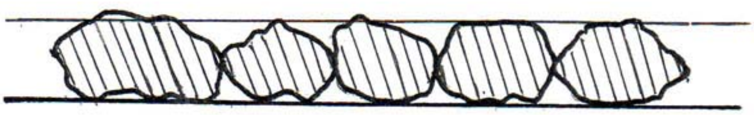


Figure 2.4 Form of percent volume of voids versus surface depth plot

The shape of the curve is explained as follows:

a) Initially, the water (corresponding to the binder) is shallow. Immersed aggregate volume is a small percentage of the total volume below the water surface. The percent of that volume filled by water (equivalent to percent voids) is high.

b) As the water level rises, the immersed aggregate volume becomes a higher proportion of the total volume below the water surface. The percent volume filled by water (equivalent to percent voids) is consequently reduced. Typically, it reaches a minimum when it is around 40 percent of the total volume below the water surface (see results in section 2.3).



c) With the further addition of water, the area of chip at the surface is reduced and the percentage of volume below the water line filled by water increases, although (since aggregate is present) this percentage will never reach 100 percent.

2.3 Results

Graphs for the six seal combinations are presented on the following pages in figures 2.5 to 2.10.

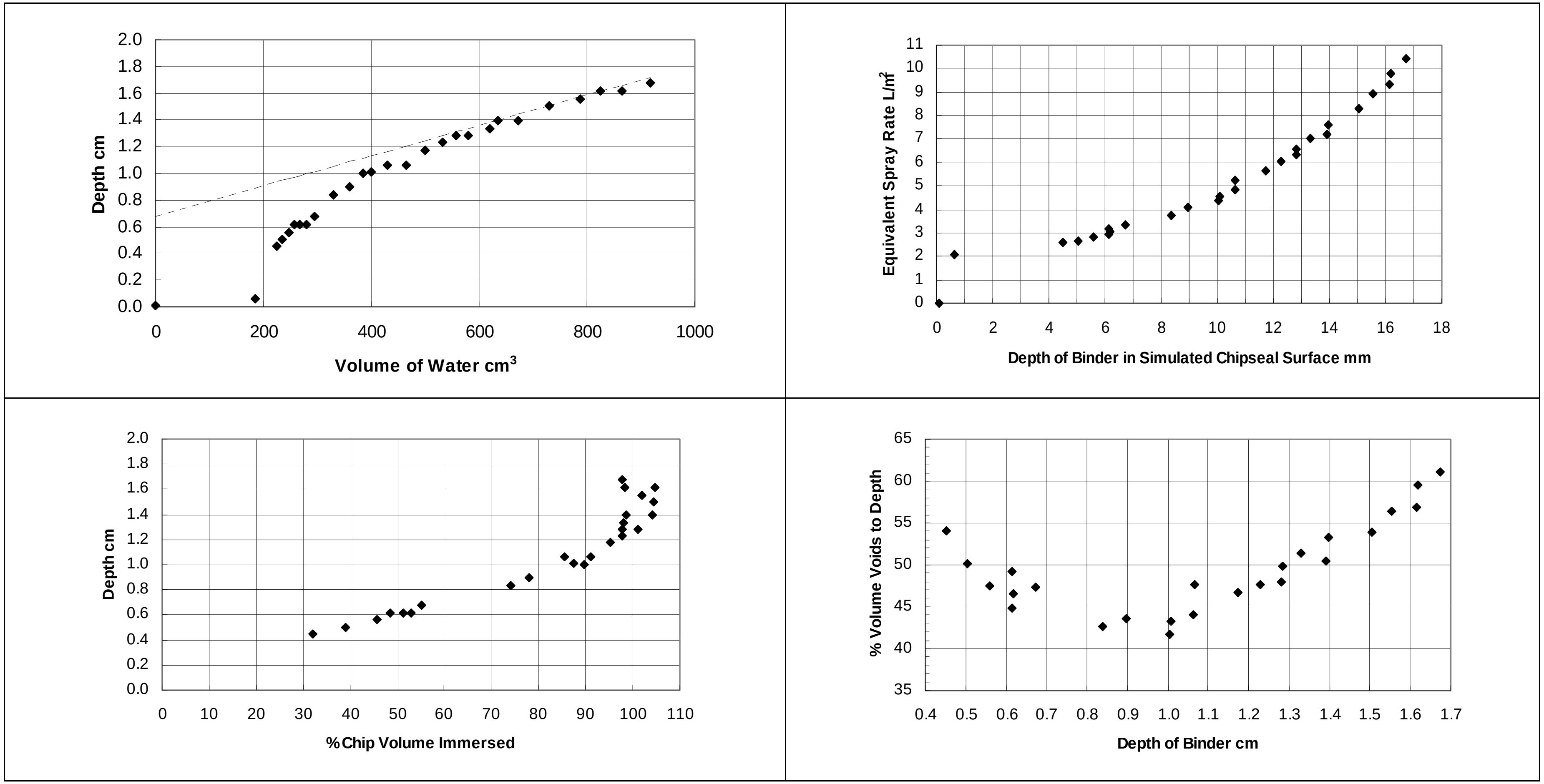


Figure 2.5 Grade 2 Surface. ALD = 12.5 mm

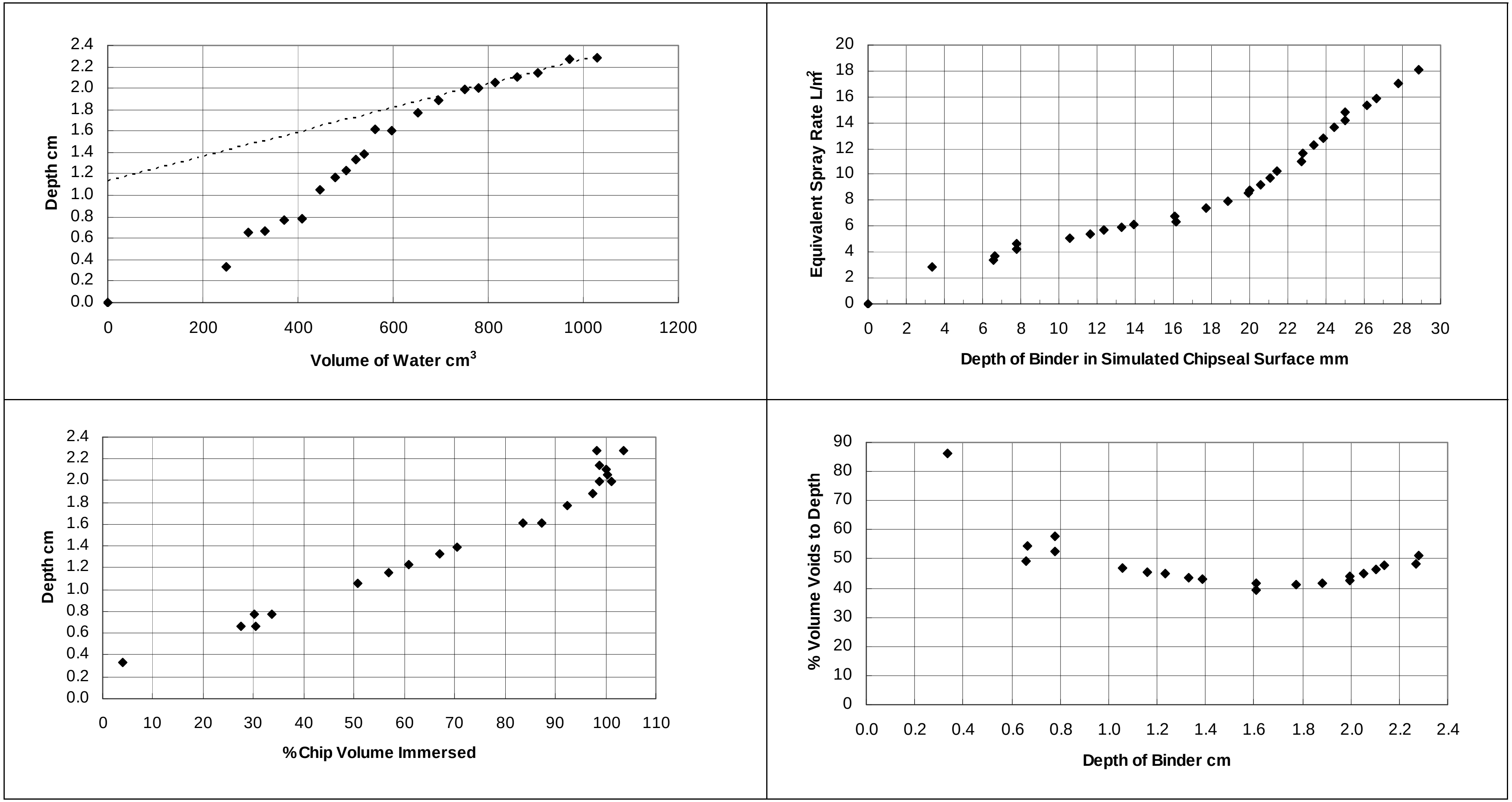


Figure 2.6 Grades 2 / 4 Surface

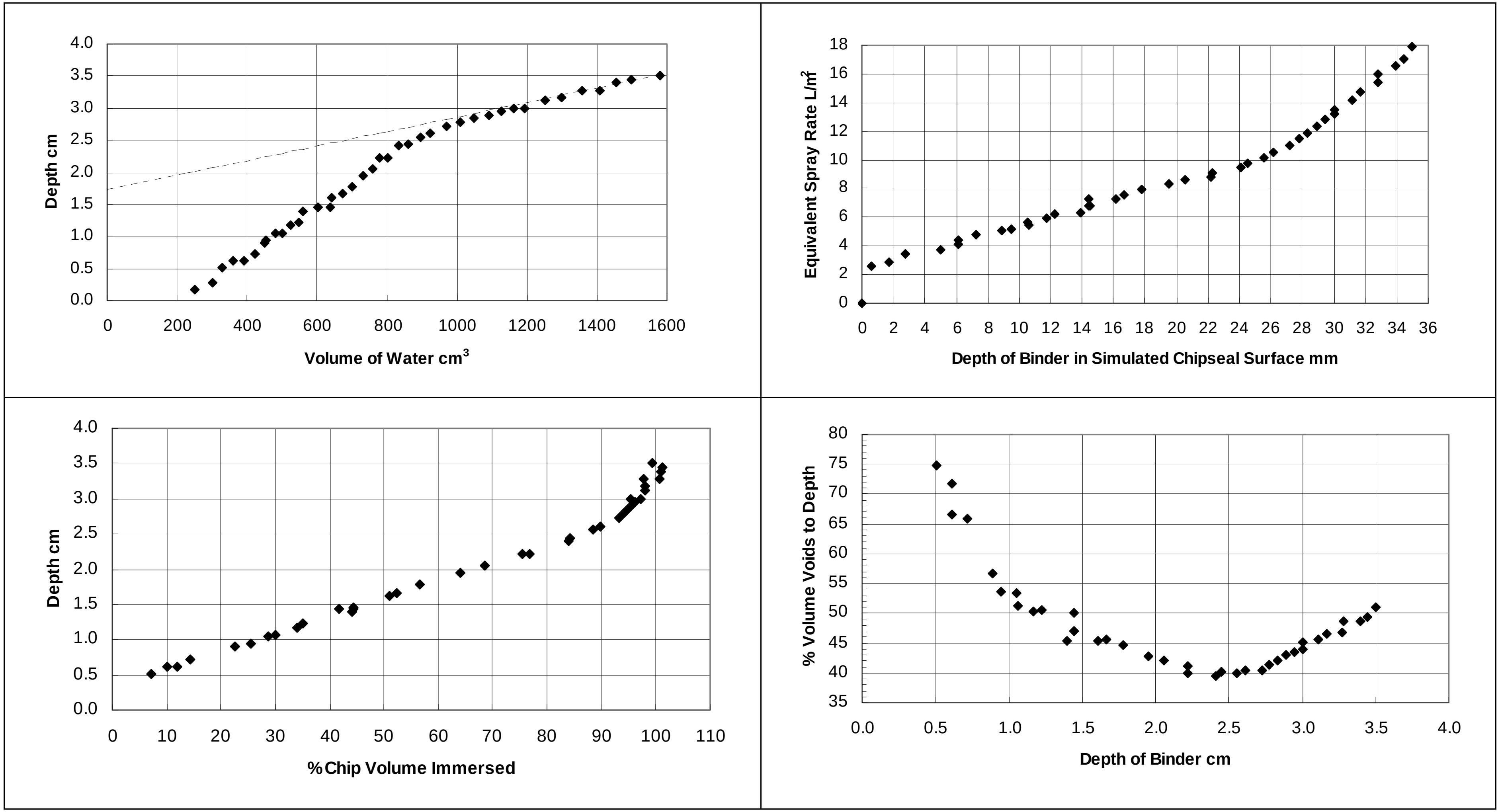


Figure 2.7 Grades 2 / 4 / 3 Surface

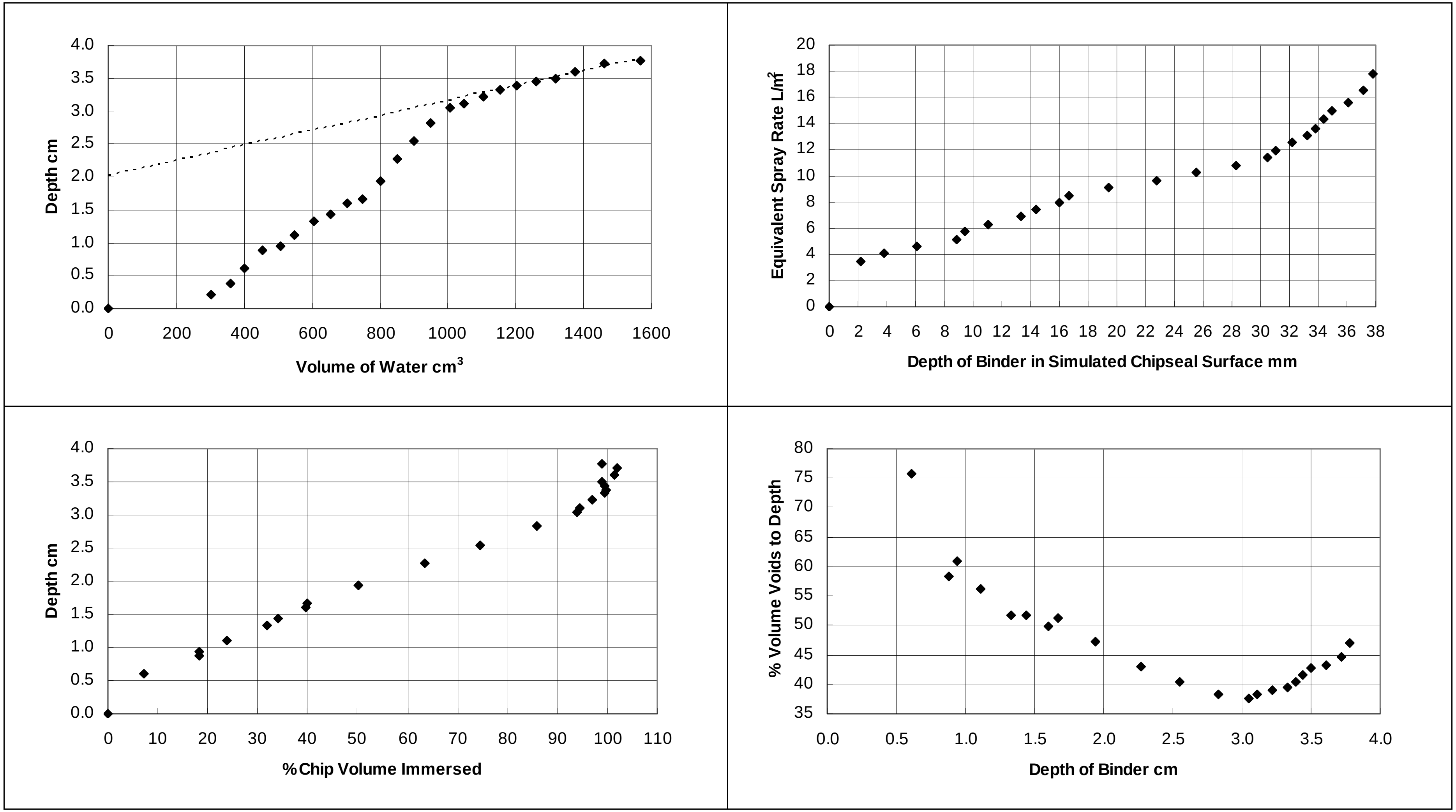


Figure 2.8 Grades 2 / 4 / 3 / 5 Surface

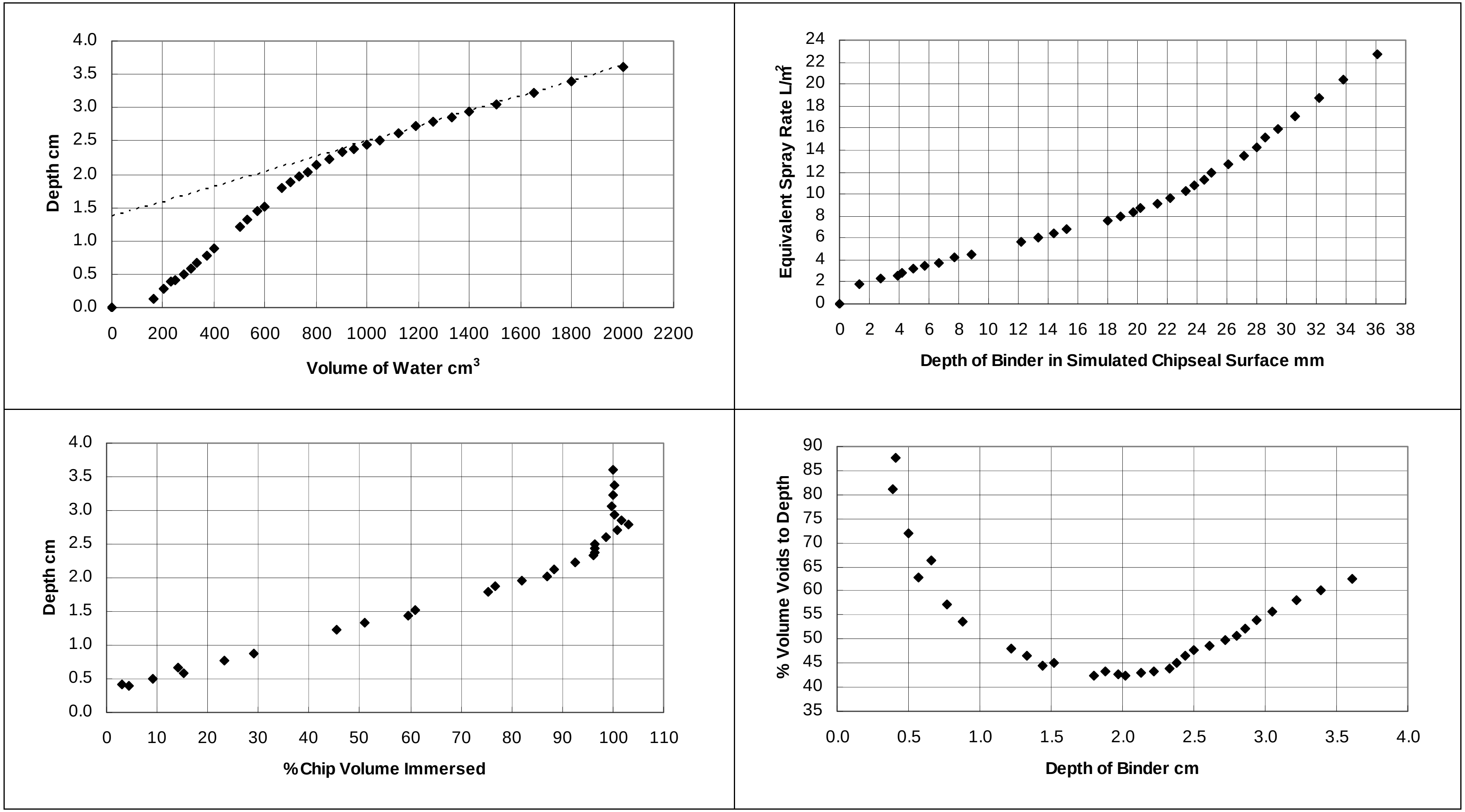


Figure 2.9 Grades 2/2 Surface

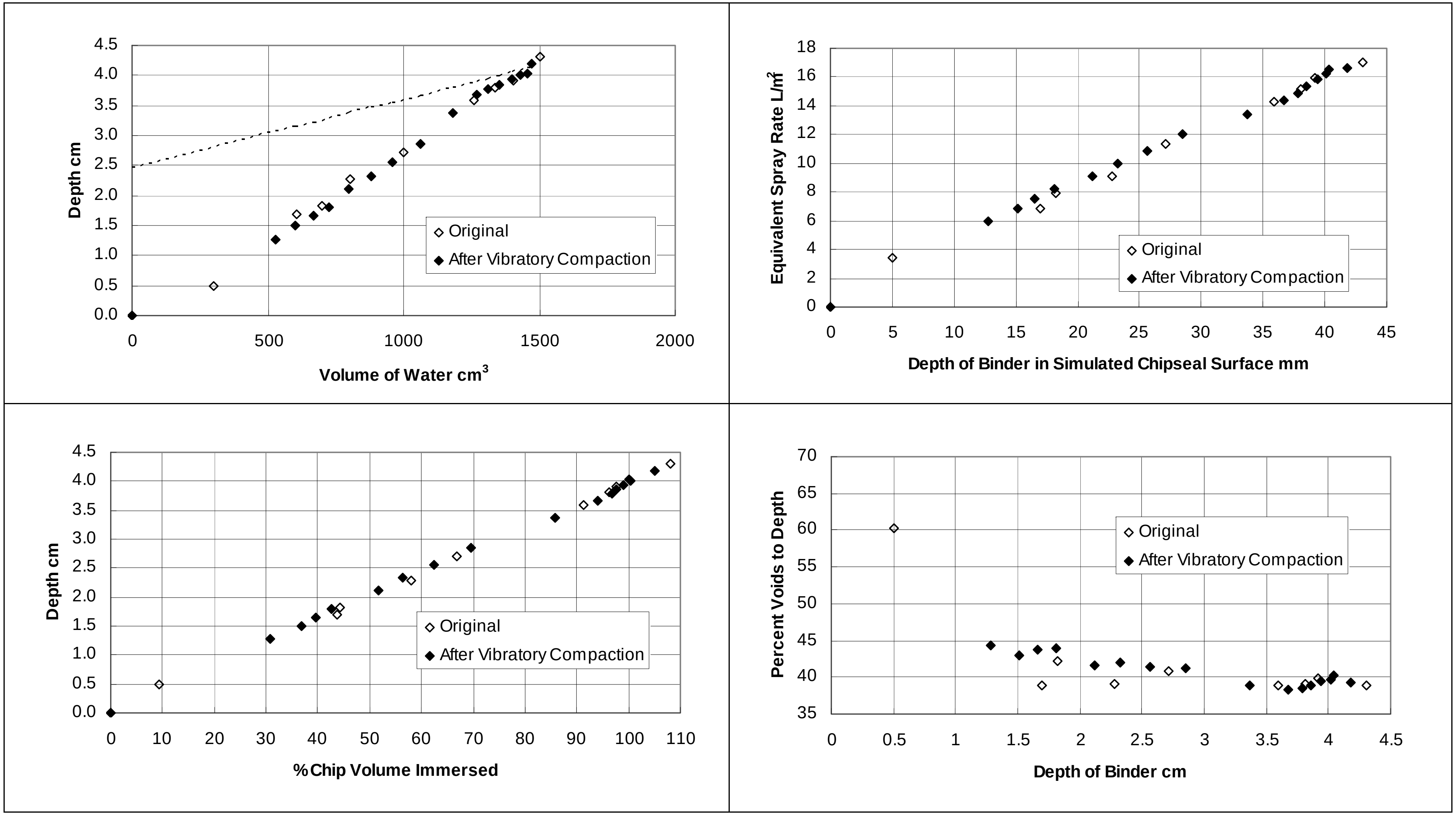


Figure 2.10 Grades 3/2/3/3 Surface

After initial volume measurements, the Grades 3/2/3/3 surface was covered with a layer of dense foam rubber to prevent chip loss, and vibrated for 30 minutes on a vibrating table (vibrational amplitude approximately 0.25 mm, frequency 50 Hz) to see if further compaction could be achieved. The void measurements were then repeated; the plots in figure 2.10 indicate that no further measurable compaction had occurred.

Table 2.3 (on the next page) summarises the graphical data. The 'calculated total spray rate' (fifth row) is an estimate of the total volume of bitumen that would be sprayed under current practice in the course of constructing, on the road, the same sequence of single-layer chipseals being evaluated.

The spray rates were calculated using the currently recommended spray rate formula (Transit NZ, 2005, equations 9–11, p. 339):

$$V_b = (ALD + 0.7T_d)(0.291 - 0.025 \times \log_{10}(2.0 \times v/l/d \times 100)) \qquad \text{(Equation 2.4)}$$

V_b is the volume of binder (L/m^2), T_d is the seal texture depth (as determined by sand circle measurement) in mm, and v/l/d represents the number of vehicles per lane per day for the road. A typical heavy commercial vehicle load of 11 percent is assumed.

For purposes of comparison, a typical traffic load of 1000 vehicles per day was considered (v/l/d = 500 – equation 2.4) then reduces to

$$V_b = (ALD + 0.7T_d)(0.291 - 0.025\log_{10}(10^5)) = 0.166\ (ALD + 0.7T_d) \qquad \text{(Equation 2.5)}$$

Spray rates were calculated for an existing texture depth T_d = 0.5 mm, which is the texture depth at which flushing is adjudged to take place. For single-coat seals with chip sizes as given in table 2.1, this gives the following spray rates:

Table 2.2 Calculated spray rates for single-coat chipseals

TNZ chip grade	ALD mm	Spray rate L/m²
2	12.5	2.13
3	10.5	1.80
4	8.5	1.47
5	5.3	0.94

These rates were added in appropriate combinations to give the calculated total rates shown in table 2.3.

Table 2.3 Summary of surface void data

Chip grades	2	2/4	2/4/3	2/4/3/5	2/2	3/2/3/3
Surface thickness[a] mm	13.0	22.0	33.0	33.9	26.0	42.0
Total voids L/m^2	6.5	10.9	16.0	13.6	12.3	16.7
Percent voids L/m^2	46.0	47.8	46.9	39.5	48.0	39.5
Available voids[b] L/m^2	4.5	8.9	14.0	11.6	10.3	15.0
Calculated total spray rate L/m^2	2.13	3.60	5.40	6.34	4.26	7.53
Available voids/calculated rate	2.1	2.5	2.6	1.8	2.4	2.0

a) Surface thickness is taken as the depth for which all the chips are just covered.

b) Available voids are the total voids minus voids in the bottom layer that would be lost because of impaction into the basecourse. A figure of 30 percent of the voids in the bottom layer has been taken, ie $0.3 \times 6.5 \approx 2.0$ L/m^2 for surfaces with a Grade 2 seal at the bottom; for a Grade 3 seal, a value of $2.0 \times (10.5/12.5) \approx 1.7$ L/m^2 has been assumed. Potter and Church (1976), examining eight single-coat seals, found that between 20 and 40 percent of the potential voids were filled with basecourse material.

2.4 Discussion of compaction study results

2.4.1 Available voids

Available voids are typically about twice the expected spray rate. On this basis, there should never be a problem of flushing. However, it is believed that, in fact, a considerable amount of fine solids is eventually incorporated in seals so that the available space to include bitumen is much reduced. Experimental data from seal cores to support this contention is presented in section 3.

2.4.2 Effect of the addition of a small chip

On addition of Grade 5 chip to the Grade 2/4/3 surface, there is a reduction of voids available. This is because the Grade 5 chip is relatively small compared to the Grade 3 chip, and so acts as a void filler. This did not happen when Grade 4 material was placed on a Grade 2 surface, as the size ratio is different.

$$\frac{ALD\ \ Grade\ \ 5}{ALD\ \ Grade\ \ 3} = \frac{5.3}{10.5} = 0.50\ , \qquad \frac{ALD\ \ Grade\ \ 4}{ALD\ \ Grade\ \ 2} = \frac{8.5}{12.5} = 0.68\ .$$

(Equation 2.6)

2.4.3 Variation in voids

There is a significant variation in the percent voids available for different seal combinations (39.5–48 percent). The low value for the Grades 2/4/3/5 surface has been discussed above. The value for the Grades 3/2/3/3 surface supports the observation that seal combinations of this type (all large chip grades, with the same grades on top of each other) may be susceptible to early flushing (Ball et al 2005b), provided the quantity of fines found in this project generated in the surfaces is typical.

3 Field data

3.1 Experimental approach

The project design required the examination of void and bitumen content of multilayer chipseal surfaces for various combinations of seal types and various degrees of trafficking. As a starting point, a number of core samples from the West Wanganui state highway region were analysed in detail. The ultimate goal was to find the same seal combinations for different degrees of trafficking and develop a void-content versus degree-of-trafficking relationship.

3.2 West Wanganui region sites, 2007

3.2.1 Primary data

Summary data for the nine sites sampled is shown in table 3.1. All sites were sampled in the wheeltracks. *Note that all compositions are expressed in volume percentages*, with aggregate volumes calculated using density measurements of the recovered chip.

Table 3.1 Volumetric composition of West Wanganui area multilayer seal sites (all quantities are volume percentages)

State highway	4	4	49	4	49	4	3A	49	49
Route position	114/0.648	127/11.8	0/1.15	114/0.46	0/2.05	188/2.49	0/14.7	0/3.65	29/8.6
Latest seal	10/12/97	15/3/05	17/1/03	10/12/97	17/1/03	10/3/99	23/2/99	17/1/03	30/1/02
Sampling date	4/9/07	4/9/07	4/9/07	4/9/07	4/9/07	5/9/07	3/9/07	4/9/07	4/9/07
Binder	17.0	17.2	12.7	15.4	14.0	15.7	14.9	17.0	15.6
Air voids	7.6	5.9	4.7	7.1	3.9	4.7	4.2	4.6	3.7
Large chip	66.7	61.0	64.9	64.2	66.4	65.5	59.9	64.6	58.3
Chip passing 4.75 mm	9.8	15.9	17.7	13.3	15.7	14.1	21.0	13.8	22.1
Binder + air voids + fines	34.3	39	35.1	35.8	33.6	34.5	40.1	35.4	41.4
Fines/total chip	12.8	20.7	21.4	17.2	19.1	17.7	26.0	17.6	27.5

All seals have been well trafficked but with some texture left. Binder content for the cores runs from 12.7–17.0 percent by volume. Air voids are typically 4–6 percent; clearly, seal compaction does not remove all voids. Fines typically make up around 20 percent of the total chip volume, with total fines content around 15 percent of the total volume of the core. If the fines come from breakdown of the larger chip, it follows that, typically, around a fifth of the original chip has been converted to fine material under trafficking and weathering stresses.

It is notable that the *total* volume of binder, air voids and fines is of the same order of total voids (around 40 percent) found in the multilayer seals constructed without binder in the laboratory.

3.2.2 Fines gradings

To investigate the possibility that a significant proportion of material passing the 4.75 mm sieve might be a result of application of Grade 5 or Grade 6 chip at some point, the breakdown of the fines for two of the sites was further examined by sieving (table 3.2, figure 3.1).

Table 3.2 Volumetric composition for two West Wanganui multilayer seal surfaces for a range of sieve gradings

	SH 3A RP 0/14.7		**SH 4 RP 188/2.490**	
Sieve mm	% passing by volume	% voids + binder + fines by volume	% passing by volume	% voids + binder + fines by volume
4.75	21.0	40.1	14.1	34.5
2.36	13.9	33.0	9.9	30.3
1.18	11.3	30.4	8.1	28.5
0.6	9.1	28.2	6.9	27.3
0.3	6.9	26.0	5.8	26.2
0.15	4.6	23.7	4.5	24.9
0.075	2.8	21.9	3.4	23.8

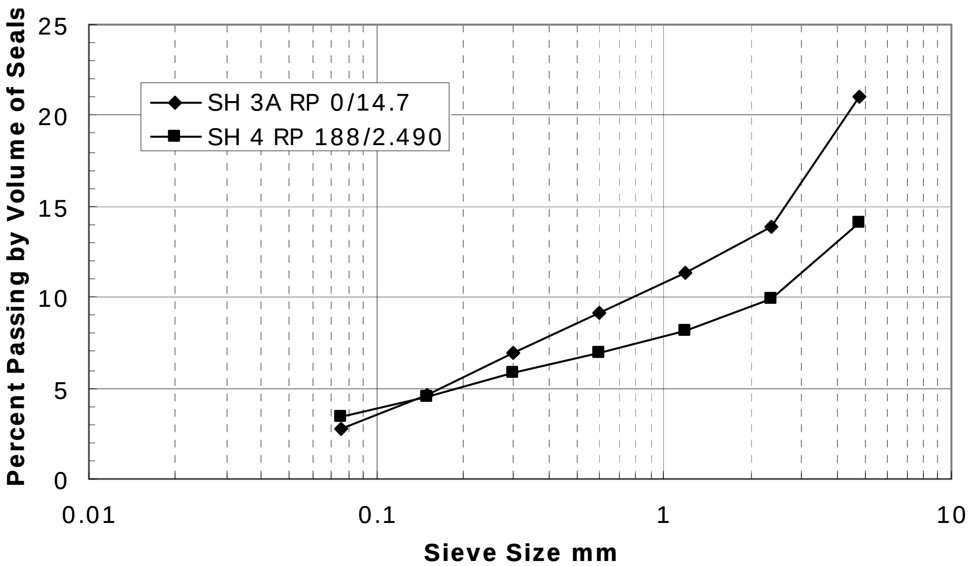


Figure 3.1 Volumetric composition for two West Wanganui multilayer seal surfaces for a range of sieve gradings

A significant amount of material passed a 2.36 mm sieve. Grade 5 chip should not contain more than 2 percent chip passing this sieve size; for Grade 6 chip, the upper limit is 15 percent. RAMM records and examination of the chip cores indicate the composition of the multiple-layer seals (table 3.3). The composition of these cores shows that little, if any, fine material would have initially been present.

Table 3.3 Composition of multiple-layer seals

Site	SH 3A RP 0/14.7	SH 4 RP 188/2.490
Top seal 1	Grade 3/5	Grade 3
Seal 2	Grade 2	Grade 3
Seal 3	*Grade 2*[a]	Grade 3
Seal 4	*Grade 2*[b, c]	Grade 2
Seal 5		*Grade 3*[b]

a) Available RAMM data confirms recent seals; chip grades in italics are from core inspection only.

b) Presence of basecourse material below the bottom-most seals indicates these are first-coat seals.

c) Possible Grade 5 material above bottom Grade 2 layer; however, this may only be broken-down material.

3.2.3 The origin of fines

The core from SH 3A RP 0/14.7 was warmed and pulled apart into layers. Clean separation of the layers was not possible, but individual extraction of binder and sieving of the layers could be used to examine the occurrence of fine material.

Table 3.4 Fine material in layers of SH 3A RP 0/14.7 core

	Chip grade/s	Sealing date	% of aggregate passing 4.75 mm
Top seal 1	Grade 3/5	23/2/99	13.4
Seal 2	Grade 2	3/3/89	12.1
Seal 3	*Grade 2*[a]		26.5
Seal 4	*Grade 2*		20.7
Averaged over core			*18.8*

a) Chip grades in italics are from core inspection, not from RAMM.

The increased amount of material in layers 3 and 4 suggests that production of the fine material is an ongoing process, with some of the material possibly migrating upward from the basecourse.

All materials from West Wanganui were from wheeltracks. If trafficking stresses are a significant producer of fines, one would expect to find a lower proportion of fines away from the wheeltracks. To examine this possibility, cores that had been obtained from both the outer wheeltrack and between the wheeltracks from a site in the Napier region for an earlier project were cleaned to remove as much basecourse as possible, and the gradings of the extracted chip were compared (figure 3.2).

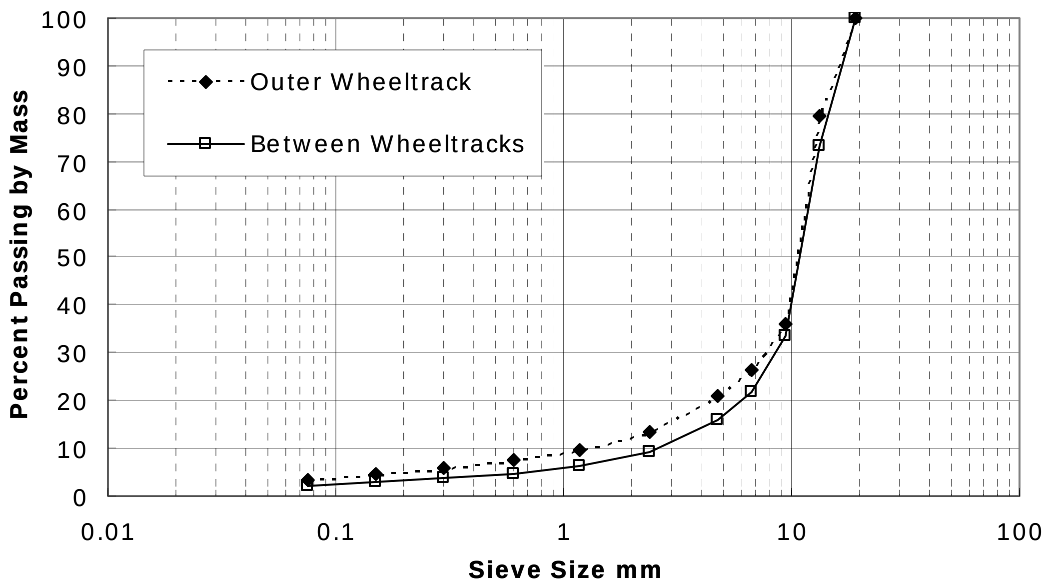


Figure 3.2 SH 2 RP 592/9.5 sampled in 2003 – comparison of chip gradings in and out of the wheeltracks

For the wheeltrack sample, 20.8 percent of aggregate passed a 4.75 mm sieve; between the wheeltracks the figure was 16.1 percent. This is consistent with the smaller chip being at least partly a result of trafficking.

Alderson (2008) examined cross-sections cut through the depth of several Australian seals and came to a similar conclusion. The number of aggregate particles for a given length of seal sample taken from a wheelpath was, on average, 1.60 times that for the corresponding length taken between wheelpaths.

Alderson suggested that this was due to a combination of aggregate breakdown and formation of a tighter chip mosaic under traffic loading.

3.3 Supplementary data on fines contents in seals

3.3.1 Introduction

With the trends noted above, a survey of information collected on multiple-layer chipseal cores for earlier projects was carried out. Results from two projects, which included aggregate mass gradings and binder quantity measurements, were located. This data was then converted to volumes, assuming an aggregate density of 2680 kg/m^3, as measured for the West Wanganui region data; without density measurements of the local aggregates, the volume percentage results are not completely accurate, but are sufficient to indicate trends.

3.3.2 Chipseal layer instability study sites, 2003

Land Transport NZ Report 278 (Ball et al 2005b) contains a listing of fines content (passing 4.75 mm) for 15 multilayer seal sites in Hawkes Bay, Bay of Plenty and mid-Canterbury. The fines content was typically between 15 percent and 20 percent by mass of aggregate, exceeding 25 percent in 4 cases. It follows that the upper limits of fines allowed for different chip grades did not account for the amounts of fines found. Measurement of bitumen content and core volume has made it possible to calculate proportions of large and small (passing 4.75 mm sieve) chip by volume for a selection of these materials (table 3.5) Total percent of air voids plus fines plus bitumen by volume is typically around 40 percent.

Table 3.5 Summary data for samples from four sites in Transit NZ chipseal layer instability study (Ball et al 2005b)

State highway	2	2	2	1S
Route position	294/6.20	304/5.25	691/0.407	416/11.00
Latest seal	16/12/98	22/1/02	26/2/99	27/1/97
Sampling date	19/3/03	20/3/03	7/7/03	7/8/03
Binder	22.2	21.9	21.2	19.8
Air voids	3.0	5.2	1.3	1.8
Large chip	54.4	61.0	62.3	56.4
Chip passing 4.75 mm	20.4	12.0	15.1	22.0
Binder + air voids + fines	45.6	39.0	37.7	43.6
Fines/total chip	27.3	16.4	19.5	28.1

Notes:

- All sites were sampled between the wheeltracks.
- All quantities are percentage volumes.

3.3.3 Central Otago sites, May 2007

Summary data for flushed seal samples from six sites in the Transit NZ Central Otago region are shown in tables 3.6A–3.6C. All sites were sampled in the wheeltracks. The cores had been sawn into two or three layers before bitumen content measurements and aggregate gradings were carried out.

Variation of fines contents between core sections was noted in all cases, although not always in the direction expected (which would be higher fines content with increasing depth). Prolonged sealing history is not available for these sites without further core sampling. It is possible that a high fines content (eg the middle section of the SH 6 RP 901/11.69 core) may be associated with the presence of a void fill or of a smoothing coat. There are a number of instances where the percent by volume of the binder-plus-air-voids-plus-fines combination is significantly greater than the typical value of around 40 percent obtained with the North Island cores.

Table 3.6A Volumetric composition of Central Otago area multilayer seal sites (all quantities are percentage volumes)

State highway	6		6		
Route position	901/2.58		901/11.69		
Latest seal	1/11/96		29/11/99		
Sampling date	1/5/07		1/5/07		
Wheeltrack	Outer		Outer		
Core section	Top	Bottom	Top	Middle	Bottom
Binder	22.1	12.4	15.1	20.0	9.9
Air voids	11.9	4.6	12.1	14.2	10.5
Large chip	40.9	53.1	48.1	20.4	50.2
Chip passing 4.75 mm	25.1	29.9	24.8	45.4	29.5
Binder + air voids + fines	59.1	46.9	51.9	79.6	49.8
Fines/total chip	38.0	36.0	35.4	69.0	37.0

Table 3.6B Volumetric composition of Central Otago area multilayer seal sites (all quantities are percentage volumes)

State highway	6		6	
Route position	901/12.06		918/8.71	
Latest seal	29/11/99		22/11/00	
Sampling date	1/5/07		1/5/07	
Wheeltrack	Inner		Outer	
Core section	Top	Bottom	Top	Bottom
Binder	34.8	14.3	21.7	8.9
Air voids	4.4	8.5	3.6	15.2
Large chip	48.7	53.2	50.8	50.1
Chip passing 4.75 mm	12.2	23.9	23.9	25.8
Binder + air voids + fines	51.3	46.8	49.2	49.9
Fines/total chip	20.0	31.3	32.0	34.0

Table 3.6C Volumetric composition of Central Otago area multilayer seal sites (all quantities are percentage volumes)

State highway	6		6	
Route position	983/2.10		983/3.41	
Latest seal	9/11/00		25/1/02	
Sampling date	1/5/07		1/5/07	
Wheeltrack	Inner		Outer	
Core section	Top	Bottom	Top	Bottom
Binder	15.0	14.4	17.9	13.1
Air voids	22.5	17.7	6.7	11.6
Large chip	26.3	42.1	50.5	24.1
Chip passing 4.75 mm	36.3	25.8	24.9	51.2
Binder + air voids + fines	73.7	57.9	49.5	75.9
Fines/total chip	58.1	38.0	33.0	68.0

3.4 Discussion of results

Trafficked multiple-layer chipseal sites examined in this project contain significant proportions of continuously graded fine materials (passing 4.75 mm) that cannot be accounted for by the original fines in the constituent chips used for seal construction. Typically, these fines occupy about half the volume in the seals unoccupied by the larger chip and will therefore strongly affect the voids available for bitumen.

In his early work on chipsealing methodology, Hanson (1935) concluded that a layer of single-sized chips would be compacted eventually by traffic to around a 20 percent void condition. Potter and Church (1976) concluded that compaction alone was 'unlikely to result in total voids in the stone layer falling below 35–40 percent', and that any reduction below this would be due to embedment into the underlying pavement. It has been suggested that use of steel drum construction rollers and the presence of solid rubber-tyred and steel-tyred vehicles in Hanson's day would have resulted in the production of significantly more fines than would be produced nowadays, thus accounting for the low air voids he observed (Transit NZ 2005, p. 331). The current work suggests that this is not, in fact, the case, and that fine material in seals is still a significant contributor to voids reduction.

New Zealand sealing chip is produced from material that is relatively resistant to abrasion. Nonetheless, it is postulated that some fine material is produced from this chip by traffic stresses. Further fine material may migrate upwards from the basecourse into the overlying seals. At this stage, other sources of fines (eg wind-blown or traffic-sourced detritus rolled into the surface, or inadequate sweeping of the road prior to chipsealing) cannot be excluded as significant contributors of fine materials. In areas that experience a cold climate for part of the year, another possibility for consideration is that grit applied to deal with icy surface conditions may ultimately contribute to fine material in the surface layers.

The presence of fine material accounts for the void-plus-bitumen volume being generally much lower than would be predicted from the laboratory seal modelling described in section 2 of this report.

4 Summary and conclusions

4.1 Summary of results

In laboratory studies of maximum potential seal compaction for various combinations of sealing chip grades, it was found that the void content varied through the range 39.5–48.0 percent. Available voids were approximately twice the volume that would be filled by bitumen for typical spray rates. In view of this, flushing would not be expected, and an explanation for that actually occurring is required.

Recovered cores of multiple-layer chipseal surfaces from several state highways had typical bitumen-plus-air-voids contents of 20–25 percent; ie around half the void content found for the laboratory potential compaction study.

The difference between the measured void contents and the larger voids predicted from laboratory seal models is accounted for by the presence of fine material between the larger sealing chips.

These fines have a continuous grading and their proportion varies with depth below the upper surface, although no consistent variation with depth has been found.

The existence of these fines provides an explanation for the occurrence of flushing where the predicted void content between large chips appears, at first sight, to be too high for this to take place.

The study of one set of cores taken in and between the wheeltracks at a single site suggested that wheeltracked sites are likely to have a higher fines content. This could support the hypothesis that the fines largely come from aggregate degradation caused by traffic, although it would be expected that any fine material on the surface, from whatever source, would be incorporated more effectively into the seal structure at the wheeltrack location.

Some potential sources of fine material are:

i) traffic wear of the aggregate

ii) fine basecouse material migrating upwards

iii) wind-blown detritus, particularly soil and vegetable matter

iv) traffic-sourced materials eg material transferred from unsealed roads and tracks, brake-pad material and rubber

v) grit from iced road treatments

vi) inadequate sweeping of the road surface prior to chipsealing.

The relative contributions from different sources may vary from site to site. Chemical and petrographic testing and x-ray diffraction studies would be needed to discern the actual types of fine material.

4.2 Implications of findings

The working hypothesis of this project was that there is a maximum compaction level for a particular multilayer chipseal with a corresponding void content (say V_∞); if the total binder content is greater than this, flushing will eventually occur. For a series of sites of similar seal layer profile but different levels of trafficking ($V(T_1)$, $V(T_2)$, etc) it would be possible to plot voids versus degree of trafficking tending asymptotically to V_∞.

Behind this is the assumption that the aggregate does not degrade significantly under traffic. In fact, the work described above has indicated that fines can be of the order of 20 percent of the chip, if fines are defined as passing a 4.75 mm sieve, or around 16 percent for a 2.36 mm sieve. The production of fines, by whatever means, changes the effective void content and the degree of compaction possible; the indications to date are that the total content of fines plus air voids plus bitumen tends, under trafficking, towards the order of 35–40 percent by volume, if fines are taken as material passing a 4.75 mm sieve.

In any analysis it is not clear whether the fines should be counted as part of the binder content or part of the aggregate, or divided in some way between the two, and there is no guarantee that the proportion of fines would be constant for a particular combination of seals. In fact, it would be expected to increase over time.

Because of the evidence that significant production of fines occurs over time, it is currently impossible to predict the void content of a completely compacted multilayer chipseal surface. Thus, the proposed method of predicting seal compaction and availability, under trafficking, of voids to contain bitumen is not practicable at present.

At this stage, a more complete understanding of the processes that produce fines in seals is required before a means to predict compaction and liability to flushing through loss of voids in seals can be developed.

5 Recommendations

The approaches outlined below are suggested to develop an understanding of the function of fines in chipseals. Any investigation should aim to settle the following two questions, arising from the work described in this report – the answers may affect chipseal performance:

a) Are the fines amounts and gradings predictable, given initial aggregate gradings, chip source and traffic levels?

b) Does the fines content significantly affect the tendency of a seal to flush early, and if so, to what degree?

A combination of field results and testing of laboratory-constructed seals, designed to have varying quantities of fines, may assist in answering this second question.

Recommended investigations:

1. A selection of newly sprayed seals should be monitored to observe the development of fines content. Cores should be taken immediately prior to sealing and at intervals thereafter. The cores should be sectioned horizontally and progression of the fines content measured.

2. To ascertain the source/s of the fines material, a combined chemical and petrographic and x-ray diffraction analysis should be carried out on fines material in several samples from a representative selection of seal cores from around the country. Any significant regional differences should be noted, and the reasons for these differences be ascertained.

3. Indoor trafficking of seals that are constructed in the course of other research work (eg in the CAPTIF apparatus in Christchurch) could provide samples that exclude some possible sources of fine material that are present in the field. Examination of fines in core samples from CAPTIF work would therefore provide further insight into the processes of fines generation.

6 References

Alderson, A. J. 2001. Aggregate packing and its effect on sprayed seal design. *Austroads Project RC2009-D.* 24 pp.

Alderson, A. J. 2008. *Flushing distress mechanism in seals.* Presented at the 1st International Sprayed Sealing Conference, 21–29 July 2008, Adelaide.

Ball, G. F. A., and Patrick, J. E. 2005a. Failure modes and lifetimes on New Zealand state highways. *Central Laboratories Report 05-521071.01*. Opus International Consultants. 35 pp.

Ball, G. F. A., Patrick J. E., and Herrington P. R. 2005b. Factors affecting multiple chipseals layer instability. *Land Transport NZ Research Report 278*. 42 pp.

Dickinson, E. J. 1990. Sprayed seal design using the voids, and the void distribution with depth in layers of cover aggregate. *ARRB 20,* no. 2: 38–53.

Hanson, F. M. 1935. Bituminous surface treatment of rural highways. In *Proceedings of the New Zealand Society of Civil Engineers*: 89–179.

Houghton, L. D., and Hallett, J. E. 1983. An analysis of single-coat seal design. In *New Zealand Roading Symposium 1983 2*: 249–263. Wellington.

Potter, J. L., and Church, M. 1976. The design of sprayed single seals. In *Proceedings of the 8th ARRB Conference 8*, no. 4, session 16: 18–24.

Transit New Zealand. 2004. Specification for sealing chip. *TNZ M/6:2004.* 4 pp.

Transit New Zealand. 2005. *Chipsealing in New Zealand.* Transit NZ, Wellington.