Improved Methodology for Selecting Polishing Resistant Aggregates for Chipseals

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ABSTRACT

In 1997, based on earlier work in the United Kingdom (UK), the New Zealand (NZ) State Highway agency introduced a procedure for identifying sites where treatment is required to improve skid resistance. Subsequent versions of the T/10 specification (1998, 1999 and 2002) gradually modified the procedure. However, all of the revised versions still relied on the Polished Stone Value (PSV) test to select aggregates that provided adequate skid resistance performance in-service on New Zealand's state highways.

In response to the perceived inadequacies of the 2002 methodology, the 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 T/10:2012 "Specification for State Highway Skid Resistance Management".

The concept of assessing aggregate polishing performance described in T/10:2012 is a significant step in the right direction. However the authors believe that the methodology described is too generic, and does not ensure that an aggregate selected for a specific site will provide adequate in-service skid resistance performance.

This paper proposes a simple methodology to compare the polishing performance of different aggregates on sites with similar characteristics. The proposed methodology processes the data using simple filters that reduce the data set to sites with similar characteristics. Much of the data and characteristics are available within data sources currently available to the industry.

This paper identifies the key characteristics and discusses improvements to the aggregate polishing assessment methodology that will ensure that the most appropriate aggregate will be selected for each resurfacing site.

1. INTRODUCTION

In the last few decades, New Zealand Transport Agency (NZTA) has increased its focus on road surface characteristics and their 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 concepts of skid resistance requirements 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 (Spray Seal) (>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 curves (Category 2) which had only applied to those with radii < 250m to those with radii < 400m, it also included a further assessment of each curve regarding risk and also a check to see if it is out of context (Cenek et al (2011a), as many crashes on the network are loss of control on curves.

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 maintain 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 resulted in higher cost aggregates with higher PSV being transported to and from other regions of New Zealand to comply with the skid resistance calculation based on the UK model; however, the PSV model used for selecting aggregates for sites, which was based on data from the UK network, has not worked well 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 to improve the in-service skid resistance performance of surfacings.

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 factors that should be used when sites for comparative analysis. 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 T/10:2012 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 to ensure accurate performance prediction. These key factors 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.

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 aggregate 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 curves comprise a major component of the high demand sites on the New Zealand State Highway network that suffer from premature failure due to skid resistance. It elaborates on the factors that could be used, and discusses the effects that some of these factors have on the assessment of aggregate performance and selection of an appropriate aggregate for a chipseal to be constructed on curves with similar characteristics.

In addition to issues with in-service performance the cost of implementation of the 2010 version of T/10 meant it had to be revised because it raised the standards too high identifying additional lengths of the network that required resurfacing that had complied with the previous standards, hence T/10:2012 Specification and T/10:2012 Notes which revised the standard to a more economic level.

2. 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 types of pavement surfaces in all conditions 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 many 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 surface effects of the various chipseal treatments can affect the skid resistance performance on the road.

2.1 PAVEMENT SURFACE CHARACTERISTICS

2.1.1 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.

2.1.2 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.

2.2 SURFACE AGGREGATES 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, resulting in 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;

- 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.
- 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.
- 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.
- Durability – the aggregate must be chemically stable and able to withstand the climate in which it is applied; this includes freeze-thaw cycles and long wet and long dry periods.

2.4 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 especially in wet conditions.

2.5 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.

2.6 VEHICLE CHARACTERISTICS

Heavy commercial vehicles (HCV) 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.

2.7 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 detritus may occur as the cleaning of the surface is controlled by the intensity and frequency of rain events. The detritus can include; debris from paint materials, windblown dust and dirt, pollutants from the surrounding environment, vehicle droppings such as; 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 various proportions of these products landing on the road surface depend on the vehicle speeds, the vehicle types, the traffic density, the surrounding environment, and vehicle maintenance regimes.

2.8 DRIVING BEHAVIOUR

Driving behaviour can cause differences in skid resistance on sites at isolated sections with extreme polishing stress. Where the radius of a curve decreases after entry this can surprise the driver and lead to 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.

2.9 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. There are many lengths of State Highway with long sequences of interconnected curves which include sections with extreme polishing stresses caused by the geometric shape.

3. 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.

4. 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."*

5. 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.

6. 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. However, in the author's opinion 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. It does not provide detail about the process of normalising the data for heavy traffic which is an important factor in the polishing.

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

The first publicly documented implementation of the Aggregate Performance Method described in T/10:2012 (NZTA 2012) by Mortimer et al (2012) showed that the generic nature of the methodology as described allows different conceptions to be used. The methodology used by Mortimer et al (2012) followed the method prescribed in T/10:2012 but because of the shortcomings of the method produced outputs that selected an aggregate that has performed well in one network as likely to perform better in higher demand situations in another network as described below and in Mortimer et al (2012).

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) see Figure 1 for Site Category details)). Mortimer et al (2012) used all Site Category 2 site data from the two networks analysed in their 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 were not considered separately, there was a wide variation in the polishing performance of the aggregates within the data set they used for the aggregate performance comparison.

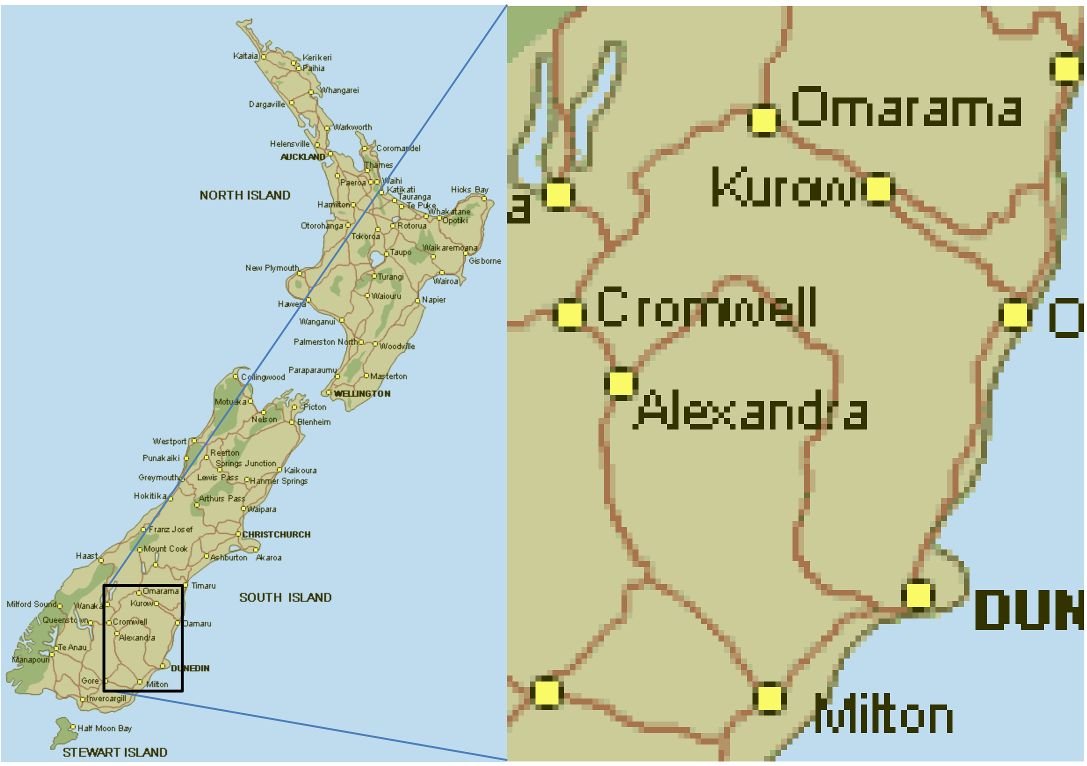


Figure 3. Map of New Zealand inset Central and Coastal Otago.

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 Mortimer et al (2012) found that there was not enough data in this sample and made the decision to compare all category 2 curves 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 surface friction performance of the surface is measured during the annual SCRIM+ survey carried out on the entire State Highway network. 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 surface contamination or texture loss. The SCRIM+ survey also includes a measure of the surface texture (Mean Profile Depth MPD) that could be used to filter out all sections that have texture below a set level. Also, the higher PSV aggregates are normally used on sites with the highest polishing demand on which the surfacing treatments are subjected to high to extreme sheer stresses which are more likely to fail prematurely than other aggregates used in less severe conditions.

So surfacing treatments containing high PSV aggregates constructed in high stress situations are more likely to fail prematurely due to flushing and chip rollover than surfacing treatments constructed in lower stress situations. Previous skid resistance issues on high demand curves, where polishing of surfacing treatments has caused a premature resurfacing requirement. Because the seal is comparatively new and failed by polishing the surface texture may be coarser than a seal failing at the end of its expected life, the coarse texture would then require a surfacing design with a higher than normal application rate increasing the binder to aggregate ratio in the surfacing and increasing the risk of subsequent flushing.

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.

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 and where the surface treatment is not contaminated or suffering from premature texture loss so that the measured changes in surface friction are due entirely 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.

7. 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 is 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, the many parameters that can be found in the NZTA Road Asset and Maintenance Management (RAMM) database for each 10m section on the entire NZTA network, 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.

7.1 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. They would also have a better polishing performance record because they are less likely to fail prematurely and the data gathered would be mostly a measure of the actual aggregate performance.

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 surface treatment types, 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.

If a network has many high demand bends with high traffic volumes on which the surfacing treatments consistently fail prematurely due to texture loss, flushing and aggregate rollover, then the data for high PSV chip in that network would suggest that the aggregate had poor polishing performance especially if compared with another network with less high demand bends and lower traffic volumes where the surfacing treatments perform well.

Mortimer et al (2012) compared the performance of chip from Parkburn Quarry (located near Cromwell) 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 are larger, curves are less frequent, on roads with higher traffic, the vehicles are more likely to drive within their lane, and the polished wheelpaths of the surface in the expected location then the polished wheelpaths 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.

7.2 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) as concluded by Mortimer et al (2012), three sites constructed with aggregate from the Parkburn Quarry were chosen on State Highway 6 that were subjected to different shear stresses. The Mean Summer SCRIM Coefficient (MSSC) data for the three curves with the same traffic, same aggregate source but different stress situations are compared in Figure 4 below. To allow a direct comparison of performance the difference between the measure MSSC and the appropriate minimum allowed for the site is used.

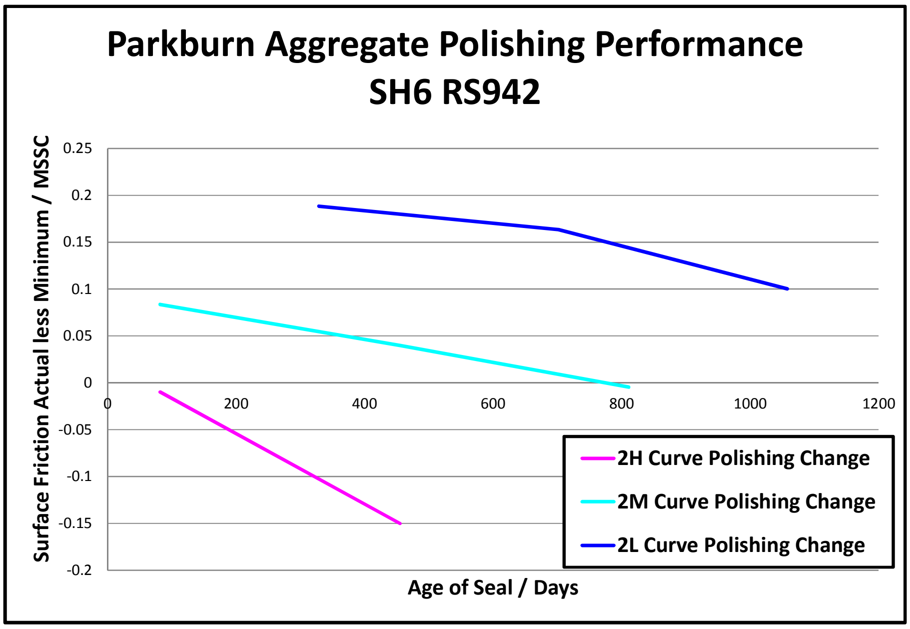


Figure 4. Comparing Parkburn aggregate polishing performance

The negative results for the 2H (High demand) curve mean that it had polished to below the minimum (0.55) within 80 days of construction while it took the same aggregate on the 2M (Medium demand) curve almost 800 days to polish to below the minimum (0.5). The results for the 2L (Low demand) curve are well above the minimum (0.4) after more than 1000 days.

The surface texture of the three sites shown in Figure 5 below is well above the minimum that suggests contamination, confirming that the reduction in skid resistance measured on the sites most likely related to polishing of the Parkburn aggregate and visual assessment confirms this.

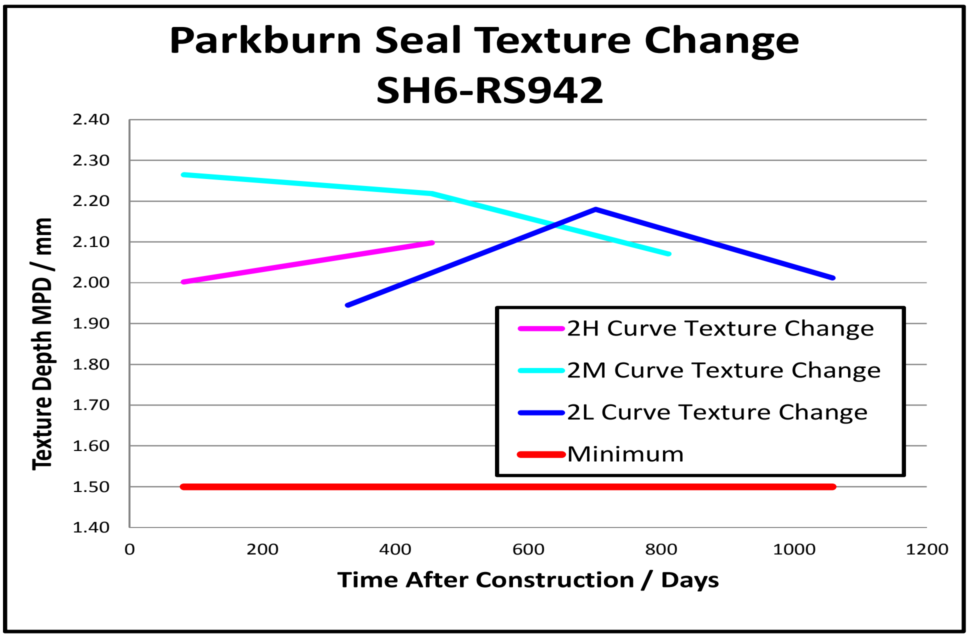


Figure 5. Comparison of Texture Change.

Figure 6 shows the data for another site on the Lindis Pass, which has a medium risk rating (2M). The surfacing has good texture see Figure 7 and one wheelpath (Right Lane - Left Wheelpath (RL LWP)) has polished more than the others, most likely due to much higher polishing stress than the rest of the site. The texture for RL LWP has remained above 2.0mm during the entire monitoring period.

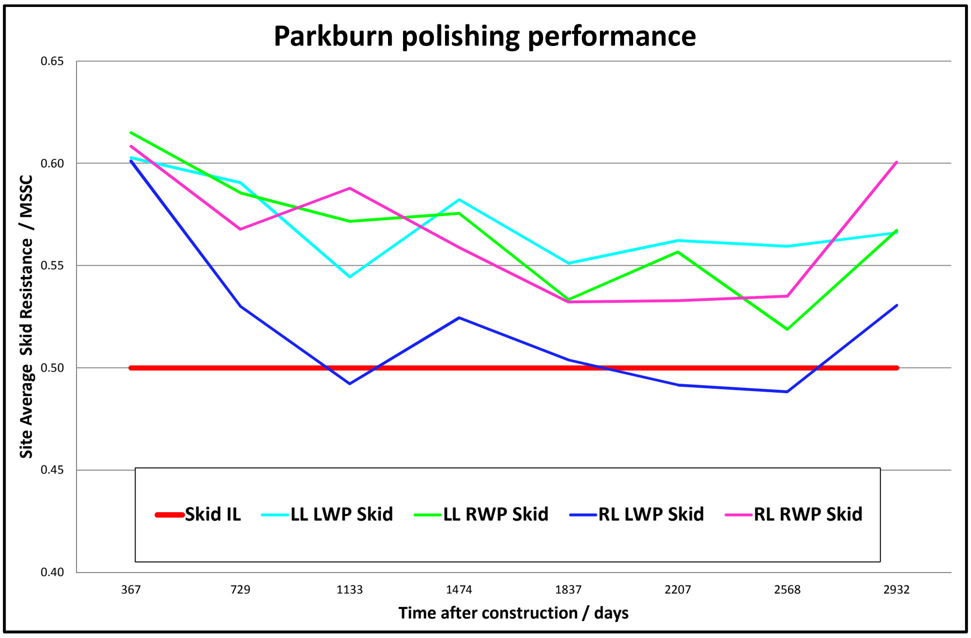


Figure 6. Uneven polishing stresses on Lindis Pass Site

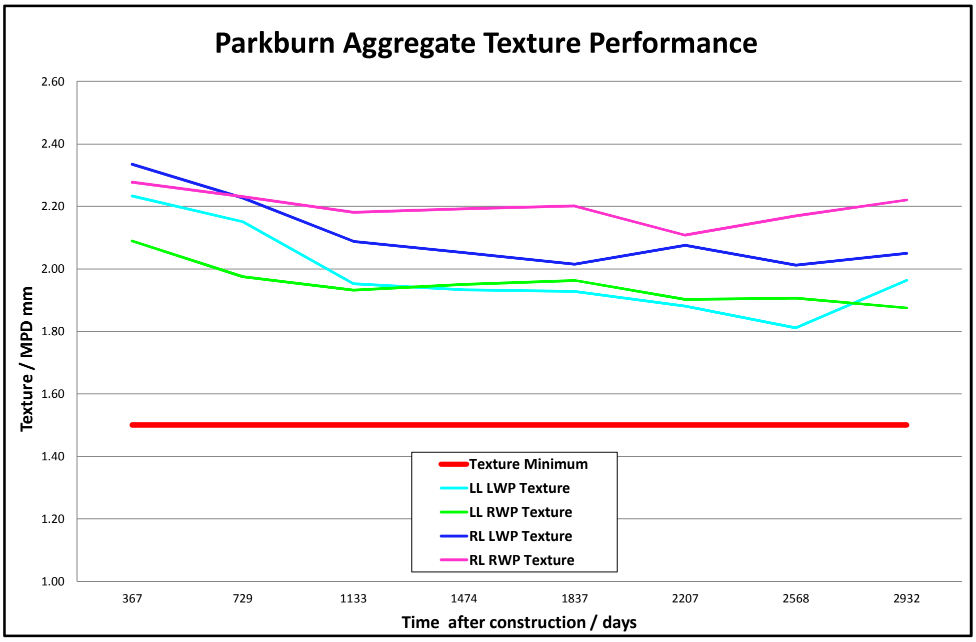


Figure 7. Texture Data for Lindis Pass Site.

The data in Figures 6 and 7 shows that the chipseal is working well but the aggregate has polished in one wheelpath the RL LWP.

7.3 PARKBURN COMPARISON CLIMATE FACTORS

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.

Most of the surfacing treatments where Parkburn aggregate has been used in the comparison are located in Central Otago which has some significant areas with extreme microclimates, vastly different from the majority of the climate found in Coastal Otago. For example, 27% of the curves in the Parkburn analysis are in a high rainfall area close to the Main Divide in the South Island and subjected to annual rainfall more than quadruple the rainfall in Coastal Otago so the microtexture on the surfacings in these high rainfall areas will be refreshed more often and the skid resistance is likely to be higher on these sites.

7.4 AGGREGATE PETROGRAPHIC COMPARISON

Parkburn sealing chip generally complies in all respects with NZTA M6:2011; however it is produced from an alluvial source formed by the Clutha River which has reworked glacial moraine deposits. The sources are many and varied and include various metamorphic grades of schist and gneiss. The chipseals produced using Parkburn chips 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 with low polishing resistance, mid-strength gneissic particles and the less durable schist fragments seems to have excellent polishing resistance properties on the low to medium demand sites.

7.5 POLISHING FACTORS

Polishing factors can be used in two ways to assess aggregate polishing performance;

1. To find a suitable aggregate based on finding an aggregate that has performed well and then using it in similar locations elsewhere.

2. To compare the polishing performance of different aggregates by finding sites with similar polishing factors and comparing their performance.

Figure 8 includes most of the factors that should be considered for both of the above.

The more similar the sites are, the more comparative the analysis and the more likely it is that the results will be an accurate prediction of the polishing performance.

Table 1. Comparing factors and effect on aggregate polishing

Factor	**Compare site with site**	**Measure**	**Effect on comparison**
Texture Existing	No flushing, bleeding, or contaminated	>1.5mm in RAMM	Critical
HCV's	Number of HCV's	Calculated in RAMM	High
Site Category	Same Site Category	Given in RAMM	High
Chip Size	Same chip size/s	ALD in RAMM	High
Treatment Selection	Same treatment – Racked-In, Two Coat, Single Coat, etc	Seal Type in RAMM	High
Chip Shape	Crushed faces on chip	Check source testing	High
Curve Speed	Similar speed ±5 kph	Calculated in RAMM	Medium
Total Curve Radius	Similar radius ±5m	Calculated in RAMM	Medium
Gradient	Similar gradient increasing and decreasing	Given in RAMM	Medium
Climate	Similar Climate	Climate Maps	Medium
Rainfall	Similar rainfall	Climate Maps	Medium

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 State Highway 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. Analysis of aggregate performance so far suggests that most South Island of New Zealand aggregates are not capable of maintaining the required level of skid resistance on surfaces in high demand situations on the South Island State Highway network.

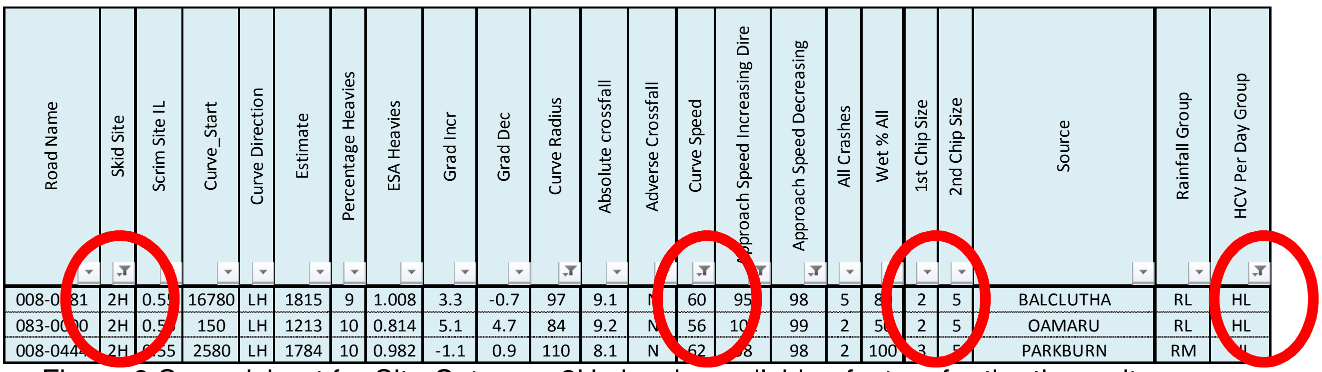
7.6 Methodology for finding similar sites

In the proposed methodology described in this paper, and using the same database and regional networks as Mortimer et al (2012), 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.

7.7 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 19mm 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 8 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
008-0[illegible]81	2H	0.5[illegible]	16780	LH	1815	9	1.008	3.3	-0.7	97	9.1	N	60	95	98	5	8[illegible]	2	5	BALCLUTHA	RL	HL
083-00[illegible]0	2H	0.5[illegible]	150	LH	1213	10	0.814	5.1	4.7	84	9.2	N	56	10[illegible]	99	2	5[illegible]	2	5	OAMARU	RL	HL
008-044[illegible]	2H	[illegible].55	2580	LH	1784	10	0.982	-1.1	0.9	110	8.1	N	62	[illegible]8	98	2	100	3	[illegible]	PARKBURN	RM	[illegible]

Figure 8 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 10. The data shows that none of the aggregates are suitable for surfacing Site Category 2H curves with such extreme polishing stresses. Some maintenance work was carried out on the Balclutha site after the year 3 testing. The graph also shows that all aggregates seem to be polishing at a similar rate.

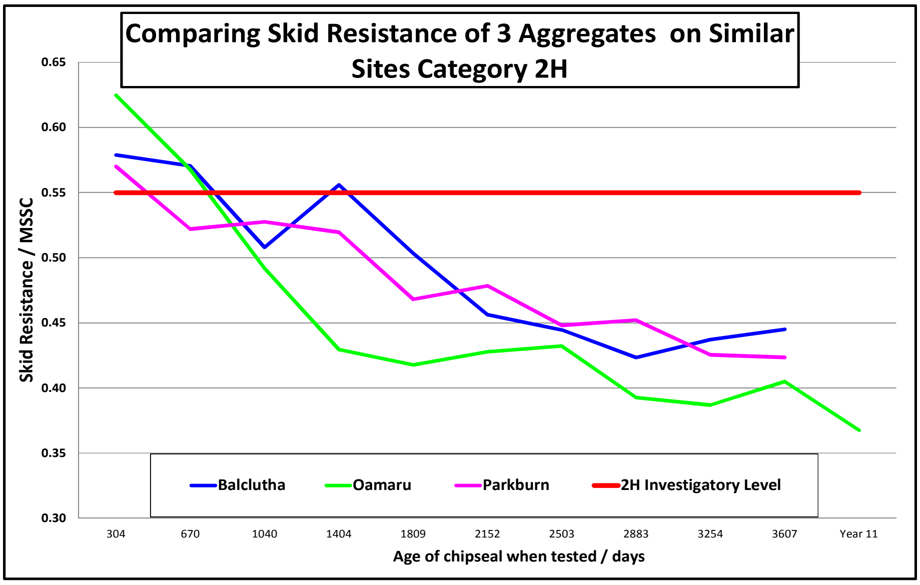


Figure 9 Graph of skid resistance three similar sites with different aggregates

The texture data (Figure 11) shows a slow reduction over time at a similar rate for the three aggregates. It also shows that the texture for all 3 treatments has been > 1.70mm for the ten years of monitoring, suggesting that they had performed well and that the skid resistance measurements were likely to be measurements of the aggregate microtexture and a fair comparison of the polishing performance of the three aggregates.

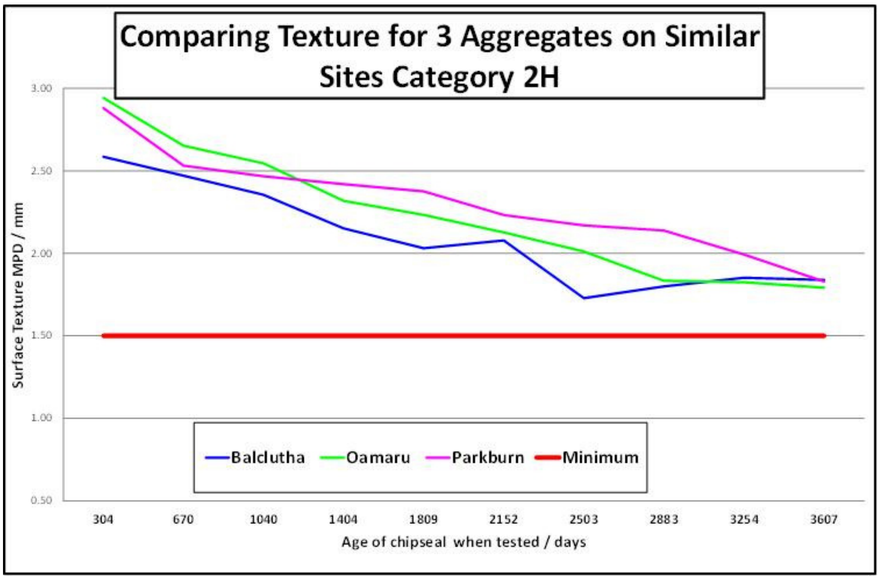


Figure 10 Graph of texture on three similar sites with different aggregates

7.9 Case Study 2

The next trial of the methodology was 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 aggregate and one site with Oamaru aggregate but no sites with Parkburn aggregate. 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 12.

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

The average skid resistance (Figure 13) for two of the three aggregates stay above the IL for 9 years while the Oamaru aggregate falls below the IL in the third year above the Site Category 2M IL. The average surface texture (Figure 14) for all three sites stays above the 1.5mm confirming that the surface treatment was performing okay and that the surface friction results may represent the polishing performance of the aggregates on these sites. Closer investigation shows that the Parkburn aggregate that performed best of the three aggregates was on the least stressed site of the three with the lowest %HCVs. The Oamaru aggregate was the worst performing, polishing after three years however it was subjected to the highest stresses and the highest %HCVs of the three sites.

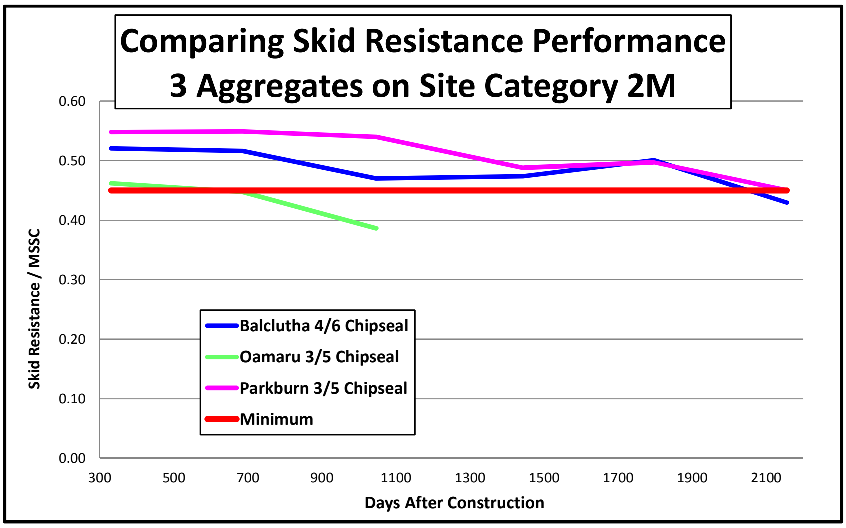


Figure 12. Graph of skid resistance comparison of three similar sites with different aggregates

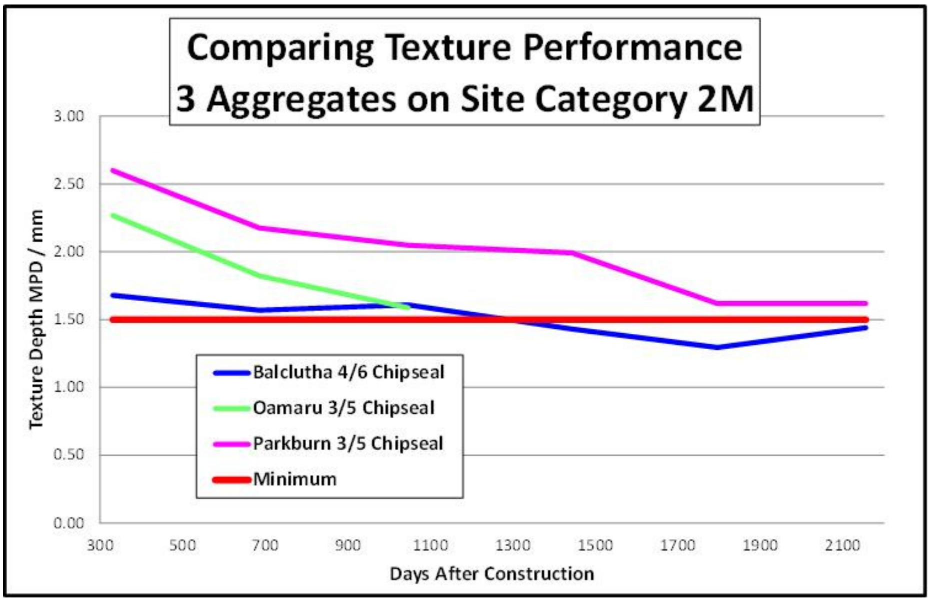


Figure 13. Graph of texture comparison of three similar sites with different aggregates

The 12mm/7mm (Grade 4/6) Balclutha chipseal had low texture - just above 1.5mm for the first three years and below for the next four years. Visual inspection confirms there has been some retexturing treatment carried out on this site during the analysis period.

The graphs of the skid resistance and surface texture of the Parkburn and Balclutha aggregate surfacing performance are relatively flat compared to the Oamaru aggregate graphs. This is consistent with the Oamaru aggregate surface being subjected to higher stresses and traffic than the other aggregates.

8. CONCLUSIONS

1. The concept of assessing aggregate polishing performance described in T/10:2012 is a significant step in the right direction. However the authors believe that the methodology described is too generic, and does not ensure that an aggregate selected for a specific site will provide adequate in-service skid resistance performance.
2. 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 refinement, as proposed in this paper.
3. It is important to ensure that the aggregate polishing performance is analysed 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.
4. Network level comparative analyses lose the detail that is required to assess actual site specific performance and will fail to accurately predict individual site surfacing performance.
5. The site-specific comparison in Case Study 1 shows that all three aggregates performed similarly under similar climate, traffic, and curve stress.
6. Case study 2 shows that the aggregate polishing conditions in the Coastal Otago network are generally too different from those in the Central Otago network to

directly compare aggregate performance from one network with the other for various combinations of factors.

7. 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.
8. No surfacing site is exactly the same as another, and there are a large number of parameters that need to be aligned so that the aggregate polishing performance of an aggregate on one site will be achieved on the new surfacing site.
9. 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.
10. 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.
11. New Zealand aggregates sourced in the South Island do not seem capable of resisting polishing and providing levels of skid resistance above 0.55 for the expected life of the chipseal in high demand situations.
12. Transporting aggregate to resurface complete sites from distant sources when only isolated high demand sections need the more polish-resistant aggregate adds an unnecessary and substantial cost to network maintenance.
13. High demand situations on curves that cause premature failure by polishing can be resolved by improving the geometrics of the curve.
14. Surfacing treatments using small sized aggregate such as 12/7mm two coat seals on high demand sites produce less texture than the larger aggregate chipseals. Many sites analysed had texture close to the 1.5mm level very early in their lives increasing the risk of premature failure by low skid resistance caused by surface contamination rather than polishing.
15. The New Zealand State Highway network includes many short radius bends on relatively low trafficked sections of road which allows traffic wander outside of the lanes so that in some cases the polished surfaces may

9. 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 further 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 on that site.

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.
6. It is recommended that small aggregate two coat seals are not used in rural situations in high demand situations as there is increased risk of this treatment failing prematurely due to surface contamination and loss of texture.

10. GLOSSARY

SCRIM+	Sideways-Force Coefficient Routine Investigation Machine used for testing network skid resistance, the + is added because the machine is set up for New Zealand testing of both wheelpaths at the same time.
PSV	Polished Stone Value test compares the polishing rate of different aggregates under standard polishing conditions.
MPD	Mean Profile Depth is a measure of texture depth measurement output produced by high speed laser texture measurement devices.
Chipseal	New Zealand name for Spray Seals which involves the application of liquid binder followed by an application of sealing chips (aggregate). Includes many variations including numbers of coats, different sized chips.
Sealing Chip Grades	Sealing chip in New Zealand is produced to meet the M/6 Specification NZTA M/6 (2011). The chip sizes are called grades as follows Grade 2 chip (19mm), Grade 3 chip (15mm), Grade 4 chip (12mm), Grade 5 chip (10mm) and grade 6 chip (7mm).
Petrographic	Petrography is a branch of petrology that focuses on detailed descriptions of rocks.
RAMM	Road Asset and Maintenance Management database that is used by Road Controlling Authorities in New Zealand to store data relating to their Road Asset network. The data is made available to Contractors and Consultants to monitor and maintain the network.
ALD	Average least dimension of sealing chip as per NZTA M/6 (2011)
IL	The investigatory level for skid resistance (IL) is a maintenance priority level.
RL LWP	Right Lane Left Wheelpath is the transverse location on the road where the measurements were taken. LL is Left Lane, Mid is between the wheelpaths and RWP is the Right Wheelpath.

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