DELIVERING POLISHING RESISTANCE PERFORMANCE ON CURVES

Jeffrey C. Waters - BSc, Dip Sci. (Geology), NZCE (Civil). (Presenter)

Corporate Surfacing Engineer, Fulton Hogan

Jeff.waters@fultonhogan.com

Sean A. Rainsford - NZCE (Civil), ASSC. Diploma Computer Science

Corporate Technical Asset Engineer, Fulton Hogan

Sean.rainsford@fultonhogan.com

Michael Topp – BE (Civil)

Graduate Engineer, Harrison Grierson

ABSTRACT

In 2010, New Zealand Transport Agency (NZTA) included the concept of assessing the actual in-service performance of an aggregate's resistance to polishing in the updated version of T/10 specification entitled "Specification for State Highway Skid Resistance Management". This was in response to the perceived inability of T/10 specification to prescribe a methodology that could use the Polished Stone Value (PSV) source rock test to select an appropriate polish resistant stone for high demand sites throughout New Zealand.

The T/10 process used up until 2010 used an equation established in T/10:2002 to calculate the required PSV for the aggregate for the various surface friction requirement categories. This meant that the closest aggregate with the highest PSV was used in all high demand areas so that most high demand sites in each network were resurfaced with the same aggregate. However the polishing performance of the aggregates chosen using the PSV method has not been consistent for each category in each network.

The new concept described in T/10:2012 is excellent, however the methodology described is too generic, which means that not all of the parameters that should be used to ensure that an aggregate selected using the performance method for a specific site should provide adequate in-service performance for that site are used.

Much of the data for the parameters that should be used is available in RAMM now. This paper reports on the inclusion of other parameters that should be considered to ensure the polishing resistance performance of aggregates on curves.

INTRODUCTION

In the last few decades, NZTA has increased its focus on road surface and its contribution to road safety as part of a holistic plan to reduce crashes. The emphasis has been on maintaining the skid resistance of the road surface at levels that provide equal crash risk for road users across the network.

NZTA based their skid resistance management strategy on the UK concept, skid resistance and PSV model, and as the fatality rate in the UK was one of the lowest in the world this was a pragmatic approach.

However, the NZTA network is vastly different than the UK network. Many of the roads on the NZTA network are two-lane undivided carriageway with a high proportion of tight radius bends and steep gradients, compared with much of the UK network, which was heavily-trafficked four lane divided carriageway. Another difference is that most of the surfacing on the NZTA network is chipseal (>90%) and most of the surfacing on the UK network is asphaltic concrete including hot rolled asphalt.

Cenek et al (2011a) states *"… Loss of control on curves remains the largest cause of crashes on rural state highways."* Cenek et al (2011a) also developed a prioritisation scheme for the safety management of curves and this has been included in the recent review of the NZTA skid resistance management system. The review extended the requirements on the bends (Category 2) from < 250m to < 400m radius bends and also included further assessment of each bend regarding risk and also a check to see if it is out of context, as many crashes on the network are loss of control on bends.

The Cenek et al (2011a) research included *"… the assignment of investigatory levels based primarily on predicted personal crash."* These new investigatory levels mean a higher level of skid resistance is required on many sites throughout the country and that sealing chip (aggregate) that had provided complying skid resistance on many of these bends before the change could not now provide the higher level of skid resistance required. Lowest cost complying aggregate, which was usually from the closest aggregate supplier to the site with the appropriate PSV, was used. The new requirements mean that higher cost imported aggregates may have to be used to achieve the required skid resistance; however, the model used for selecting aggregates using the PSV test, which was based on data from the UK network, has not worked in New Zealand conditions.

Cenek et al (2004) suggested that the PSV equation in T/10:2002 (TNZ 2002) *"… does not adequately reflect on-road skid resistance performance of roading aggregates."* NZTA, in T/10: 2010 (NZTA 2010), introduced the concept of assessing the in-service performance of aggregates at providing the required skid resistance. However; the cost of implementation of the 2010 version of T/10 meant it had to be revised, hence T/10:2012 Specification and T/10:2012 Notes.
While evaluating the aggregate performance methodology provided in T/10, to ascertain its potential application for a number of road maintenance contracts around New Zealand, the authors identified a simple methodology and some additional key parameters that should be used when assessing the similarity of sites. The T/10:2012 notes mention other aspects that should be considered in the performance method process, but these are not expressly included in the specification.

For example, the performance assessment process outlined in the T/10:2012 specification only requires the assessment of Heavy Commercial Vehicles (HCV) and site categories (See figure 1). The notes include some discussion about factors that are outside the scope of T/10 but there are still other important factors outside the notes and scope that should be included. These key parameters would enable the actual polishing performance of an aggregate on an existing site to be used for selecting an appropriate aggregate for a site with similar polishing issues, thus ensuring appropriate polishing performance on the road.

Table 1 Skid resistance investigatory levels

Site category	Skid site description	Investigatory level (IL), units ESC					
		0.35	0.40	0.45	0.50	0.55	0.60
1	Approaches to: a) Railway level crossings b) Traffic signals c) Pedestrian crossings d) Stop and Give Way controlled intersections (where state highway traffic is required to stop or give way) e) Roundabouts. One lane bridges: a) Approaches and bridge deck.						
2	a) Urban curves <250m radius						
	b) Rural curves <250m radius			L	M	H	
	c) Rural curves 250-400m radius		L	L	M	H	
	a) Down gradients >10%. b) On ramps with ramp metering.						
3	a) State highway approach to a local road junction. b) Down gradients 5-10% c) Motorway junction area including on/off Ramps d) Roundabouts, circular section only.						
4	Undivided carriageways (event-free).						
5	Divided carriageways (event-free).						

Figure 1. Skid resistance investigatory levels (from NZTA T/10:2012).

An important aspect missing from the performance method discussion is that no site is exactly the same as another just as no natural sealing chip is exactly the same as its neighbour and sources change over time. To ensure that an aggregate is selected that will perform well on a site we need to assess its performance on a site constructed with characteristics as similar as possible: same surfacing treatment (including chip sizes), same chip (recent construction), same climate, same stresses, and same traffic demographics. This paper focusses on polishing performance on curves, because they comprise a major component of skid deficient sites. It elaborates on the parameters that could be used, and discusses the effects that some of these parameters have on the assessment of aggregate performance and selection of an appropriate aggregate for a chipseal to be constructed on a curve with similar characteristics.

FACTORS AFFECTING SKID RESISTANCE

The interaction between the vehicle tyres and the road surface creates surface friction which is measured as skid resistance. The surface friction is a combination of both adhesive friction and hysteretic friction which depend largely on pavement surface characteristics, contact between the tyre and the pavement surface and properties of the tyre. Adhesive force is most responsive to the micro-level asperities (microtexture) of the aggregate particles. Hysteretic force developed in the tyre is most responsive to the macro-level asperities.

The aim of a skid resistance management system is to provide adequate friction on all pavement surfaces to minimise skid related accidents. As there are numerous factors that affect skid resistance, care should be taken to include as many as possible when comparing site with site and aggregate polishing performance.

Some of the numerous factors and explanations regarding their possible influence on the skid resistance on a site are listed below. As over 90% of the NZTA state highway network is surfaced with chipseals, this paper focusses on chipseals and how the various chipseal treatments can affect the skid resistance performance on the road.

Pavement surface characteristics

- Treatment selection and construction methodology: there are many types of chipseal treatments utilising various aggregate sizes and combinations of aggregates. How the surfacing is constructed can change the surface characteristics - for example, the aggregate spread rates and aggregate size and shape affect the distance between and number of aggregate tips that the tyre interacts with. The polishing rate depends on the level of interface shear stress and the tyre-surface contact area, so high stress from tyres on widely spaced aggregate tips can cause rapid wear and polishing compared with the interaction from tyres with closely spaced aggregate tips.
- Surfacing drainage: the chipseal treatment and the macrotexture it creates are important in ensuring that surface moisture does not prevent the interaction between the tyre and the road surface. Large aggregate chipseals generally provide coarse texture which allows water to drain beneath the tyres while smaller aggregate chipseals provide less texture. Nearly all chipseals when constructed produce macrotexture much greater than that required to allow water to escape from under the tyre in normal conditions, however on bends with gradients the road surface drainage paths can be much longer and water films can be much thicker than found on flat straight sections of road which can in extreme circumstances lead to hydroplaning and crashes.

Surface aggregate properties

The surface aggregate or sealing chip provides the interface with the tyre and how the aggregate and tyre interact is critical to the skid resistance of the system.

Mean spacing between aggregate tips increases the loading substantially causing accelerated polishing and deposition of rubber and binder. Figure 2 is a photo of a chipseal that polished prematurely as the vehicle tyres only touched the points of the aggregate.

Figure 2. Polished and rubber/binder coated aggregate tips

The paradox of aggregate performance in chipseals is that very hard durable aggregate can polish readily in the field but will resist abrasion, resulting in low skid resistance but good texture; whereas less durable aggregate that wears readily, thereby constantly refreshing its interface with the tyre, results in less polishing, higher skid resistance but less texture.

This creates a serious concern for the road asset manager, who has to maintain a safe road surface, a surface with good skid resistance and little texture is no better than a surface with poor skid resistance with good texture especially in wet conditions.

Most properties of the aggregates used in the surfacing contribute to the surface skid resistance.

- Aggregate: physical and geometrical properties – the size and shape of the chip is very important to the friction created by the interaction. Crushed angular cubic aggregate in a chipseal will produce much higher friction through both adhesive and hysteretic friction than will uncrushed rounded aggregate.
- Aggregate: mineralogical and petrographic properties – the aggregate composition, how it is formed, its internal structure and the mineral hardness, which may cement particles or resist wear, are important properties that contribute to the aggregates mechanical properties.
- Aggregate: mechanical properties - the aggregates resistance to abrasion, its wear resistance, and its polish characteristics are critical to the performance on the road but there is no single laboratory test for aggregates that predicts in-field performance.
- Aggregate: durability – the aggregate must be chemically stable and able to withstand the climate in which it is applied, this includes freeze-thaw cycles, long wet and long dry periods.

Contamination

An important aspect of the surface condition is where surface contamination can mask the contribution of the aggregate to the adhesive friction component of the skid resistance and, at the extremes, can mask the hysteretic friction component as well. A common contaminant on chipseal surfaces is the chipseal binder; where it covers the aggregate surfaces the skid resistance is reduced significantly. These phenomena can occur in two ways: the first (bleeding) is where tyres pick up the binder from the chipseal interstices and deposit it down the road onto the surface, and the second (flushing) is where the binder rises to the surface filling the surface voids. In both instances the binder lubricates the tyre-aggregate interface causing significant loss of friction.

Tyre characteristics

Tyre rubber is a visco-elastic material, so temperature and sliding speed affect both the adhesive and hysteretic components of the interaction. The tyre rubber used in heavy commercial vehicle tyres is different from that used in car tyres; generally it is much harder and can provide much higher stress to the tyre surface interaction.

Vehicle characteristics

Heavy commercial vehicles apply more shear stress to the interface due to their heavier loadings, load application and centre of gravity, axle and tyre layout, and slower speeds especially around curves. Hilly, very tight sections of road with high proportions of large HCVs will contain a high proportion of the worst performing surfaces with respect to skid resistance.

Environment conditions

The environmental conditions that the road surface is subjected to have an important role in the long-term wearing and polishing performance of the aggregate on site. Where dry conditions predominate, the polishing is more severe than where wet conditions predominate.

Also, during dry periods a build-up of contaminants may occur as the amount of contaminants is controlled by the intensity and frequency of rain events. The contaminants can include; debris from paint materials, pollutants from the surrounding environment, hydrocarbons from vehicles, carbon particles, other vapours from the vehicles exhausts, tyre rubber wear products, engine wear products, brake pad wear products, and metal wear from moving vehicle parts. The proportion of these contaminants depends on the vehicle speeds, the vehicle types, the traffic density, the surrounding environment, and vehicle maintenance.

Driving behaviour

Driving behaviour can cause differences in skid resistance on sites at isolated sections with extreme polishing stress. Surprises on a curve can cause a higher amount of hard late braking compared to normal curves where drivers slow down appropriately. Other examples causing isolated extremely polished sections include: high vehicle speeds on curves that creates some slippage of the tyres on the outside of curves, and very sharp bends causing truck wheels to be dragged sideways.

Road geometry and topology

Poor road geometry and topology can contribute to polishing of the surface; for example, where the horizontal alignment transitions at the tangent point to a horizontal curve, this can create super elevations that are not appropriate to the radius of the curve and long drainage paths.

NZTA T/10:2012 "SPECIFICATION FOR STATE HIGHWAY SKID RESISTANCE MANAGEMENT" DEVELOPMENT

In 2010, New Zealand Transport Agency (NZTA) included the concept of assessing the actual in-service performance of an aggregate's resistance to polishing in the updated version of T/10 specification entitled "Specification for State Highway Skid Resistance Management" (NZTA 2010). This was in response to the perceived inability of T/10 specification to prescribe a methodology that could use the Polished Stone Value (PSV) source rock test to select an appropriate polish resistant stone for high demand sites throughout New Zealand.

The T/10 process used up until 2010 used an equation established in T/10:2002 (TNZ 2002) to calculate the required PSV for the aggregate for the various surface friction requirement categories. This meant that the closest aggregate with the highest PSV was used in all high demand areas, so that most high demand sites in each network were resurfaced with the same aggregate. However the polishing performance of the aggregates chosen using the PSV method has not been consistent for each category in each network.

This issue was recognised in earlier work in the UK, which is discussed in the next section.

UNITED KINGDOM (UK) SKID RESISTANCE POLICY AND STANDARD

In the late 1950s, Giles (1957) recognised that it was unrealistic to have the same skid resistance across the whole network and suggested that skid resistance would need to be related to skidding risk. Szatkowski and Hosking (1972) developed a model showing a relationship between polished stone value (PSV), Sideways Force Coefficient (SFC) and traffic volumes.

Roe and Caudwell (2008) stated that: "*In 1976, standards for the polishing resistance of aggregates used in new surface courses were introduced for trunk roads."* This linked the PSV of the aggregate to the level of traffic expected to use the road.

Roe and Caudwell (2008) stated that: *"…the new standard for the in-service skid resistance of UK Trunk Roads was introduced on 19 January 1988."* The new standard included the concept of dividing the network into sites of different categories with different levels of accident risk.

However, Roe and Hartshorne (1998) had raised concerns about the ability of the model to predict in-service skid resistance after observing varied polishing performance where aggregates appeared to polish more or polish less than predicted; this led to improvements to the material requirements specification.

Roe and Caudwell (2008) discussed the "…full review of the policy and revision of the standards…" was carried out in the early 2000's. This produced *"The revised standard … published in October 2004 and came into practical effect in 2005."*

UK MATERIALS PERFORMANCE

The materials traditionally used on the network that were used in developing the UK standards were mostly hot rolled asphalt (HRA) and surface dressing. Since the development of the standards there has been a significant change in traffic volumes and stress experienced by the surfacing aggregate, and this is likely to be contributing to the variations in performance of the surfacing aggregate.

The latest version Volume 7, Section 5 Part 1 HD 36/06 in Design Manual for Roads and Bridges (2006) "*Surfacing materials for new maintenance and construction."* recognised the limitations of the PSV test and the model, and provided for the use of local area experience of aggregate performance.

T/10:2012 AGGREGATE PERFORMANCE METHOD IMPLEMENTATION

The new concept described in T/10:2012 (NZTA 2012) of using the in-service polishing resistance performance of aggregates to select aggregates for other sites with polishing issues is an excellent development according to the authors. However, the methodology prescribed is too generic and does not explicitly take into account the many important factors contributing to surface friction loss. The process requires that a matrix of aggregate performance in a variety of polishing stress situations normalised for heavy traffic is produced.

Different aggregate sources are ranked according to resistance to polishing performance; the table is then used to select aggregates that will achieve the required skid resistance in-service.

The first publicly documented implementation by Mortimer et al (2012) showed that the generic nature of the method allows different conceptions to be used.

The T10:2012 (NZTA 2012) methodology for assessing aggregate polishing performance includes: "… variety of polishing stress situations …" which could mean just gathering the data from Category 2 sites or it could mean gathering specific data from Category 2 Low (2L), Category 2 Medium (2M) and Category 2 High (2H). Mortimer et al (2012) used all Site Category 2 sites in the only documented implementation of the aggregate performance method. However Category 2 sites cover the range of curves (2L, 2M and 2H) that include a large variety of polishing stress situations. As these are not considered separately, there is a wide variation in the polishing performance within the data set.

Mortimer et al (2012) also recognised that there were other issues that should be considered in the comparison and initially limited their analysis to State Highway 8 *"… to eliminate the bias of Heavy Commercial Vehicle (HCV) variation and possible environmental effects."* However they decided that there was not enough data in this sample and made the decision to compare all category 2 corners on the Coastal Otago and Otago Central networks.

A common presumption when selecting treatments is that no site is ever exactly the same as another, and this applies equally as well to the selection of aggregates based on their polishing performance. The polishing performance of an aggregate has to be measured from a site that is as similar as possible in all respects such as climate, microclimate, traffic volume and percentage HCVs, surfacing type, surfacing age, aspect to sun, curve speed, curve radius, approach speed, crossfall, and gradient.

The performance of the surface is measured by the skid resistance during the annual SCRIM survey. Care must be taken to ensure that reduction of skid resistance on the site is due purely to polishing of the aggregate and is not caused by contamination or texture loss.

So, instead of trying to use as much data as possible to ensure that the comparison is statistically relevant, the only methodology that may accurately predict an aggregate's performance is to find sites that are as similar as possible to those where the aggregate is to be used.

Another compounding issue is that the extreme polishing stresses do not occur on the entire curve and can be limited to small sections within the curve. Cenek et al (2011b) suggested that chip loss on curves *"… tends to occur where large lateral tyre loading is combined with small vertical tyre* *loading. This corresponds to the tightest part of the curve in the innermost wheel path."* This part of the curve would also be where the highest polishing stresses are applied to the surface. If chips are not dislodged by the traffic then they will be subjected to extreme polishing. If chip loss or chip rollover has occurred then loss of skid resistance may not be due to polishing of the aggregate.

Therefore, before the data set for each curve used in an analysis is used, the site should be assessed to ensure the seal and aggregate in question is still intact. Once the aggregate performance has been established as suitable for comparison then the skid resistance performance should be assessed to predict the expected life on the site. This expected life should then be used in a life cycle cost analysis in comparison with the life cycle cost of the alternative local aggregates.

If an aggregate is found to polish slowly on sites with the most extreme polishing stresses then it would generally be suitable for use on most sites with similar or lower polishing stresses and if an aggregate is found to polish quickly on sites with minimal polishing stresses then it would not be suitable for use on any sites with polishing stresses.

ASSESSING THE POLISHING PERFORMANCE OF AGGREGATES IN CHIPSEALS

The T10:2012 (NZTA 2012) aggregate performance method requires the investigator to *"… produce a matrix of aggregate performance in a variety of polishing stress situations normalised for heavy traffic."* The simple way to sort the data would be to develop a matrix with the five Site Categories in T10:2012 (NZTA 2012) Table 1 (Figure 1 in this paper) as the various polishing stress situations and then populate the matrix with the skid resistance achieved by the various aggregates used in each. Site Category 3, 4 and 5 skid resistance requirements are reasonably low, and generally the polishing stresses are low, so chipseal surfacings using local chips generally comply.

Where testing shows that the surfacing on curves has failed because the local chip is not capable of providing the new higher skid resistance requirements due to polishing, the asset manager has to find a cost effective alternative sealing chip that will work on the site using the performance assessment method.

The parameters affecting the polishing of the surfacing on curves are many and varied; however, many parameters that can be found in the NZTA RAMM database for each 10m section on the entire NZTA network that can be relatively easily sorted and filtered to find physically very similar curves. Parameters include: total curve radius from 800m radius point to 800m radius point, specific 10m section curve radius, total crossfall, gradient both increasing and decreasing, curve speed – calculated from a combination of curve factors, approach speeds both increasing and decreasing, curve geometric e.g. inside downhill or inside uphill etc., seal type, and sealing chip size.

For all the information used in the comparison using the parameters above it is still not enough to ensure that aggregate that performs well in similar physical conditions will perform as well in the new location. Some additional factors that are not available using the RAMM database but could be crucial to making the correct decision are:

- Climate for the site - including rainfall, and maximum and minimum surface temperatures
- The likelihood of surface contamination from forestry operations, agricultural operations, heavy summer season traffic e.g. wine and fruit growing areas.
- Application of grit for ice or snow in winter and to blind out bleeding and flushing in summer
- Whether the surface has been retexturised.

These factors or actions can all have a significant effect on the polishing and wear of the stone, if the site where the aggregate is performing well is not subjected to this extra wear but the site for the new surface is, then the new surfacing may polish and lose texture prematurely.

The role of the aggregate in the skid resistance failure

The main cause of skid resistance failure on curves is assumed to be polishing of the aggregate, and this is usually the case. However, high risk curves with high skid resistance requirements are high demand sites, which can include short sections with intense scrubbing/shear stress that can lead to chip loss, chip rollover, chip breakdown and surfacing failure.

If the surfacing has failed in the short sections the skid resistance measurement may not include the microtexture of the new aggregate or the macrotexture of the chipseal but it may include measurement of the binder. As a chipseal wears the macrotexture reduces and this increases the likelihood of the test tyres including bitumen in the skid resistance measurement.

The previous selection system utilising PSV to select the appropriate aggregate has meant that aggregates with high PSV have been used in surfacings on high demand sites, which will include sections that have a strong likelihood of surfacing failure due to the surface shear stress. Aggregates with lower PSV that have not been selected because they did not comply would have been used on lower demand sites, where the chipseal is more likely to handle the lower shear stresses and would have a better polishing performance record.

The issue with utilising an all-encompassing assessment of performance is that the site specific information is lost. On a statistically significant basis, the data for each 10m section on Category 2 curves can show that one aggregate generally performs better than other aggregates on Category 2 curves. However, the comparison will not accurately predict the aggregate polishing performance as the data sets are from different networks with different traffic demographics, different curve stresses, different climate, and different rainfall patterns.

If a network has many curves and the high shear sections on the curves are isolated areas within larger sites, because of the traffic demographics, road geometry and the topography, then there would be a small percentage of failures compared with a network that has a different traffic demographic, topography and road geometry and has fewer curves with more intense shear stress spread over larger proportions of the site. The performance data would show much lower levels of skid resistance.

If the traffic is consistently cutting corners and straightening curves because of the geometrics of the curves alignments and the lower traffic density, then the measured skid resistance will be high and the polished areas on these curves may not be identified.

Mortimer et al (2012) compared the performance of chip from Parkburn on the Central Otago network with the performance of chip from Balclutha and Oamaru on both the Central Otago and Coastal Otago networks. As the Balclutha and Oamaru chips had a higher PSV than Parkburn, the former were used as required by the old system on the high demand areas in Central Otago and Coastal Otago as well as other sites where they were the lowest cost alternative for general surfacing.

Data provided in Mortimer et al (2012) suggested that the Parkburn sealing chip had much higher skid resistance than the Balclutha and Oamaru sealing chips over time and this was the basis of their conclusion that it had a better polishing performance than the other two aggregates.

Where the curve radii curves are larger and the curves less frequent on roads with higher traffic the vehicles are more likely to drive within their lane the polished wheelpaths of the surface will be tested. If however, there is less traffic and the geometry is such that the vehicles may stray outside the lane then the polished wheelpaths may not be tested. Test results for non-polished surfaces could account for some of the high skid resistance readings recorded in the data.

Parkburn aggregate polishing performance

In order to test whether the polishing performance of Parkburn aggregate in Central Otago was better (than the other two sources), two sites were chosen on State Highway 6 that were subjected to the same traffic but with different surfacing treatments, different shear stresses, and different speed environments; one is a Site Category 2L curve resurfaced November 2011 the other is a Site Category 2H curve resurfaced March 2010.

The Mean Summer SCRIM Coefficient (MSSC) data for the worst wheelpath from the low stress situation is compared with the worst wheelpath from the high stress situation in Figure 3 below. Both sites were surfaced with Parkburn chip previously.

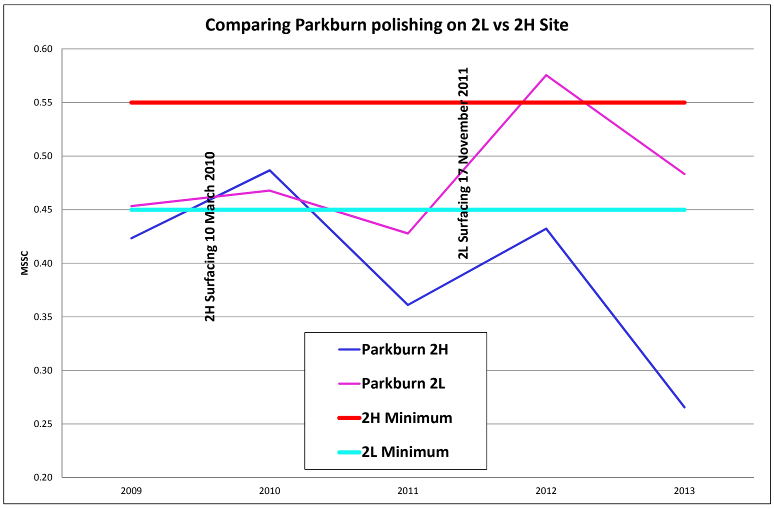


Figure 3. Comparing Parkburn aggregate polishing performance

Figure 3 shows that, on the low risk low demand curve (2L), the Parkburn chip has performed adequately, staying above the Intervention Level (IL) for a low risk curve (0.45). However, the Parkburn chip has performed poorly on the high risk high demand curve (2H), never getting over the IL for a high risk curve (0.55). The increase in skid resistance in 2012 is the result of retexturing treatments. An inspection of the site (see Figure 4) suggests that the March 2010 surfacing failed and that the skid resistance test results are for a binder rich surface and not a polished surface. Figure 4 shows evidence of binder removal in the wheelpaths by either waterblasting or watercutting and there is evidence that the binder is being tracked by vehicles from the flushed patches.

Figure 4. Bleeding and flushing on Category 2H curve

Figure 5 has the data for another site on the Lindis Pass, which has a medium risk rating (2M). The surfacing has good texture (> 2.0mm) and one wheelpath (RL LWP) has polished more than the others probably due to much higher polishing stress than the rest of the site.

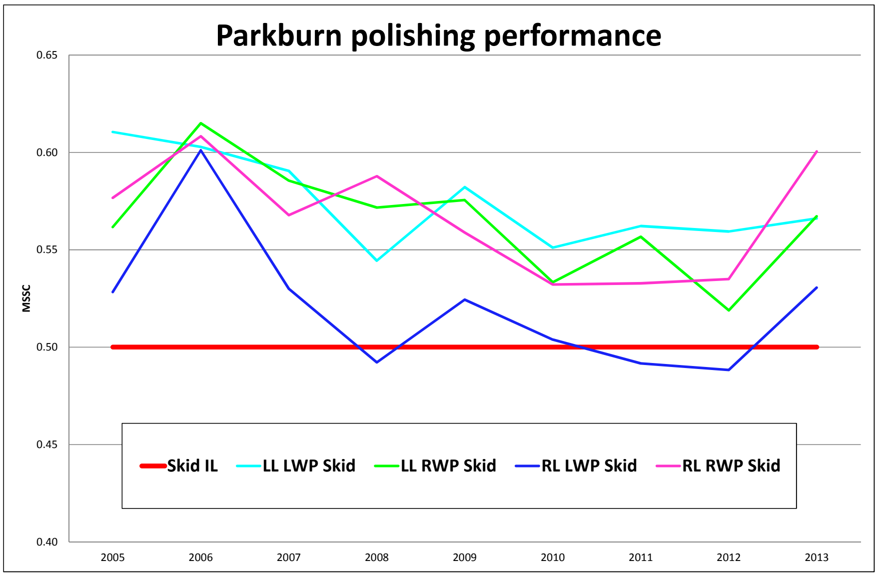


Figure 5. Uneven polishing stress

Climate is an important facet of both polishing and skid resistance measurement as discussed earlier; high rainfall areas have less polishing than low rainfall areas and skid resistance measured on a surface after a period of rain is generally higher than after a period without rain.

Aggregate Petrographic Comparison

Parkburn sealing chip generally complies in all respects with NZTA M6:2011; however it is produced from an alluvial source (Clutha River) that is fed from the Southern Alps, which include various metamorphic grades of schist and gneiss. The chipseals are light coloured because many of the chips contain quartz, which is a hard durable mineral compared with the schist fragments that tend to crack along the schistose planes within. A mixture of very hard wearing quartz and the less durable schist fragments seems to have great polishing resistance properties except for on the high demand sections where it fails readily.

Polishing factors

Figure 6 includes some of the important factors that should be considered when selecting aggregates based on the aggregate performance method.

	Texture Existing	Treatment Selection	Chip Size	Chip Shape	Curve Speed	Total Curve Radius	Gradient	HCVs	Rainfall
Consider	Not flushing or bleeding	Same treatment	Same chip size/s	Crushed faces	Similar speed	Similar radius	Similar increasing and decreasing	Demographics of HCVs	Similar rainfall
Measure	>1.5mm In RAMM	Seal Type in RAMM.	ALD in RAMM	Ratio	Calculated in RAMM	Calculated in RAMM	Similar	Calculated in RAMM	
Effect	High	High	High	Medium	Medium	Medium	Medium	High	Medium

Figure 6. Comparing factors and effect on polishing

Cenek et al (2012) found that pavement aggregate source had the strongest influence on in-service skid resistance followed by curve stress, traffic and the size of the chip using statistical modelling. The analysis included data for all site categories and ranked the aggregates based on the skid resistance measured in the field. Cenek et al (2012) found that *"The major finding of the research was that the categorical variable 'aggregate source' was a better predictor of in-service skid resistance performance than the numeric variable 'polished stone value'."*

The use of nearly a million pieces of data meant that "statistically significant relationships" could be identified and these are most likely valid for most of the NZTA network. However, the research did not look at all factors or combinations of factors or site specific differences or similarities to ensure that the selected aggregate would perform adequately on every site it is used on.

Cenek et al (2012) states that there are 17,363 curves on the NZ rural SH network with a horizontal radius less than or equal to 400m and 4,434 of these have been classified as high risk curves, which in T/10:2012 are required to have a skid resistance of 0.55 or better. The report also states that it will not be feasible to manage high demand road sections (Site Category 1) to an IL value of 0.55. This also means that it is probably not "feasible" to ensure that the skid resistance on curves is maintained at the 0.55 level on the isolated high demand sections. It seems that most New Zealand aggregates are not capable of maintaining this level of skid resistance on surfaces in high demand situations.

Methodology for finding similar sites

RAMM data from Coastal Otago and Central Otago for all category 2 sites were combined in a table with all parameters set up as filters. A site is selected, then the data is filtered using the parameters as required to find other sites with similar characteristics but with different aggregate source, so that polishing performance can be compared.

Additional groups and parameters combining other parameters were developed such as low medium and high HCVs.

Climate data was sourced and overlaid onto the state highway RPs so that various parameters can be used as filters. For example, groups with low medium or high rainfall can be selected.

Case Study 1

A trial of the methodology to assess the polishing resistance of three aggregates was carried out by choosing curves classified as Site Category 2H, low HCVs, low curve speed, low rainfall, large grade 2 chip chipseal and wet crashes >0. Unfortunately there were no Low Rainfall sites with Parkburn chip that had similar characteristics so the filter was changed to include medium rainfall and a site with Parkburn chip was then selected. Figure 7 compares some of the factors for the sites.

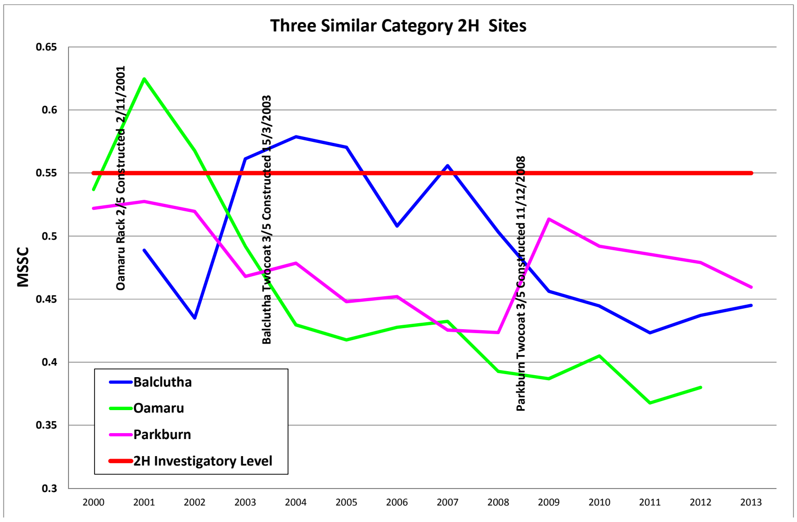
Road Name	Skid Site	Scrim Site IL	Curve_Start	Curve Direction	Estimate	Percentage Heavies	ESA Heavies	Grad Incr	Grad Dec	Curve Radius	Absolute crossfall	Adverse Crossfall	Curve Speed	Approach Speed Increasing Dire	Approach Speed Decreasing	All Crashes	Wet % All	1st Chip Size	2nd Chip Size	Source	Rainfall Group	HCV Per Day Group
008-0381	2H	0.55	16780	LH	1815	9	1.008	3.3	-0.7	97	9.1	N	60	95	98	5	80	2	5	BALCLUTHA	RL	HL
083-0000	2H	0.55	150	LH	1213	10	0.814	5.1	4.7	84	9.2	N	56	102	99	2	50	2	5	OAMARU	RL	HL
008-0444	2H	0.55	2580	LH	1784	10	0.982	-1.1	0.9	110	8.1	N	62	98	98	2	100	3	5	PARKBURN	RM	HL

Figure 7 Spreadsheet for Site Category 2H showing polishing factors for the three sites

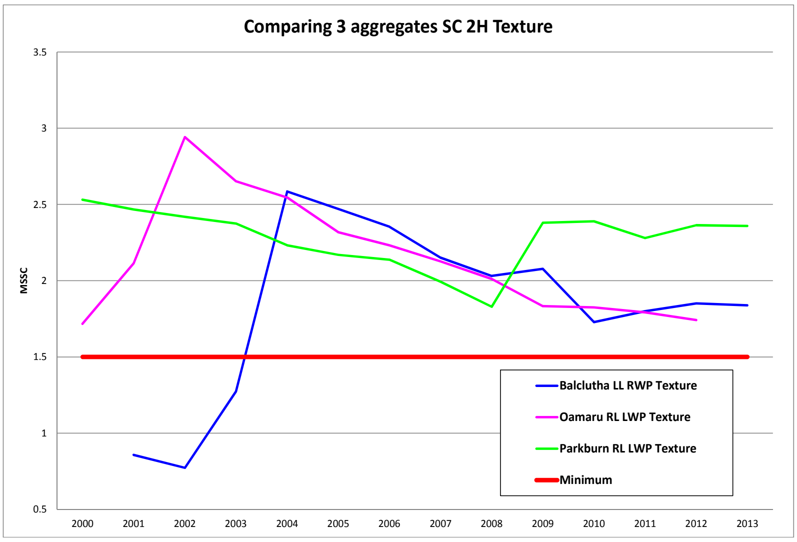
The average skid resistance for each wheelpath for each of the curves was calculated and the worst performing is compared on Figure 8.

The data shows that none of the aggregates are suitable for surfacing Site Category 2H curves with such extreme polishing stresses.

The graph also shows that all aggregates seem to be polishing at a similar rate. The texture data (Figure 9) shows slow reduction over time at a similar rate for the three aggregates.



Figures 8 Graph of skid resistance three similar sites with different aggregates



Figures 9 Graph of texture on three similar sites with different aggregates

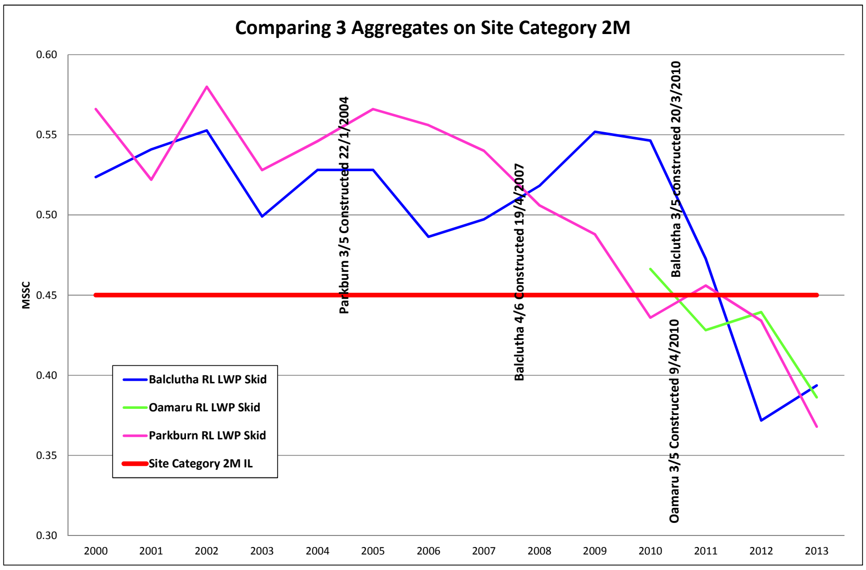
Case Study 2

This was a trial of the methodology to assess the polishing resistance capability of the three aggregates for Site Category 2M, with medium HCVs, and medium rainfall. These filters selected just one site with Balclutha chip and one site with Oamaru chip but no sites with Parkburn. The filters were changed to include sites with high HCVs and then low rainfall before sites with Parkburn chip were identified. The site with the most similar curve characteristics with the highest curve radius was selected as shown in Figure 10.

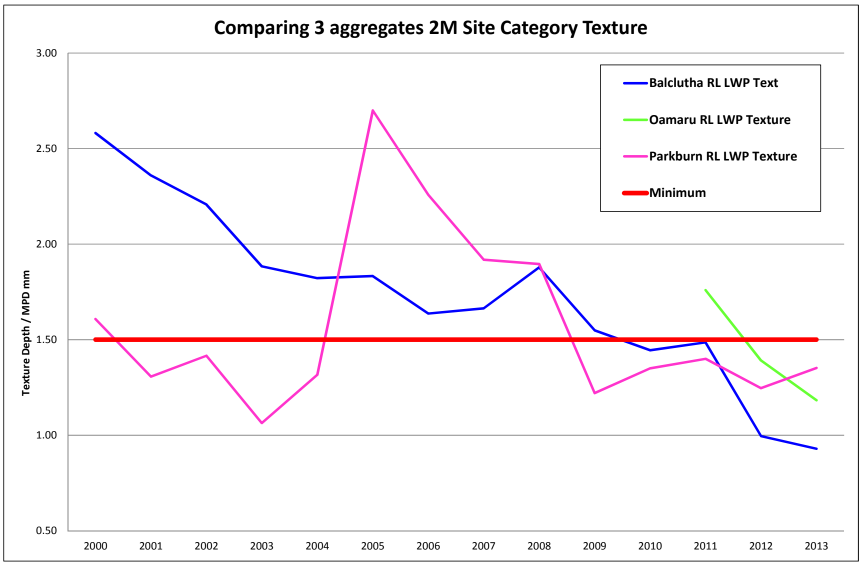
Road Name	Skid Site	Scrim Site IL	Curve_Start	Curve Direction	Estimate	Percentage Heavies	ESA Heavies	Grad Incr	Grad Dec	Curve Radius	Absolute crossfall	Adverse Crossfall	Curve Speed	Approach Speed Increasing Dire	Approach Speed Decreasing	All Crashes	Wet % All	Surfacing Date	1st Chip Size	2nd Chip Size	Source	Rainfall Group	Chip Seal Zone	HCV Per Day Group
01S-0774	2M	0.45	9190	RH	4488	14	1.119	-0.4	-3.1	225	7.4	N	82	77	87	0		19/04/2007	4	6	BALCLUTHA	RM	SA	HH
01S-0774	2M	0.45	9380	LH	4488	14	1.119	2.9	3.6	169	8.5	N	74	87	92	3	33	9/04/2010	3	5	HILDERTHORPE	RM	SA	HH
006-0956	2M	0.45	3490	RH	3271	15	0.758	0.3	0.7	175	1.8	N	67	84	81	1	0	22/01/2004	3	5	PARKBURN	RL	SE	HM
006-0956	2M	0.45	3540	LH	3271	15	0.758	0.3	0.4	167	3	N	67	83	81	1	0	22/01/2004	3	5	PARKBURN	RL	SE	HM
006-0956	2M	0.45	3590	RH	3271	15	0.758	-0.1	-1.6	165	2.3	N	66	85	78	0		22/01/2004	3	5	PARKBURN	RL	SE	HM

Figure 10. Spreadsheet for Site Category 2H showing polishing factors for the three sites

Unfortunately the average skid resistance (Figure 11) for all three aggregates are measuring below the Site Category 2M IL. The average surface texture (Figure 12) for all three sites is also below the 1.5mm that confirms a surfacing failure with flushing, bleeding and tracking, which is confirmed by visual assessment.



Figures 11. Graph of skid resistance on three similar sites with different aggregates



Figures 12. Graph of texture on three similar sites with different aggregates

CONCLUSIONS

1. It is important to ensure that the aggregate performance is measured on an uncontaminated chipseal surface, that the surfacing being assessed is as similar as possible to the proposed new surfacing and that the traffic stress is as similar as possible.
2. Network level comparisons lose the detail that is required to assess actual site specific performance.
3. The site specific comparisons above show that all three aggregates tested perform similarly under similar climate, traffic, and curve stress.
4. The concept of using aggregate polishing performance to select an aggregate that should perform in a similar situation is excellent but the methodology needs more work.

5. Polishing stresses on curves vary considerably and the skid resistance on many curves fails in isolated sections where the shear stress is the highest while the rest of the site performs well.
6. No surfacing site is exactly the same as another, and there are a large number of parameters that should be aligned so that the aggregate polishing performance on one site can be achieved on the new surfacing.
7. Inappropriate application of the aggregate polishing performance assessment methodology will result in poor performance of aggregates on the new site. SCRIM+ data is useful for desktop investigations to identify sections that may be subjected to extreme polishing stresses, however care must be taken to ensure that the data is meaningful and not used out of context.
8. T/10:2012 allows the treatment of just the non-complying sections on a site; however, the treatments are not recorded in the RAMM database for carriageway surface and this could result in aggregate that is polishing prematurely in isolated sections looking like it is performing better than it really is.
9. New Zealand aggregates are not capable of resisting polishing and providing levels of skid resistance above 0.55 for the expected life of the chipseal in high demand situations.
10. It is expensive to transport aggregate to resurface complete sites from distant sources when only isolated high demand sections need the more polish resistant aggregate.
11. High demand situations on curves that cause premature failure by polishing can be resolved by improving the geometrics of the curve.

RECOMMENDATIONS

1. The aggregate polishing performance assessment method needs to be extended to ensure that only polished surfaces are used in the assessment of failure and performance of aggregates.
2. The polishing performance of an aggregate should be assessed based on the highest shear stress it is subjected to on each site. Use of averaging or data that includes the skid resistance of aggregate subjected to lower shear stresses on a site masks its real polishing performance and may lead to aggregates selected that are inappropriate for the site leading to early failure due to polishing.
3. Analysis of aggregate performance should be completed on a site by site basis and must include physical site inspection of both the high performing aggregate and the poor performing aggregate to confirm that the data is meaningful and that the sites are as similar as possible.
4. The T/10 methodology needs to be developed to ensure that it looks very closely at the overall skid resistance performance on each site that needs resurfacing to ensure that the aggregate selected has suitable polishing resistance for the highest shear stresses it will be subjected to.
5. The polishing performance of aggregates chosen using the aggregate polishing performance method should be monitored closely to ensure that value for money is achieved.

REFERENCES

CENEK, P.D., CARPENTER, P., JAMIESON N.J. AND STEWART, P.F., (2004). Prediction of skid resistance performance of chipseal roads in NZ. *Transfund New Zealand research report* 256.

CENEK, P.D., HENDERSON, R.J., AND DAVIES, R.B., (2012). Selection of aggregates for skid resistance. *NZ Transport Agency research report* 470, 56pp.

CENEK, P.D., BRODIE, C.A., DAVIES, R.B., AND TATE, F.N., (2011a). A prioritisation scheme for the safety management of curves. *3rd International Surface Friction Conference, Safer Road Surfaces – Saving Lives*, Gold Coast, Australia.

CENEK, P.D., HERRINGTON, P.K., HENDERSON, R.J., HOLLAND, B.J.H., MCIVER, I.V., AND WALTON, D.K. (2011b). High Stress Corners. *NZ Transport Agency Research Report* 466. 58pp.

GILES, C.G. (1957) The skidding resistance of roads and the requirements of modern traffic. *Proceedings of the Institute of Civil Engineers, Volume 6* pp.216-249.

Design Manual for Road and Bridges (2006)*. Volume 7 Pavement Design and Maintenance, Section 5 Pavement Materials, Part 1 Surfacing materials for new and maintenance construction*. London: TSO, HD36/06.

MORTIMER, P., STEWART, P., AND BAILEY, R., (2012). Coastal Otago Chip Source Performance Analysis*. NZTA and NZIHT 13th Annual Conference*, Nelson NZ.

NEW ZEALAND TRANSPORT AGENCY (NZTA) (2010) NZTA T/10:2010 Specification for State Highway skid resistance management. Wellington: NZTA.

NEW ZEALAND TRANSPORT AGENCY (NZTA) (2011) NZTA M6:2011 Specification for Sealing Chip. Wellington: NZTA.

NEW ZEALAND TRANSPORT AGENCY (NZTA) (2012) NZTA T/10:2012 Specification for State Highway skid resistance management. Wellington: NZTA.

NEW ZEALAND TRANSPORT AGENCY (NZTA) (2012) NZTA T/10 Notes: 2012 Notes to specification for state highway skid resistance management. Wellington: NZTA.

ROE, P.G. AND CAUDWELL, L (2008). *Skid Resistance policy in the UK – where did it come from and where is it going?* International Safer Roads Conference, Cheltenham UK, 1-14 May 2008

ROE, P.G. AND HARTSHORNE, S.A., (1998) The Polished Stone Value of Aggregates and In-service Skidding Resistance*, TRL Report 322*.

SZATKOWSKI, W.S. and HOSKING, J.R., (1972). The effect of traffic and aggregate on the skidding resistance of bituminous surfacings. TRRL Laboratory Report LR504, TRRL, Crowthorne.

TRANSIT NEW ZEALAND (TNZ) 2002 TNZ T/10:2002 Specification for skid resistance investigation and treatment selection. Wellington: Transit New Zealand (now NZTA)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the peer reviewers both internal and external for their many helpful comments, the NZ Transport Agency who supplied skid resistance, texture and video data, and Fulton Hogan who funded the research.