Potential of the Wehner-Schulze test to predict the on-road friction performance of aggregate

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H Arampamoorthy and J Patrick

Opus, Central Laboratories, Lower Hutt, New Zealand

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NZ Transport Agency
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

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An important note for the reader

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- Peter Cenek supplied the necessary quarry information and other data
- the project's steering group
- Gary Bentley and David Pollard for PSV testing
- Mr Andreas Otto, Technical University Dresden, for the Wehner-Schulze test
- Mr David Cook and Mr Jeff Waters – peer reviewers

Abbreviations and acronyms

NZTA	NZ Transport Agency
PSV	Polished Stone Value
V	Velocity (km/h)
WS	Wehner-Schulze

Contents

Executive summary

The specification for aggregates for use on New Zealand roads includes the British Polished Stone Value (PSV) test. This test and the acceptance criteria were adopted in New Zealand in the 1990s, based on British experience that they were the best available method of predicting the on-road friction performance of aggregate. However, research performed by a number of people in New Zealand has shown that the prediction of performance by the PSV test is extremely variable. Current research by Cenek, Davies and Henderson shows that the test is a poor predictor of on-road friction.

The German Wehner-Schulze (WS) test has recently gained international prominence as a method that can test asphalt cores or laboratory-prepared mixes, and appears to be a better friction predictor than the PSV test. This research, which was carried out between December 2009 and August 2010, aimed to assess the potential of the WS test for New Zealand conditions. Six New Zealand quarry aggregates were selected for assessing with the WS test. The selection criteria were based on the variability of PSV-predicted friction compared with field-measured friction.

The aggregate samples were sent to the Technical University Dresden in Germany for the WS test. It was found that chipseal samples taken from the road could not be used in the WS equipment, as the very high texture would impose too much stress on the instrument. Therefore, hand-placed chip specimens were tested – this is an accepted technique in the German method.

It was found that the WS test results from manually prepared specimens were highly correlated with the PSV test. Therefore, when using hand-placed chips, the WS test would also not correctly predict road surface friction. It is recommended that discussion should continue with the designers and manufacturers of the equipment to determine whether it can be adapted to be able to test typical New Zealand chipseal surfaces.

Abstract

The specification for aggregates for use on New Zealand roads includes the British Polished Stone Value (PSV) test. This test and the acceptance criteria were adopted in New Zealand in the 1990s, based on British experience that they were the best available method of predicting the on-road friction performance of aggregate. However, research performed by a number of people in New Zealand has shown that the prediction of performance by the PSV test is extremely variable.

The Wehner-Schulze (WS) test method, developed in Germany in the 1960s and commonly used there, can test samples taken from the road. This research, which was carried out between December 2009 and August 2010, aimed to assess the potential of the WS test for predicting chipseal surface friction.

The chipseal samples taken from New Zealand roads could not be used for testing because their very high texture imposed too much stress on the equipment. Therefore, hand-placed chips were tested (a specified variation in the test method). Six New Zealand quarry aggregates, covering a range of on-road friction performance, were used to assess the WS test. The test results showed that PSV and WS test results on the hand-placed samples were highly correlated. Therefore, in this form the test is not a better predictor of on-road friction than the PSV test.

1 Introduction

The aim of this research was to determine whether the German Wehner-Schulze (WS) test is a better and more appropriate method to identify the surface friction properties of the road than the Polished Stone Value (PSV) test. Surfacing aggregate is currently selected according to *T10: 2010 Specification for state highway skid resistance management* (2010), which is included in the specification of aggregates for use on New Zealand roads. This test and the acceptance criteria were adopted in New Zealand in the 1990s, based on British experience that they were the best available means of predicting the on-road friction performance of aggregate.

However, research performed by a number of people in New Zealand since then has shown that the prediction of performance by the PSV test is extremely variable. Current research by Cenek et al (2008) shows that the test is a poor predictor of performance, and aggregate source appears to be a better predictor. If aggregate source becomes the main predictor of on-road skid performance, an aggregate supplier would need to conduct trials on a range of traffic and site conditions in order to get the material approved. The specifier would also face the risk that the properties (that affect skid resistance) of a particular aggregate may be different from those of the trialled aggregate, as the consistency of the source could not be assured.

The WS test method, developed in Germany in the 1960s and commonly used there, has the ability to test samples taken from the road. It therefore has the potential to measure aggregate polishing when the aggregate orientation is typical of a normal road surface. In contrast, the PSV test relies on an operator hand-placing stones so there are no sharp aggregate protrusions.

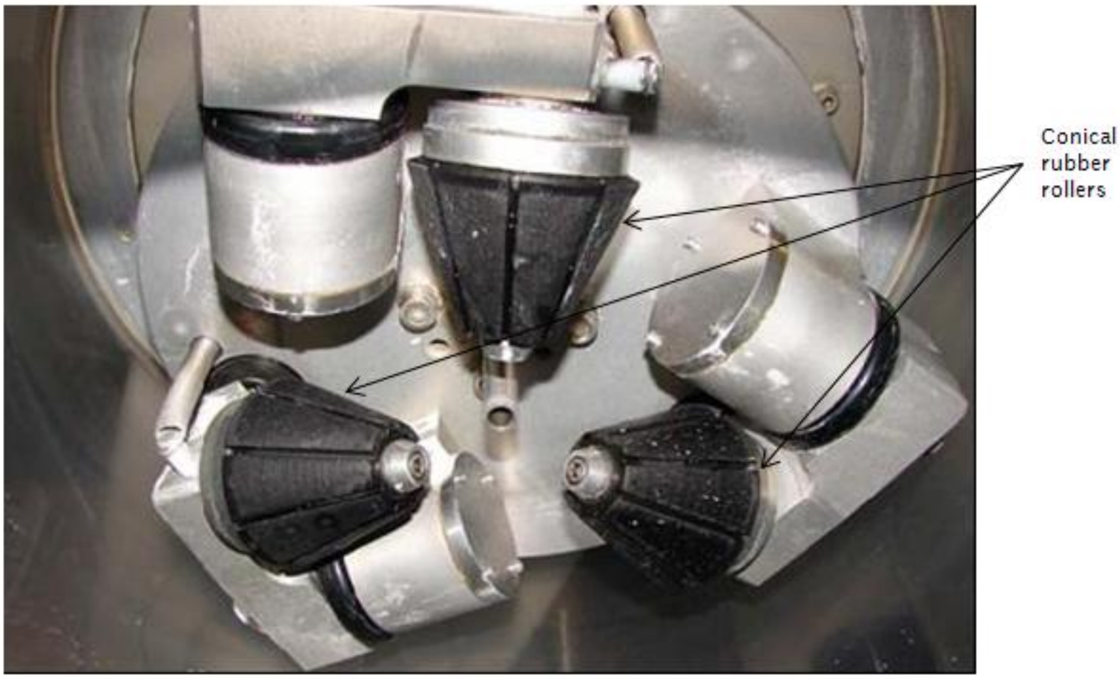
1.1 Description of the Wehner-Schulze test (WS)

The WS test was developed at the Technical University of Berlin and was initially used mainly as a research instrument. In the 1990s the instrument was further developed and became commercially available. It is estimated that the cost of the machine is approximately NZ$200,000. It is now being considered as a European standard test for assessing the polishing resistance of pavement surfaces. The instrument is shown in figure 1.1.

Figure 1.1 Wehner-Schulze (WS) test instrument

The instrument consists of two main parts: the accelerated polisher and the skid resistance tester. The polishing part consists of three conical rubber rollers (see figure 1.2).

Figure 1.2 Accelerated polishing part



The skid resistance tester mainly consists of three rubber pieces, as shown in figure 1.3.

Figure 1.3 Main skid resistance tester

The method states that the specimens must be as flat as possible, to avoid unbalancing effects.

The test is normally performed on cores taken from a road surface or on laboratory-compacted samples of asphalt mixes. It was hoped that road samples of chipseal surfacing could be cored and tested in the equipment. The operators of the equipment (Technical University Dresden) considered that the very harsh texture of chipseal would over-stress the equipment, and advised that chipseal samples could not be tested.

The standard German test method does allow for the testing of aggregate samples, and thus this was the method used in this research. Following the German method of test, the chips were placed manually on the respective testing plates (see figure 1.4) and then epoxied into position. The final specimens were 225mm in diameter.

Figure 1.4 The aggregate size fraction used was 8–11mm – the finished specimens are shown in the appendices

The standard polishing operation involves the roller head rotating at 500rpm for an hour, giving 90,000 roller passes over the sample surface. Each roller is independently loaded to a contact pressure of approximately 400kPa, and polishing is performed with a 5% quartz powder in 95% water.

Once polishing is complete, the specimen is washed and placed on the skid resistance tester. Figure 1.3 shows three rubber pads (the third is temporarily removed). The rubber pads attached with the disk can rotate on the specimen at a range of speeds. In the standard test, the rubber pieces with the disk are accelerated to rotate at 3000rpm (approximately 100km/h). Water is applied to the surface to approximate a 0.5mm film thickness, and the tester is lowered to the surface. The drum with attached rubber pads is allowed to decelerate, whilst the sensor system measures the torque from the drum and the attached computer continuously calculates the friction.

The coefficient of friction at 60km/hr is taken as the test result, although other speeds could be used.

The test specimens used in this project are shown in appendices A to F.

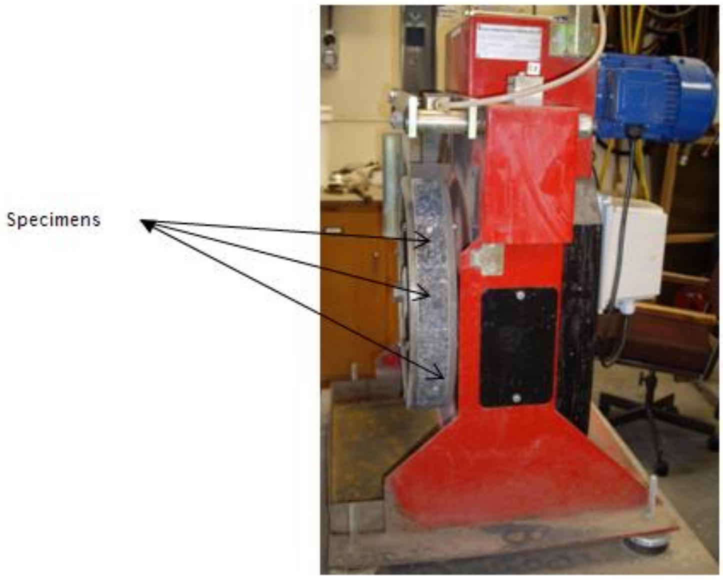
1.2 Description of the Polished Stone Value (PSV) test

The PSV test was developed in Britain and has commonly been used in New Zealand and Australia. The test consists of hand-placing 7–10mm chips onto a curved plate, using epoxy resin to secure them.

In contrast to the WS test specimens, each plate measures only 45mm x 90mm. The plates are mounted on a revolving drum and polished through the action of a loaded solid-rubber tyre and emery power mixed with water, in two stages. The first stage consists of ‘conditioning’ the specimens with coarse emery grit for three hours; the second ‘polishing’ stage uses a fine emery flour for a further three hours.

Figure 1.5 shows the polishing machine for the British pendulum test, and figure 1.6 shows a British pendulum tester.

Figure 1.5 Polisher for the British pendulum tester equipment



After polishing, the specimens are removed, washed, and tested for friction using the British Pendulum Tester with a special rubber slider. In each test, a control stone is also used and the final result adjusted if necessary. The results are reported as the British Pendulum number obtained on the specimen surface.

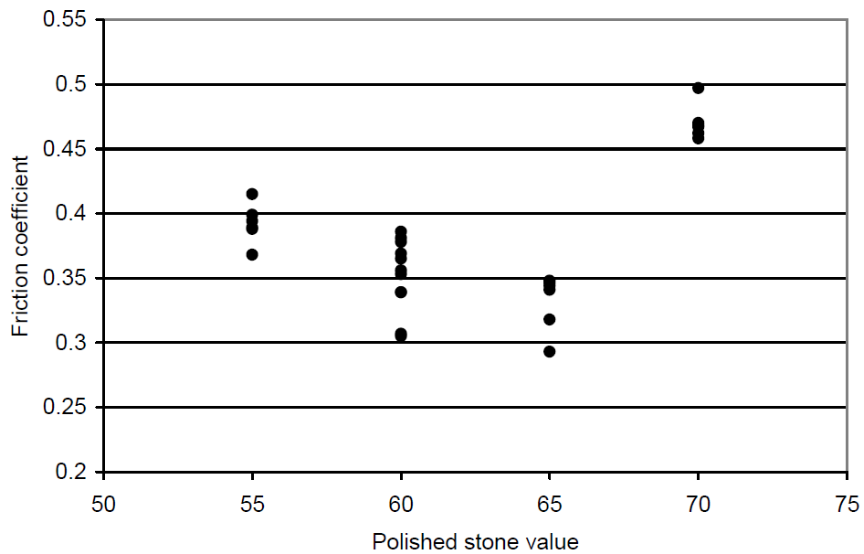
Figure 1.6 British pendulum tester

2 Literature review

Allen et al (2008) noted that the advantage of the WS machine is that it is able to test asphalt mixtures of laboratory-prepared and in-situ samples, as well as crushed, uncoated aggregate. They investigated and compared the prediction of skid resistance from the WS and PSV test methods for a range of UK asphalt surfacing mixes. The WS results suggested that the 'optimum texture depth would appear to be 1.0mm, with further improvement achieved by decreasing the nominal aggregate size or increasing the PSV of the aggregate used'. This was based on the range of aggregate sizes they used, which influenced the texture depths. At the high texture depths obtained with large aggregate, they concluded that the reduced amount of surface area in touch with the polishing wheels resulted in increased polishing. This, coupled with the reduced surface area in contact with the friction tester, resulted in lower WS values than could be obtained with smaller-sized aggregate. Their test results showed a decrease in WS friction coefficient with increasing PSV from 55 to 65, and then a sudden increase for the mix made with PSV 70. They also noted that their assessment was based on a limited number of asphalt types, aggregate types, and the nominal size of the mix and bitumen-type combinations possible in the UK.

It would be expected that generally, the PSV would increase as the WS friction coefficient increases, but Allen et al's 2008 results showed that friction of the first three asphalt mixtures decreased with PSV (see the figure 2.1).

Figure 2.1 Friction coefficient from the WS test against PSV for a range of asphalt mixes (Allen et al 2008)



These results indicate that the WS friction coefficient was being influenced by factors other than the PSV.

Woodbridge et al (2006) assessed the WS test and noted that 'the use of different coarse and fine aggregate in an aggregate mix has shown differences in skid resistance after polishing, compared with specimens made from a single aggregate type'. This shows that skid resistance is not only dependent on PSV, but also on the particle size in the mixture.

Wilson and Black (2008) noted:

> *... the actual PSV of the aggregate sample generally predicts the same ranking order of the initial level of the three greywacke aggregates tested with the [dynamic friction tester] prior*

> *to any accelerated polishing; however it does not predict well the equilibrium skid resistance as reflected in field.*

They found that for the greywacke and melter slag samples, the time taken to polish, and the ranking order of the equilibrium skid resistance, were not the same as the PSV ranking. They also noted that the dynamic friction tester, which they used to measure the surface friction, used a large surface area compared with the British Pendulum used in the PSV test method. Compared with the PSV test, the WS test also used a large sample area for polishing and friction testing.

All the literature notes that because the WS test can test mixes and cores from the road, it has the potential to predict road surface friction better than the PSV test.

The use of the WS test on chipseal surfaces does not feature in the literature. Woodbridge et al (2006) noted that the hand-placing of chips could be used as a method of assessing aggregate polishing in a chipseal.

3 Data selection

In a current NZ Transport Agency (NZTA) research project, Peter Cenek and Robert Davies are investigating the relationship between quarry-sourced PSV and the SCRIM value achieved on the road. They have found that quarry source is a better predictor of SCRIM value than PSV. Preliminary results for the Northland and Hawke's Bay regions were presented in a paper at the NZTA and NZIHT 9th annual conference (Cenek et al 2008).

Their research focused on the prediction of road surface friction (SCRIM value) in terms of a range of geometric and traffic variables, and aggregate properties. The basic form of the relationship is:

SCRIM=Constant + f(macrotexture) + f(curvature) + f(gradient) + f(skid-site category) + f(traffic adt) + f(age) + f(seal type) + f(urban/rural) + f(aggregate source)

The last function shown in the above equation is called a source estimate, or estimator.

A description of the variables is given below in table 3.1.

Table 3.1 Description of predictor variables

Variable	Description
Poly(macrotexture, 4)	Fourth-degree polynomial transformation of macrotexture
Poly(recip.curv, 2)	Second-degree polynomial transformation of the absolute value of the reciprocal of horizontal curvature
Poly(gradient, 3)	Third-degree polynomial transformation of gradient
Skid.site.sel	T/10 skid-site category – categories 1, 2 and 3 combined into one category; 4 and 5 into another
Poly(log10.adt, 4)	Fourth-degree polynomial transformation of log10(adt)
Poly(log10.age, 2)	Second-degree polynomial transformation of log10(age)
Surf.cat	Surface category – seal type and chip size 8
Urban.rural	Urban or rural
Agg.source.main	Quarry source of aggregate used in top layer surfacing

The basic relationship can be considered as:

SCRIM = constant + f(geometry) + f(traffic) + f(age) + f(agg.source)

The aggregate source estimate is therefore a value that can be adjusted to correct the rest of the relationship.

The analysis of the total RAMM database was completed, and the pavement source estimator (which varies for each quarry) for estimating SCRIM coefficient and the quarry PSV figures are in table 3.2. The data in this table is plotted in figure 3.1.

The agg.source.main is the aggregate effect on the resulting equilibrium SCRIM value – the higher the number, the greater the effect. It would be expected that if the PSV figure was a good predictor, there would be a strong correlation between the aggregate source estimate and PSV. Figure 3.1 shows that while there is a trend, there is a lot of scatter.

Figure 3.1 also shows that the aggregate source estimate varies from approximately -0.07 to +0.07. This means that the effect of aggregate characteristics on the SCRIM value can be 0.14 SCRIM units, even when the traffic and geometry are the same.

This data was used to choose five material sources, to compare their PSV and WS results. The five data points shown in figure 3.1 are either high or low PSV figures, or in the line shown in figure 3.1. The chips with the highest PSV were produced by Quarry-A in figure 3.1 (ie Galatea Quarry). Because this quarry had stopped producing chips, the next-highest PSV material from Quarry-3 (see table 3.3) was used.

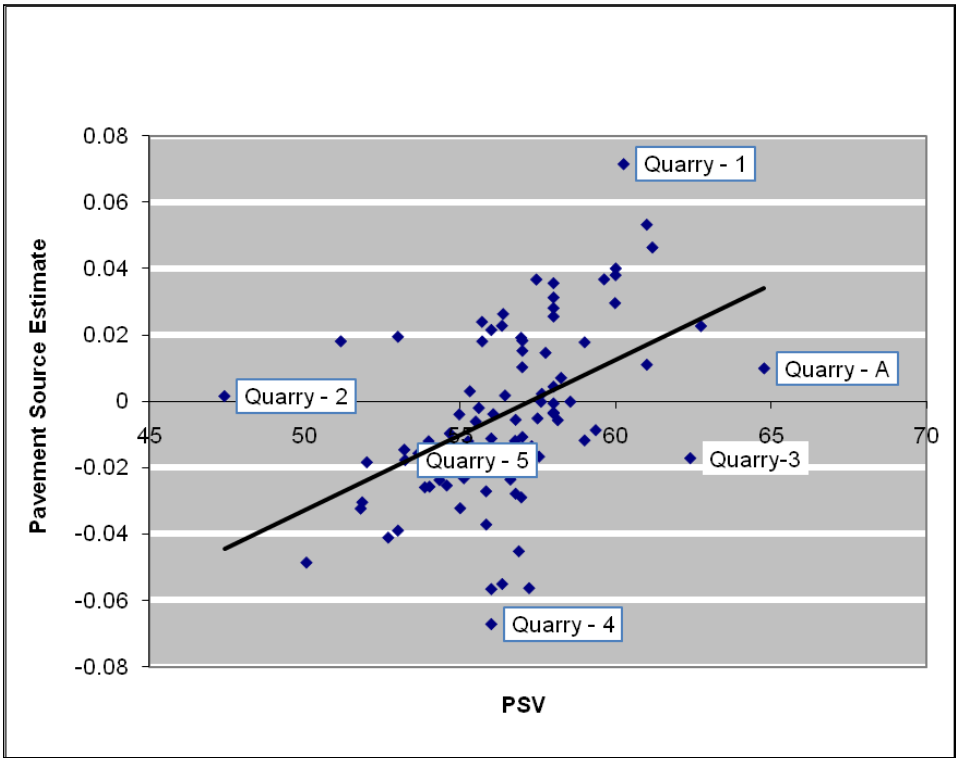
A sixth source, melter slag (a by-product of steel manufacture) that appears to be performing well on some roads, was also selected.

Table 3.2 PSV and the source estimate for 83 quarries in New Zealand

Aggregate source	Aggregate source estimate	Aggregate source	Aggregate source estimate
Alexandra	-0.0035	Otaki River	0.0182
Aparima River	-0.0564	Paihiatua Shingle	0.0367
Appleby	-0.0088	Parkburn	0.0227
Ashburton River	-0.0002	Perrys	-0.0178
Awakeri Quarry	-0.0108	Pio Pio Quarry	-0.0185
Awatoto	-0.0258	Piroa	-0.0552
Balclutha Quarry	-0.0172	Poplar Lane	0.0296
Bellingham (Larmers Rd Quarry)	-0.0237	Pound Rd	0.0152
Belmont Quarry	-0.0038	Prenters Shingle	0.0226
Boulder Creek	0.0263	Pukehou	0.0191
Bulls Metal	-0.0057	Pukekawa Quarry	0.0180
Child Metal	0.0356	Puketapu	0.0102
Couttes	0.0017	Puketona Quarry	-0.0260
Earnscleugh	-0.0039	Rangitikei	-0.0121
Ford Brothers	0.0022	Renwick	0.0177
Galatea (Colemans)	0.0099	Swaps	-0.0062
Gore Gravel	-0.0673	Taotaoroa	-0.0040
Grey River	0.0030	Tauhei	-0.0305
Harewood	0.0070	Te Matai	0.0312
Higgins	0.0281	Tetleys	-0.0233
Hilderthorpe Pit	-0.0279	Tirohia	-0.0097
Isaac	-0.0119	Toe Toe Road	-0.0140

Aggregate source	Aggregate source estimate	Aggregate source	Aggregate source estimate
Kakareke	0.0194	Tukituki	-0.0187
Kyeburn	-0.0168	Twizel	-0.0058
Leaches	-0.0113	Upukerora	-0.0323
Levels Pit	-0.0002	Waiau River	-0.0391
Lower Hutt	-0.0136	Waimana River	0.0400
Macphersons	-0.0007	Waingawa River	0.0239
Manawatu	0.0255	Waioeka River	0.0532
Mangatainoka	0.0463	Waiotahi	0.0715
Manunui	0.0180	Waipawa River	-0.0272
Matatoki	-0.0324	Wairau River	0.0367
Mataura	-0.0567	Waitawheta	-0.0021
Motueka River	0.0214	Waotu Quarry	0.0015
Motumaoho Quarry	-0.0158	West Eweburn	0.0044
Ngaruawahia	-0.0121	Whangaripo	-0.0373
Ngaruroro	-0.0255	Whangaripo Quarry	-0.0120
Oamaru	-0.0291	Whitehall Quarry	-0.0238
Ohau A Quarry	0.0146	Whitestone	-0.0052
Omarama	0.0110	Winstones 1	-0.0487
Oreti River	-0.0453	Winstones 2	-0.0147
Otaika Quarry	-0.0412	Wiremu	0.0380

Figure 3.1 Plot of aggregate source estimate against PSV



The next table shows the details of the selected quarries.

Table 3.3 Selected quarries

Quarry no.	Pavement source	PSV	Aggregate source estimate	District
1	Waiotahi	60	0.071482	Gisborne
2	Waotu Quarry	47	0.0014847	Hamilton
3	Balclutha	62	-0.01724	Dunedin
4	Gore Gravel	56	-0.067292	Invercargill
5	Whitestone	57	-0.0052299	Christchurch
6	Slag material			Napier

4 Testing

The WS tests were conducted at the Technical University Dresden. Two specimens were prepared from each aggregate sample. The polished specimens are shown in appendices A–F.

The PSV tests were performed at Opus Central Laboratories (Gracefield) in accordance with BS EN 1097-8.

Photographs of the polished specimens are shown in appendix H.

5 Test results

The average of the WS test results from the two specimens from each sample was calculated at a speed of 60km/hr.

Table 5.1 shows the test results together with the PSV figures that were in the RAMM database.

Table 5.1 Test results

Quarry no.	Sample no.	Aggregate source	District	Expected PSV	Test results	
					PSV	WS
1	6/10/19	Waiotahi	Gisborne	60	60	0.41
2	6/10/61	Waotu Quarry	Hamilton	47	51	0.31
3	6/10/21	Balclutha	Dunedin	62	61	0.42
4	6/10/22	Gore Gravel	Invercargill	56	54	0.37
5	6/10/28	Whitestone	Christchurch	57	55	0.36
6	6/10/18	Slag material	Napier		46	0.33

Figure 5.1 shows the relationship between the WS results and the aggregate source, and figure 5.2 shows the relationship between the PSV and the aggregate source estimate.

Figure 5.1 Aggregate source estimate versus WS

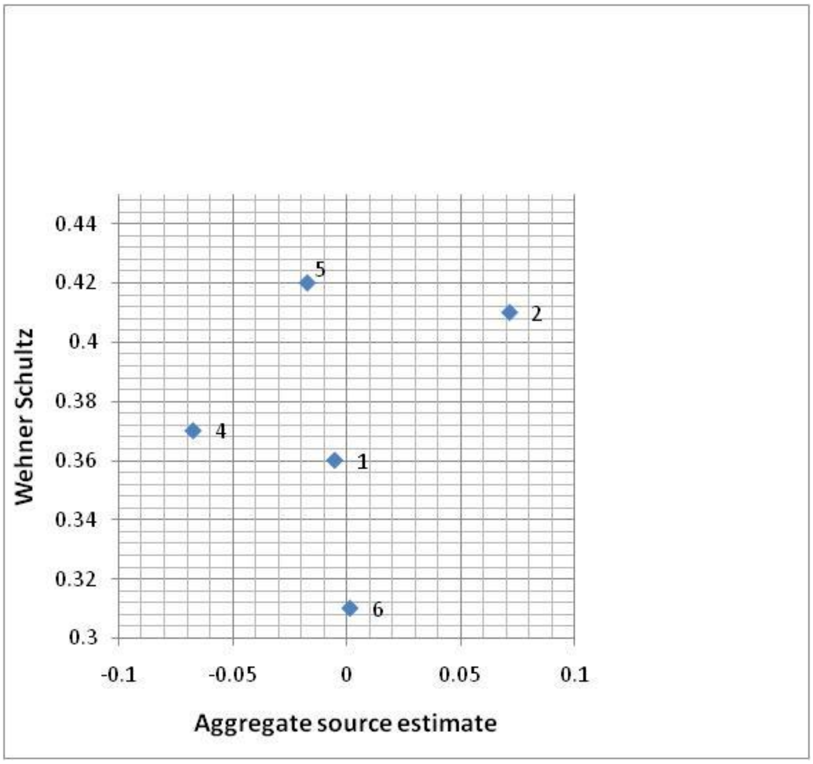


Figure 5.2 Relationship between aggregate source estimate and PSV

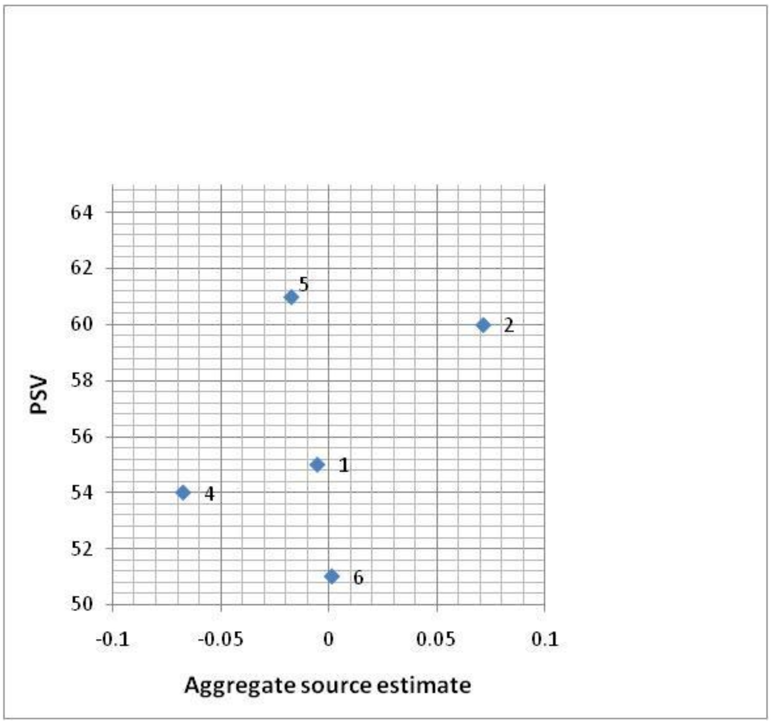
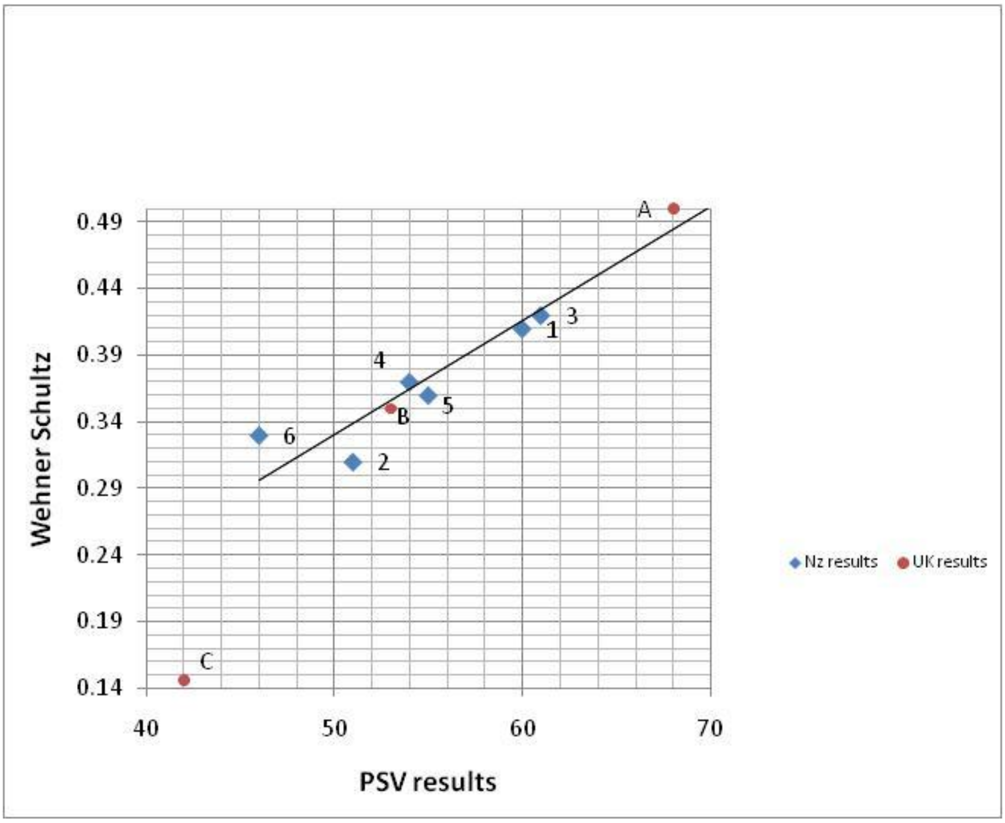


Figure 5.3 shows the relationship between the WS value and the PSV. In this figure, three test results on gritstone, granite and limestone, from Woodbridge et al (2006), are also included.

Figure 5.3 WS test results versus PSV results (points A, B and C from Woodbridge et al 2006)



6 Discussion and conclusion

If the WS test correctly predicted the field condition, then there would be a strong correlation in figure 5.1 between the aggregate source estimate and the WS test value. However, the scatter in figure 5.1 is similar to that in figure 5.2, which is the PSV vs aggregate source estimate relationship. Both figures show that the tests were not good predictors of on-road performance.

There was a good correlation between the WS value and PSV, as can be seen in figure 5.3. Two of the three British materials had similar results to the New Zealand data, which confirms that the testing performed was consistent for the 8 or 9 test points plotted.

There is one significant outlier in figure 5.3 – the British limestone, point C, which has a low PSV and WS value.

The slag (no. 6), which is not a natural aggregate, shows a similar relationship to WS values as the natural aggregates.

The test results did not confirm that the WS is better than the PSV test in terms of predicting the in-field performance of chipsealing aggregate.

The WS test method is capable of producing road surface friction data at different speeds. The speed/velocity relationship showed an almost linear relationship between 10 and 70km/h (see appendix G). All the other specimens from other samples also showed a very similar relationship. Therefore, the rankings would not change if a different test speed was selected.

The WS test specimens were made by packing the chips very closely to obtain a flat surface. In reality, the chips are not packed like this in a chipseal surface. The PSV specimens were also very similar in that the chips were hand-placed to obtain a smooth surface.

Tyre road friction is affected by the hysteretic excitation of the tyre by the chip. By placing the chip in a flat position, the degree of hysteretic excitation will be lower than when the chips are protruding.

The literature review indicated that the WS test should have the potential to evaluate bituminous mixes. It was disappointing to find that we could not test highly textured chipseals. If a core of a chipseal surface cannot be tested using the WS test, then the test in its present form is not appropriate for New Zealand.

7 Recommendations for future research

As the WS test is gaining international acceptance, it is recommended that the potential of the test for use on chipseals be further investigated by liaising with the instrument manufacturer to determine whether the machine can be modified to be able to test coarse chipseals.

If it can be modified, research should investigate the effect of chip size and seal type on the WS value, and determine whether this correlates with on-road performance.

8 References

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Appendix A: Specimens 1 and 2 from sample no. 6/10/18

Appendix B: Specimens 1 and 2 from sample no. 6/10/19

Appendix C: Specimens 1 and 2 from sample no. 6/10/21

Appendix D: Specimens 1 and 2 from sample no. 6/10/22

Appendix E: Specimens 1 and 2 from sample no. 6/10/28

Appendix F: Specimens 1and 2 from sample no. 6/10/61

Appendix G: Specimen 1 from sample no. 6/10/18, tests 1 and 2

Resistance against the velocity (km/h)

Figure G1 **Test run no. 1**

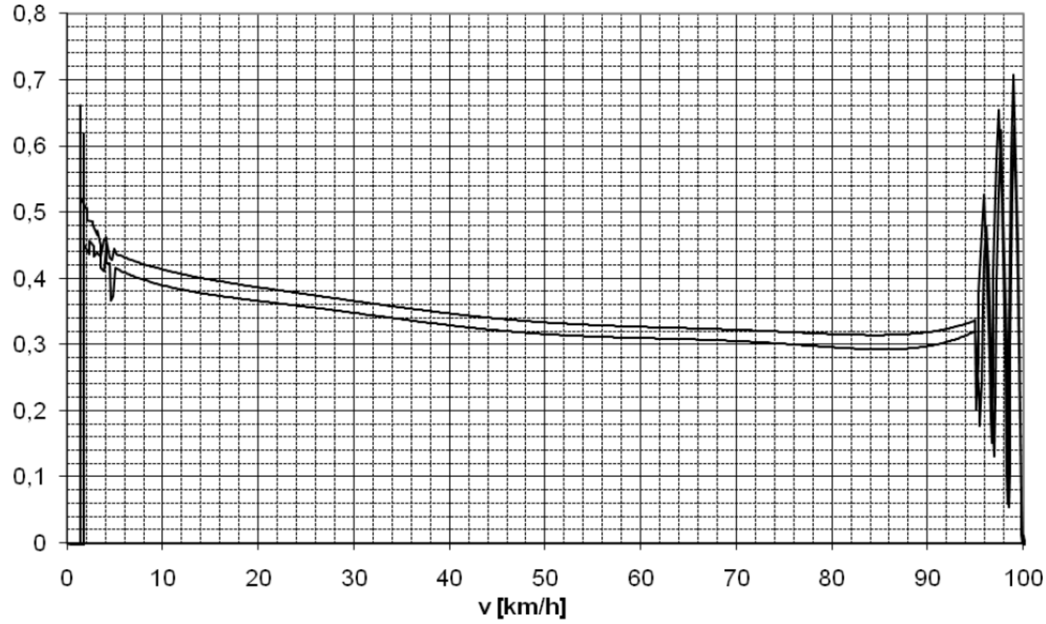
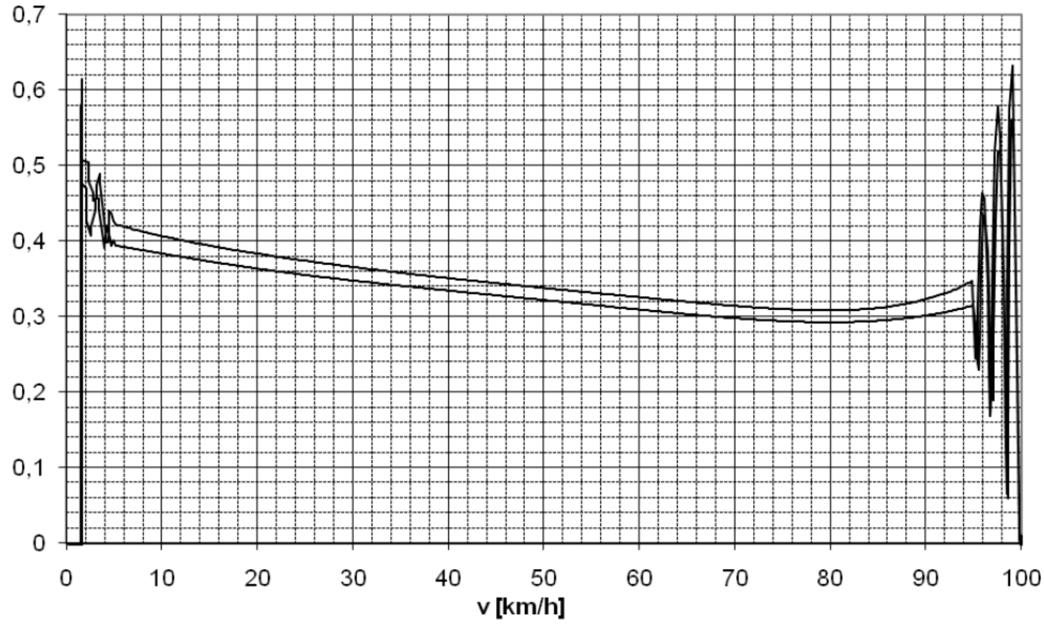


Figure G2 **Test run no. 2**



Appendix H: PSV specimens