Skid Resistance Performance of Melter Slag-Based Surface Dressings on Hawkes Bay Rural State Highways

Shaun Perrin
NZ Transport Agency, Hawkes Bay Office

David Cook
NZ Transport Agency, National Office

ABSTRACT

Rural state highways in the Hawkes Bay region of New Zealand present a significant engineering challenge to maintain safe, skid resistant road surfaces. This is a result of tight curvilinear alignments, heavy commercial traffic that travels at comparatively high speed and local surfacing aggregates with a relatively low resistance to polishing. This has resulted in the Hawkes Bay region trialling Glenbrook melter slag (GMS) surfacing aggregate. Following the success of initial surfacings further trials in higher stress areas were undertaken.

This paper investigates the skid resistance trending of GMS surface dressings constructed as either single or two coat seals that were between 4 and 8 years old on the basis of polishing stress and comparison with a previous seal constructed using natural aggregate.

The results of this investigation showed that GMS-based surface dressings provided improved skid resistance performance throughout the life of the road surfacing when compared to natural aggregate, irrespective of whether the polishing stress was low or high.
Keywords: melter slag, in-service performance, polishing stress, skid resistance

1. INTRODUCTION

As part of the NZ Transport Agency's response to the government's 'Road Safety Strategy 2010-2020', which has as its vision a safe road system increasingly free of death and serious injury, the T10 specification for state highway skid resistance management was updated so that the investigatory skid resistance level (IL) of curves with a horizontal curvature of 400m or less was assigned on the basis of estimated personal crash risk, rather than curve radius as was previously done. This was in recognition that loss of control on curves remains the largest cause of crashes on New Zealand rural state highways and that not all small radius curves constitute a safety hazard, nor do all moderate to large radius curves have a low crash risk (Cenek et al, 2011).

The consequence of this change to the T10 specification was that some curves that were previously managed to an IL level of 0.4 in terms of equilibrium skid resistance (ESC) are now managed to an IL of 0.5 ESC if considered moderate risk or 0.55 ESC if considered high risk. These higher IL's have placed an increased focus on identifying aggregate sources that can maintain the skid resistance of curves at or above the IL for the design life of the surfacing.

On the basis of the results of a laboratory based comparative study undertaken at the University of Auckland, involving controlled accelerated polishing tests and an assessment of geological properties from Scanning Electron Microscopy (SEM) photographs (Wilson and Black, 2008), Glenbrook melter slag (GMS) reseals were trialled as an alternative to high (>60) polished stone value (PSV) natural aggregates on two Hawkes Bay rural two lane state highways, 2 and 5. The 69 km long state highway (SH) 5 has been of particular interest because of the challenge it presents for skid resistance management on account of its tight curvilinear alignments and exposure to fast moving heavy commercial traffic.

The trial GMS reseals were either single or two coat surface dressings and commenced during the 2005/2006 construction season. The quantity of GMS reseals has increased significantly from 2009 and presently amounts to 37.7 km, with GMS now specified as the default sealing aggregate for all SH5 reseals and high demand sections of SH2, including bridge decks.

There was considerable interest in determining if on-road skid resistance performance of the GMS reseals matched the laboratory results and the extent of their useful service life. As a consequence, a report was prepared in 2011 that provided trending plots for one SH2 and six SH5 GMS reseal sites (Harrow, 2011). Although the report concluded that the GMS reseals were "generally performing well" and "GMS should continue being used as sealing aggregate" this was predicated on comparatively short seal lives, the longest being only 4 years. This paper builds on the Harrow report with additional information and direct site comparison to provide confirmation that GMS can provide improved skid resistance performance over high PSV aggregates and is economic despite the cost of construction being greater than seals constructed with natural aggregates.

2. OVERVIEW OF NZ MELTER SLAG AGGREGATES

2.1 SOURCE

Solid wastes have always been an inevitable part of iron and steel making. Rather than referring to these solid wastes as “by-products” they are now referred to as “co-products” because around 550,000 tonnes of the 700,000 or so tonnes of solid waste generated annually at New Zealand Steel’s Glenbrook mill have achieved value by being recycled, re-used or sold. The main co-product of the iron and steel making process is a non-metallic residue called slag. More than 300,000 tonnes are created at Glenbrook each year – 250,000 tonnes of iron-making or melter slag and 70,000 tonnes of steel-making slag.

Slag aggregate products are processed and marketed by SteelServe, formed in 1980 as a joint venture between the UK-based Slag Reduction Company and New Zealand Steel. SteelServe inherited stockpiled iron-making slag at Glenbrook totalling some 650,000 tonnes. From this vast total and New Zealand Steel’s 250,000 tonne annual output of melter slag, SteelServe produces more than 300,000 tonnes of aggregate products a year.

The process of creating such products starts by air cooling and solidifying the hot molten slag in excavated pits, followed by water sprays just before dig-out. Once it has cooled, slag is broken up and transferred to a stockpile. It is further reduced in size by standard crushing and screening processes to produce aggregates that meet market needs.

A broad range of standard aggregates is produced for a variety of traditional aggregate uses such as surface dressings, asphalt manufacture, drainage and filter materials, and basecourse and sub-base products.

Steel-making slag or Klöckner Oxygen Blowing Maximillanshuette (KOBM) slag, which is a very different material to melter slag, has been used for many years as a road stabilisation material and more recently as an additive in cement manufacture.

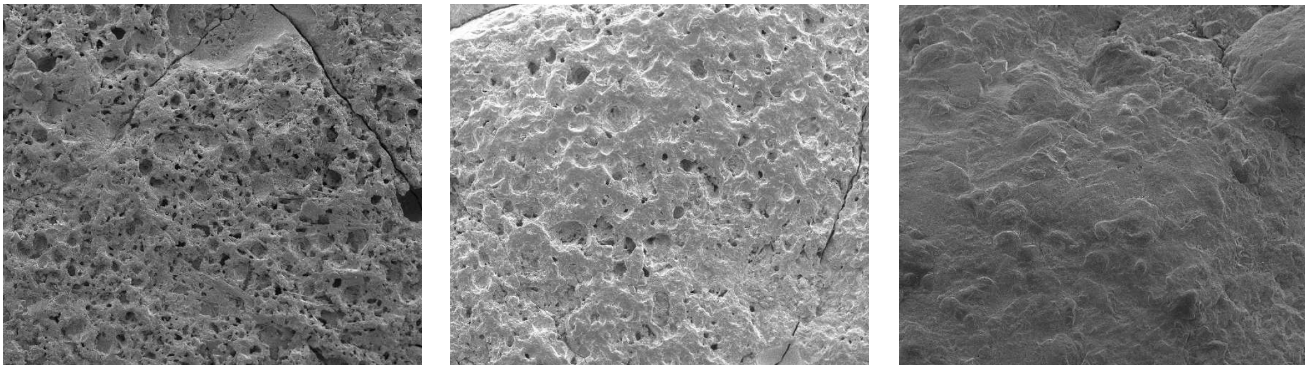
2.2 GEOLOGICAL PROPERTIES OF MELTER SLAG

With reference to Black (2009), New Zealand Steel melter slag is derived from titanomagnetite sands and so is rich in titanium, aluminium, silica and magnesium. The major mineral constituents of the melter slag can be divided into three types:

i. complex titanium oxides, which have a needle-like form
ii. spinels and similar metal oxide, which have a rather equidimensional shape
iii. calcium bearing oxides and silicates.

The interlocking needles of titanium oxide minerals in the melter slag provide strength to the material and a high degree of roughness to the slag surfaces, Aggregates produced from these slags tend to have high PSV values, crushing resistance values of less than 10% fines at 110 kN and are non-expansive.

Figure 1 shows SEM photographs taken from Douglas and Black (2008) of the titanium enriched melter slag in an unpolished and polished state respectively and coarse grained greywacke sandstone in a polished state. The polished state was achieved by subjecting the test samples to University of Auckland’s accelerated polishing machine until an ‘equilibrium level’ of measured skid resistance was reached or for a maximum of 6 hours if the measured skid resistance continued to decrease. The test PSV of the melter slag was 60 whereas for the coarse grained greywacke it was 63.



Melter Slag, unpolished surface ×200 magnification

Melter Slag, polished surface ×200 magnification

Coarse grained greywacke sandstone, polished surface ×200 magnification

Figure 1: SEM photographs of meter slag in unpolished and polished states and coarse grained greywacke in polished state

Comparing the unpolished and polished states of the melter slag sample, the gas vesicles and harsh surface texture are clearly visible in both states, with the only difference being some smoothening of elevated surfaces in the polished sample. Therefore, melter slag is very resistant to polishing action.

In contrast, comparing the polished states of the melter slag and coarse grained greywacke sandstone, it is evident that the surface coarseness is significantly less for the greywacke sandstone on account of coarse grains being plucked away during polishing.

From the perspective of skid resistance, the rougher the surface is at a microscopic scale the higher the level of skid resistance provided. Therefore, on the basis of figure 1, melter slag can be expected to outperform coarse grained greywacke over time.

The difference in the polishing properties of the greywacke and melter slag is attributed to the hardness of the minerals and to the way in which individual components of the rock are held together.

2.3 USE IN SURFACE DRESSING CONSTRUCTION

It has become apparent that single coat surface dressings employing GMS aggregate require an increase in binder application rates of up to 25% higher than when natural aggregates are used, to avoid stripping of aggregate. This need for higher application rates has been attributed to the porosity present in GSM, as can be clearly seen in figure 1. As a result, racked-in and two coat seals are now preferred to single coat seals in order to minimise the occurrence of aggregate loss as they are less sensitive to binder application rate.

Other identified differences from natural aggregates are:

- GMS aggregates are denser so results in more expensive cartage.
- The porous nature of GMS aggregate can reduce visibility of the first application of pavement marking.
- The darker colour of the GMS aggregate provides better road marking contrast.

3. ASSESSMENT METHODOLOGY

In assessing the on-road performance of aggregate sources, statistical modelling is normally employed, as demonstrated in Cenek et al. (2012). This uses linear regression to identify statistically significant relationships between the dependent variable (the measured in-service skid resistance) and the independent variables (road geometry, traffic characteristics and aggregate source). Rather than specific aggregate characteristics, the statistical modelling employs the categorical parameter, aggregate source, as this parameter inherently encompasses all important influencing factors such as chip shape, chip hardness, mineralogical properties and crusher type. However, the regression procedure adopted is not simple as there is a need to satisfactorily account for random errors associated with the skid resistance measurements and top surface layer information extracted from NZ Transport Agency's Road Assessment and Maintenance Management (RAMM) system. As a consequence, to obtain reliable comparative in-service skid resistance performance information on an aggregate source of interest, a minimum of one thousand 10 metre observations amounting to a cumulative seal length of at least 10 km is required covering as wide a range of horizontal curvature as possible and seal ages 2 years or older.

Unfortunately, the cumulative length of GMS seals on SH 2 and SH 5 , which feature in Harrow's 2011 report, amounts to only 2.19 km so a different approach had to be adopted in assessing the long-term skid resistance performance of GMS on these two rural state highways.

Advice received from a consulting statistician, indicated that the time series analysis presented in Harrow (2011), which involved comparing time histories of annual SCRIM survey results for the GMS reseal with a prior reseal constructed from natural aggregate, was appropriate so long as any changes in environmental conditions (i.e. weather, traffic characteristics, policing etc.) were appropriately controlled for. This was achieved simply by selecting a section of SH5 that was in close proximity to one of the GMS reseal sites that had a natural aggregate reseal at about the same time GMS reseal trials had recommenced in the 2005/2006 construction season.

Because two of the original sites investigated by Harrow had to be excluded on account of excessive binder rise and cracking occurring between 2009 and 2011, further reducing the length of available GSM reseal for analysis, the remaining 5 sites were subdivided in terms of being a curve or a straight so the effect of polishing stress could be considered.

For consistency with Cenek et al. (2011), a curve was defined as consisting of at least three sequential 10m segments in the same lane that have a 30m rolling average radius less than the threshold of 500m and the sign of the radius is the same for all three segments. For simplicity, this can be referred to as the curve apex. The start and end of a curve was taken to be when the average radius value over three consecutive 10m readings is greater than 800m. This takes account of the curve transition/spiral and the braking zone leading into a curve.

A straight was defined as when the average radius value over three consecutive 10m readings is greater than 1000m.

The assessment methodology adopted had the advantage that direct skid resistance value comparisons between GMS aggregate and natural aggregate could be made at precisely the same time in the life of a reseal when exposed to near identical polishing stresses. Therefore, this allowed differences between GMS and high PSV natural aggregate in the

rate of change in skid resistance and in absolute value at a particular year in the seal's life to be highlighted.

Unlike Harrow (2011), all the skid resistance value comparisons have had to be made on the basis of SCRIM coefficient (SC), which is the sideway-force coefficient measured by SCRIM corrected for consistency with earlier UK SCRIM machines of the period 1963-1972, load, temperature and travel speed, rather than equilibrium SCRIM coefficient (ESC), which is the SC adjusted for within-year and between-year variations. This is because some of the long-term skid resistance data available for the natural aggregate based reseals went as far back as 1998 and so predated ESC measures of skid resistance, which commenced being entered in RAMM in 2002. In addition use of SC values allowed inclusion of just acquired but not yet ESC processed skid resistance data from the latest 2013/14 survey, providing an additional year for the GMS reseal trending.

To minimise the effect of locational errors between inter-year SCRIM skid resistance surveys, road geometry data in RAMM was used to ensure the same section of road was being analysed throughout the time period of interest. In addition, the left and right wheelpath data was averaged across both lanes to provide yearly site averaged carriageway values of skid resistance for the time-series comparisons as this allowed trends to be more clearly seen.

4. ROAD SURFACE TYPES CONSIDERED

Only single, two coat and racked-in surface dressings were considered as they are the prevalent seal types used on rural New Zealand state highways. A brief description of each of these types of surface dressing follows.

A single coat is a single application of sealing binder followed immediately with a single application of aggregate, which is spread and rolled. It is best in situations where traffic stresses are not great.

A two coat is a surface dressing with two applications of binder and two applications of aggregate applied in the following sequence:

i. An application of sprayed binder, followed immediately by an application of a large size (i.e. grade 2 or 3) aggregate (refer table 1)
ii. A second application of sprayed binder and a second application of smaller aggregate (i.e. grade 4 or 5).

Both coats are applied one after the other with little or no time delay between coats.

A racked-in surface dressing consists of one application of binder and two applications of aggregate applied in the following sequence:

i. A single application of binder is applied, followed by the application of a large sized aggregate which is widely spaced (with 'windows' between the aggregates).
ii. This is followed by a further application of smaller sized aggregate.
iii. The smaller sized aggregates fall into the windows between the large sized aggregates of the first application,and adhere to the layer of binder below.

Typically two coat and racked-in surface dressings are used in high-stress areas.
Sealing aggregate size in New Zealand is specified in grades from grade 2 (coarsest) to grade 5 (finest). The relationship between the grade of sealing aggregate, maximum sieve size and average least dimension (ALD) is summarised in table1 for ready reference.

Table 1: Characteristics of New Zealand Sealing Aggregate

Grade	Mean ALD (mm)	Maximum Sieve Size (mm)
2	10.75	19
3	8.75	16
4	6.75	12
5	5.00	9

5. SITE DESCRIPTIONS

5.1 GMS RESEAL SITES

5.1.1 SH2 RP 707/ 0.00-0.30

This site on SH2 south of Napier is a large radius right hand curve of about 534m radius, starting at 0.06km and ending at 0.21km. The average annual daily traffic (AADT) is 7111 vehicles with 14% heavy commercial vehicles (HCV's). The curve is managed to an investigatory skid resistance level of 0.4 ESC.

The GMS reseal is a grade 3/5 two coat constructed as a second coat seal on the 13th of January 2009. No recorded maintenance has been completed at this site since its construction.

The underlying seal was also a grade 3/5 two coat constructed on the 25th of November 2007 using natural aggregate from an unknown source having a PSV of 60.

Panoramic views of the curve of interest are shown in figure 2.

Left lane Right lane

Figure 2: Approaches to 534m radius curve at SH2 RP 707/0.06-0.21

5.1.2 SH5 RP 190/ 3.76-4.03

This site on SH5 contains a 192m radius left hand curve with relatively low demand approaches. The curve has a calculated 85 percentile speed of 75 km/h with a left lane approach speed of about 90 km/h and a right lane approach speed of about 80 km/h. The average annual daily traffic (AADT) is 2498 with 18% HCV. The curve is managed to an investigatory skid resistance level of 0.45 ESC.

A grade 5 void fill GMS reseal was originally constructed on 21st of January 2006 on this site. However, it began to exhibit binder rise and cracking and so was heavily patched with

extensive bandage crack sealing when resealed on 15th of December 2009 with a grade 2/4 racked-in GMS surface dressing. However, some of the crack sealing repairs are reflecting through and so is likely to be reducing the skid performance of the second GMS reseal.

No maintenance has been completed at this site since the 2009 reseal.

The natural aggregate surface at this site used for comparison purposes was a 3/5 two coat constructed using aggregate sourced from Whitehall quarry with a PSV of 55. It was in place from 6th of March 2002 till 21st January 2006.

For analysis purposes, this site was divided into a curve, starting at 3.78km and ending at 3.87km and a straight from 3.89km to 4.02km. Panoramic views of the curve section are shown in figure 3.

Left lane Right lane

Figure 3: Approaches to 192m radius curve at SH5 RP 190/3.78-3.87

5.1.3 SH5 RP 233/ 4.98-5.73

This site on SH5 is an easy curvilinear alignment. The AADT is 2918 vehicles with 16% HCV's.

The GMS reseal is a grade 3 single coat seal constructed on the 20th of February 2007. A bitumen fog coat was required in 2007 due to the GMS aggregate stripping as the initial bitumen application rate was too low. No maintenance repairs have been completed at this site since the fog coat was applied.

The underlying seal was a grade 5 single coat constructed on the 5th of December 2001 using natural aggregate sourced from Whitehall quarry having a PSV of 60.

For analysis purposes the site was divided into two curves and a straight as follows:

- A straight starting at 5.03km and ending at 5.24km
- A 267m radius left hand curve with relatively low demand approaches, starting at 5.26km and ending at 5.53km. The curve has a calculated 85 percentile speed of 81 km/h with left and right lane approach speeds of 100 km/h. This curve is managed to an investigatory skid resistance level of 0.5 ESC.
- A 338m radius right hand curve with relatively low demand approaches, starting at 5.62km and ending at 5.73km. The curve has a calculated 85 percentile speed of 87 km/h with left and right lane approach speeds of 100 km/h. This curve is managed to an investigatory skid resistance level of 0.4 ESC.

The 0.1 ESC difference in investigatory skid resistance levels between the two curves is to account for the additional crash risk posed by the tighter curve radius (267m c.f. 338m) and larger difference between the approach speed and 85 percentile curve speed (19 km/h c.f. 13 km/h) of the curve at SH5 RP 233/5.26-5.53.

Panoramic views of the two curves are shown in figures 4 and 5.

Left lane Right lane

Figure 4: Approaches to curve at SH5 RP 233/5.26-5.53

Left lane Right lane

Figure 5: Approaches to curve at SH5 RP 233/5.62-5.73

5.1.4 SH5 RP 249/ 3.98-4.48

This site on SH5 is an easy curvilinear alignment. The AADT is 3455 vehicles with 16% HCV's.

The GMS reseal is a grade 3 single coat constructed on the 20th of February 2006. Some scabbing of the reseal followed soon after construction resulting in localised scabbing repairs being carried out using natural aggregate.

The underlying seal was a grade 3/5 two coat constructed on the 1st of June 1997 using natural aggregate sourced from Ngaruroro quarry having an assumed PSV of 55 (refer Cenek et al, 2012).
For analysis purposes, this site was divided into a left hand curve with a radius of 460m, starting at 4.29km and ending at 4.39km and a straight from 3.99km to 4.27km. Panoramic views of the curve section are shown in figure 6.

Left lane | Right lane

Figure 6: Approaches to curve at SH5 RP 249/4.29-4.39

5.1.5 SH5 RP 249/ 12.10-12.36

This site on SH5 contains a tight right hand curve near its middle that has relatively low demand approaches. The curve has a calculated 85 percentile speed of 79 km/h with left and right lane approach speeds of about 100km/h. The AADT is 3651 with 18% HCV. The curve is managed to an investigatory skid resistance level of 0.5 ESC.

The GMS reseal is a grade 3/5 racked-in surface dressing constructed on the 20th of February 2006. No maintenance has been completed at this site since construction.

The underlying seal was a grade 3/5 two coat constructed on the 31st of March 2004 using natural aggregate from an unknown source having a PSV of 60.

For analysis purposes, this site was divided into a right hand curve with a radius of 212m, starting at 12.11km and ending at 12.25km and a straight from 12.28km to 12.36km. Panoramic views of the curve section are shown in figure 7.

Left lane | Right lane

Figure 7: Approaches to curve at SH5 RP 249/12.11-12.25

5.2 CONTROL SITE

A control site was selected, located on SH5 at RP249. The AADT is 3359 vehicles with 16% HCV's.

It comprises a 271m radius left hand curve with relatively low demand approaches, starting at 3.21km and ending at 3.38km. This curve has a calculated 85 percentile speed of 87 km/h with an approach speed of 91 km/h for the left lane and 100 km/h for the right lane. It is managed to an investigatory skid resistance level of 0.5 ESC.

The sealing history of the curve is as follows:

- 17/1/1996 to18/2/2004 (8.1 years), grade 3 single coat using natural aggregate sourced from Ngaruroro quarry, PSV unknown.
- 18/2/2004 to 1/2/2008 (4.8 years), grade 5 single coat using natural aggregate sourced from Ngaruroro quarry having a PSV of 56.
- 1/2/2008 to present day, grade 3 single coat using natural aggregate sourced from Linton quarry having a PSV of 61. The age of this seal at the time of the 2013/14 SCRIM survey was 5 years.

Therefore, the sealing history at this site conforms to accepted industry practice of alternating between single coat seals with large and small aggregates so as to avoid seal instability
.
This site was of interest for the following reasons:

- It spans all of the years used in the trending comparisons of the GMS seals with natural aggregates enabling any anomalies in the trending due to measurement issues/traffic to be accounted for.
- There was a change to an aggregate with much better polishing resistance so it will be interesting to compare trending over the period 17/1/1996 to 18/2/2004 (grade 3 Ngaruroro aggregate, PSV = 56) to that over the period 1/12/2008 to 16/11/2013 (grade 3 Linton aggregate, PSV = 61).
- This curve is very similar to the one at SH5, RP233/5.26km-5.53km allowing the relative performance of GMS to a PSV 61 natural aggregate when applied to a moderately tight (~270m radius) to be assessed.

Panoramic views of the control curve section are shown in figure 8.

Left lane Right lane

Figure 8: Approaches to control curve at SH5 RP 249/3.21-3.38

6. DATA ANALYSIS

Opus previously investigated the benefits of the use of GMS aggregates at seven sites in 2011 (Harrow, 2011). Five of these sites have been selected for further analysis using latest available (2013-2014) SCRIM survey data. These sites have been selected because they each have a consistent series of SCRIM data for both the current GMS reseals and the previous natural aggregate reseals at the same sites. Up to 9 years of data is available for the GMS reseals.

The five sites that were selected for reanalysis, and the number of consecutive years of SCRIM measurements available for the natural aggregate and GMS reseals are as summarised in table 2.

Table 2: Years of Data Used in Trending Analysis

Melter Slag Reseal Site	Natural Aggregate Years of data	Melter Slag Years of data
SH2 RP 707/0.00–0.30	2 (2008 - 2009)	5 (2010 - 2014)
SH5 RP 190/3.76-4.03	4 (2003 - 2006)	4 (2011 - 2014)
SH5 RP 233/4.98-5.73	6 (2002 - 2007)	7 (2008 - 2014)
SH5 RP 249/3.98-4.48	9 (1998 - 2006)	8 (2007 - 2014)
SH5 RP 249/12.1-12.36	2 (2005 - 2006)	8 (2007 - 2014)

Natural aggregate data for the control site SH5 RP249/3.21-3.38 has also been included in the analysis.

Both the SCRIM Coefficient (SC) data and the Equilibrium SCRIM Coefficient (ESC) data have been examined for this analysis. We have decided to focus on the SC data results. One reason for this is that the ESC data was not available for surveys before 2002 and for the 2014 season at the time of writing. Any differences between conclusions resulting from examination of SC or ESC data are likely to be minimal, although the ESC data shows somewhat better correlation than the SC data.

The data has been presented so that, in all cases, the first SCRIM measurements performed after the seal was laid are labelled as Year 1, and so on.

We have selected an 8- year time period as a reasonable period for which to determine the reduction in skid resistance with the age of the seal, i.e. the difference between the SCRIM data at Year 1 and at Year 8.

Where sufficient measurement data is available, the data for each site has been split into the data where the road curves, and the data where the road is straight. This has allowed a separate analysis to be done for curved lengths of road and for straight lengths of road, as well as for all data combined.

Typically the SCRIM measurements have been averaged over a 100 m to 200 m long length of road to calculate the data points used in the analysis in this paper. The carriageway average SCRIM measurements have been used; these are the combined average of the left and right wheelpaths in both the left and right lanes.

The data has provided ten plots of comparisons between natural aggregate and GMS. Figures 9 and 10 show examples of plots for a straight section and a curved section. The T10 investigatory level for the section of road is also indicated on the plots. The site presented as the example is SH5 RP 233/4.98-5.73.

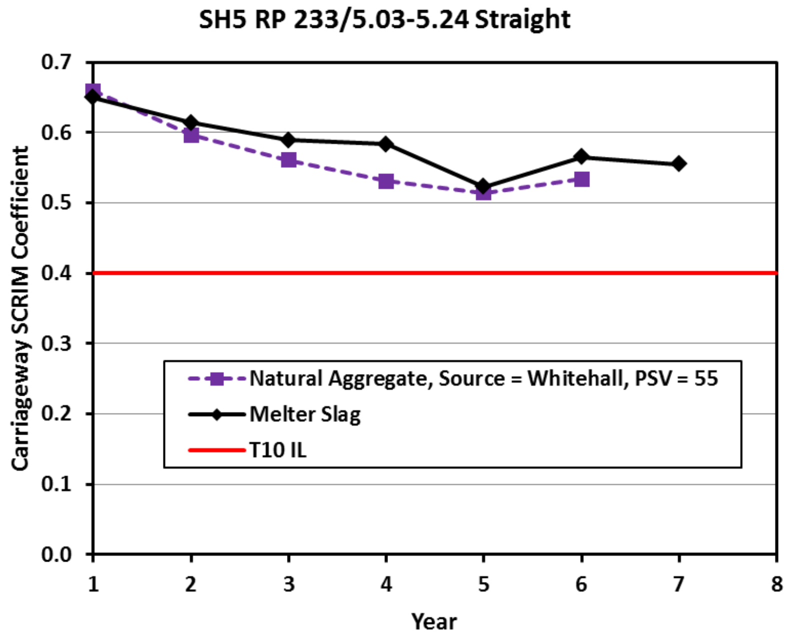


Figure 9: Example of measured decrease in SCRIM Coefficient over a period of years for a straight section of road

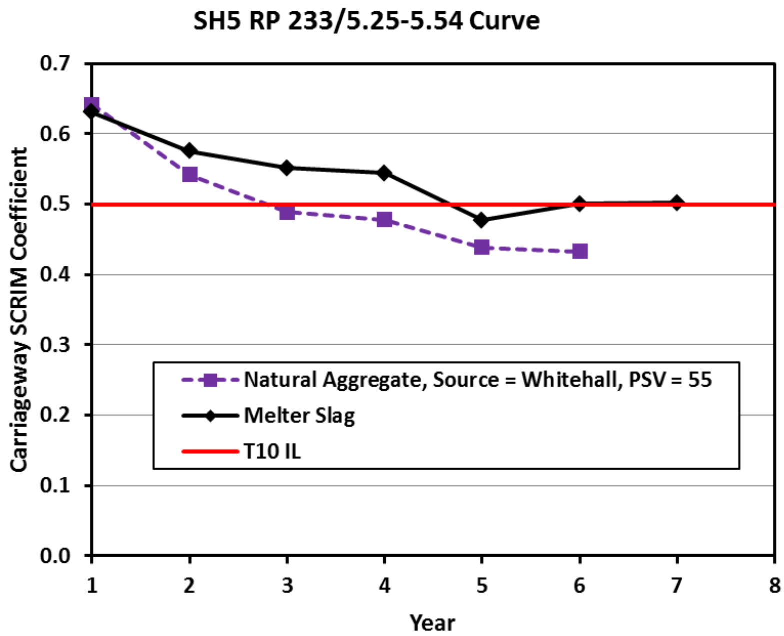


Figure 10: Example of measured decrease in SCRIM Coefficient over a period of years for the adjacent curved section of road

Corresponding plots to those shown in figures 8 and 9 for all ten comparisons are provided in the appendix to this paper.

From examination of the data for the various sites, some general comments are as follows:

1. The GMS SC is consistently higher than natural aggregate SC at every site.
2. There is a clear overall trend of SC reducing with age.
3. The typical initial values of SC are around 0.63 for GMS and 0.56 for natural aggregate.
4. The typical average values of SC are around 0.05 higher for GMS than for natural aggregate over the life of the reseal.

Figure 11 shows a plot of all the data combined for the GMS and natural aggregate reseals. Natural aggregate data from the control site SH5 RP 239/3.21–3.39 has also been included in the plot. The control site SH5 RP 239/3.21–3.39 has been included in the analysis because it includes a record of SCRIM measurements for reseals with natural aggregates from two different quarries (Ngaruroro and Linton).

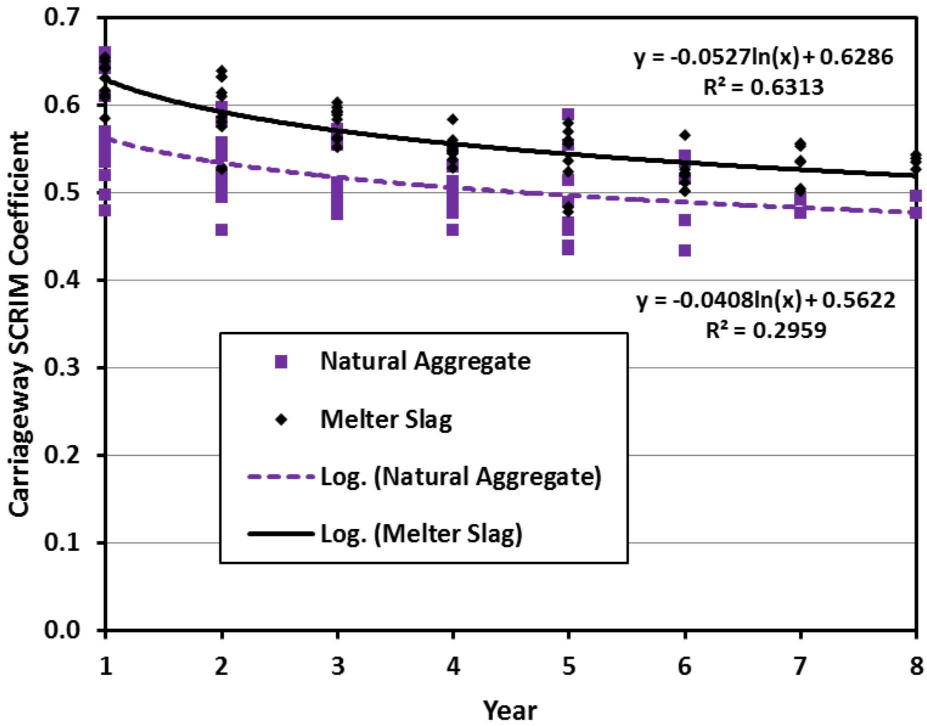


Figure 11. Plot of the SCRIM SC data, for all the test sections combined, for the natural aggregate and melter slag reseals

Figures 12 and 13 show the data separated into curves and straights respectively. Only the SH5 data with adjacent curved and straight sections has been included in this comparison.

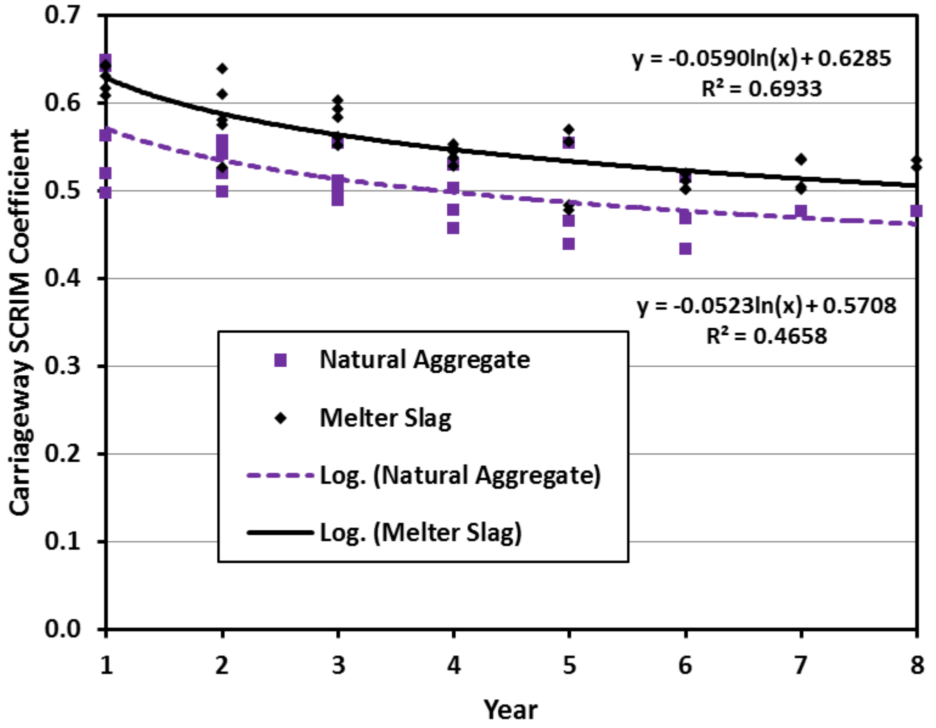


Figure 12: Plot of the SCRIM SC data, for all the test sections combined, for the natural aggregate and melter slag reseals - curves only

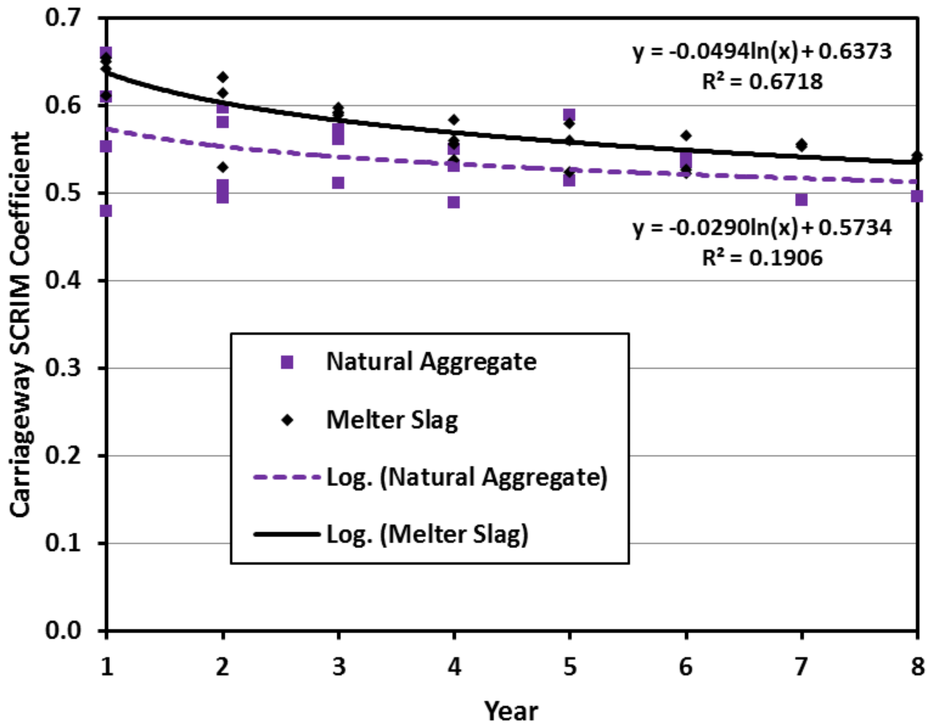


Figure 13: Plot of the SCRIM SC data, for all the test sections combined, for the natural aggregate and melter slag reseals - straight sections only

Some additional observations from figures 10 to 12 are as follows:

1. The best correlation (using just the basic trend line fit options available in Excel) is a log fit of the type: SC = -0.053*ln(Year Number) + 0.629 where 0.629 is the best fit SC value at year 1.
2. The correlation for the natural aggregates is much worse than for the GMS data. The best fit R^2 for all data combined is 0.63 for GMS and 0.30 for natural aggregate. Typically the GMS data show a steady decrease in SC over a period of years, while the natural aggregate data are less consistent. Possible reasons for this substantial difference include:
   - The natural aggregate data is typically older than the GMS data. The measurement equipment and the quality of the data have been improved over the years.
   - The natural aggregate data is typically available for a fewer number of years.
   - Some patch repairs to the natural aggregate reseals may have occurred.
3. There is a clear indication that the reduction of SC with age is greater on corners than on straights.
4. The reduction in SC over an 8 year period is about 0.08 on straights, and about 0.11 on curves.
5. The T10 IL is 0.50 at two of the corners in the selected sites. The typical SC on curves with GMS remains above 0.50 during the whole 8 year period. The equivalent typical SC on curves with natural aggregate falls below 0.50 at Year 4.
6. The correlation for curves is higher than the correlation for straights. This is simply because the reduction of SC with age is greater on corners than on straights.

The relationship between the reduction in SC and corner radius of curvature is unclear. We would expect that there is a relationship, but we probably have insufficient data to show this relationship with confidence. The data hints that the reduction in SC is greatest for a corner radius of around 300m, and reduces for both larger and small radiuses. A possible explanation for this is that drivers are more likely to misread the safe speed for negotiating a moderate curve than tight or gentle curves resulting in higher cornering stresses.

7. CONCLUSIONS

The in-service skid resistance performance of selected Glenbrook melter slag reseal sites located on two rural Hawkes Bay state highways has been trended over periods of up to eight years and also compared with previous natural aggregate reseals at the same sites. This showed that for average annual traffic (AADT) of up to 3500 vehicles with 16% being heavy commercial vehicles, Glenbrook melter slag based single and two coat surface dressings provided improved skid resistance throughout the life of the road surfacing when compared to natural aggregates having a polishing stone value (PSV) in the range 55 to 60, irrespective of whether the polishing stress was low or high.

These results were consistent with the findings of University of Auckland's two stage accelerated polishing laboratory test method, which uses large surface samples and loaded rotating pneumatic castor wheels for polishing. This suggests that this newly developed test method may better reflect in-field polishing than the polishing stone value test.

Another important finding was that Glenbrook melter slag reseals were providing carriageway SCRIM Coefficient values of around 0.5 SC on curves at age 8 years whereas

for local natural aggregates the age reduces to 4 years. Therefore, long useful lives can be expected from Glenbrook melter slag aggregates making their use on rural state highways economic.

On the basis of this limited investigation, Glenbrook melter slag provides on-road skid resistance performance that is equivalent if not better than that provided by high PSV aggregates, such as supplied by Linton quarry. Therefore, because production of Glenbrook melter slag aggregates is limited to 250,000 tonnes per annum, its use on Hawkes Bay rural state highways should be carefully managed for maximum benefit.

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9. ACKNOWLEDGEMENTS

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They also would like to recognise the role of Gordon Hart (Principal Asset Manager, NZ Transport Agency) and Bill Bourke (Planning and Technical Adviser, Aggregate and Quarry Association of NZ) in pioneering the use of GMS for improved skid resistance management of Hawkes Bay state highways.

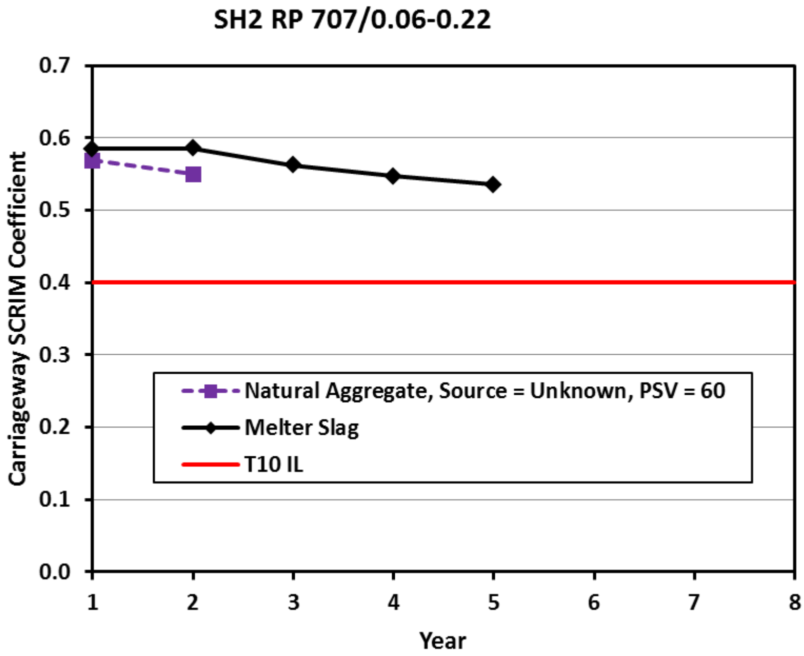
BIOGRAPHIES

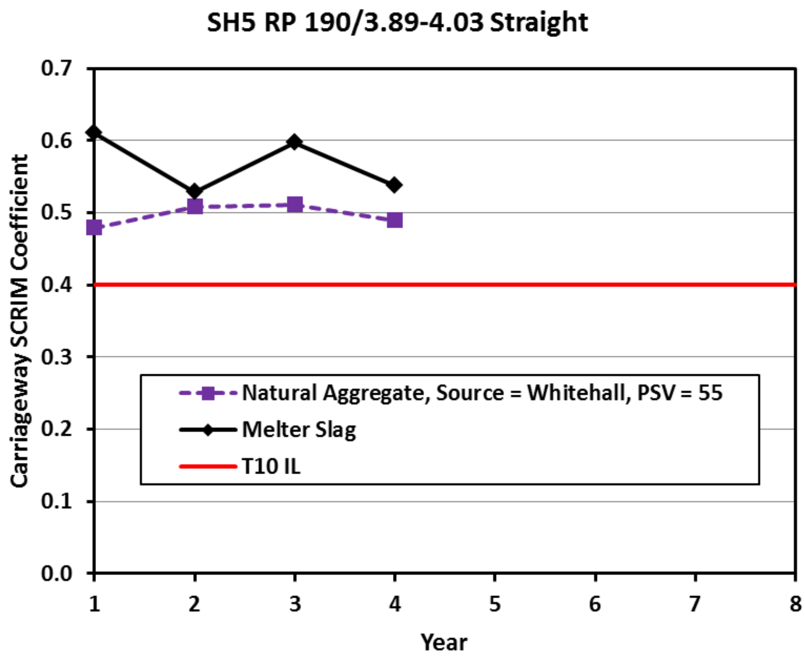
SHAUN PERRIN, MAINTENANCE CONTRACT MANAGER (CONTACT AUTHOR)
Shaun Perrin is employed as a Maintenance Contract Manager for NZ Transport Agency's Hawkes Bay Region. Shaun's background over the last 14 years has been in Operational and Asset Management in different locations throughout New Zealand. He is a member of the NZ Transport Agency's Skid Technical Advisory Group (STAG) for the Central Region and is involved with the implementation and monitoring of NZ Transport Agency's T10 Specification for state highway skid resistance management.
Phone: +64 6 974 5530
e-mail address: shaun.perrin@nzta.govt.nz
Company name: NZ Transport Agency
Address: New Zealand Transport Agency, Hawkes Bay Office, 215 Hastings Street, P.O.Box 740, Napier 4140

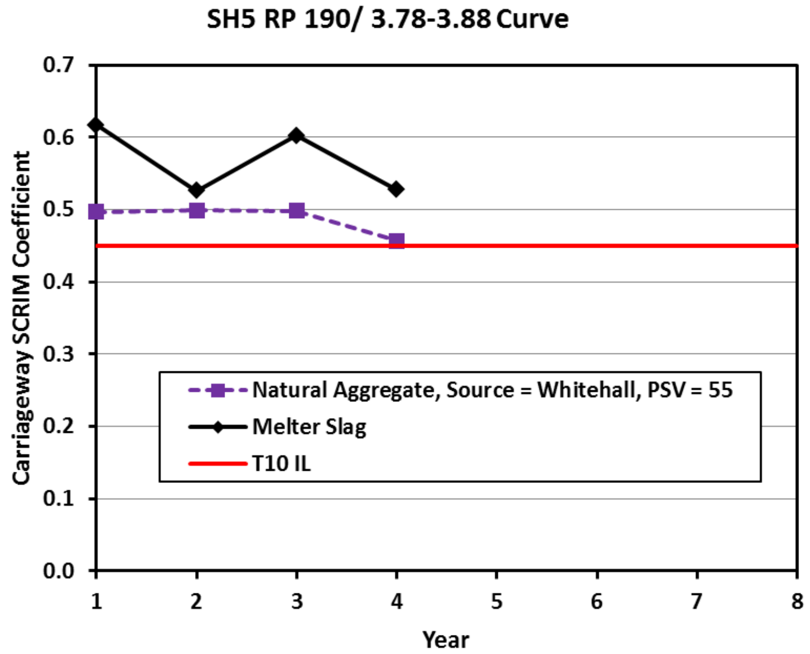
DAVID COOK, SENIOR SURFACINGS ENGINEER
David holds the position of Senior Surfacings Engineer working in the national office of the NZ Transport Agency. He has over 40 years' experience in a wide range of roading issues from construction supervision, major project development and roading maintenance and construction. He has been involved in a variety of roles relating to the development of the state highway skid resistance policy. He managed the initial High Speed Data Collection contract that included skid resistance. Recently he retired as chairman of STAG (Skid Technical Advisory Group), the group responsible for overview and management of the state highway skid resistance policy, following a period of 8 years as chairman. He currently works for the NZ Transport Agency on skid resistance, surfacings and associated safety matters.
Phone: +64 4 894 6298
e-mail address: david.cook@nzta.govt.nz
Company name: NZ Transport Agency
Address: New Zealand Transport Agency, New Zealand National Office, Victoria Arcade, 50 Victoria Street, Private Bag 6995, Wellington 6141

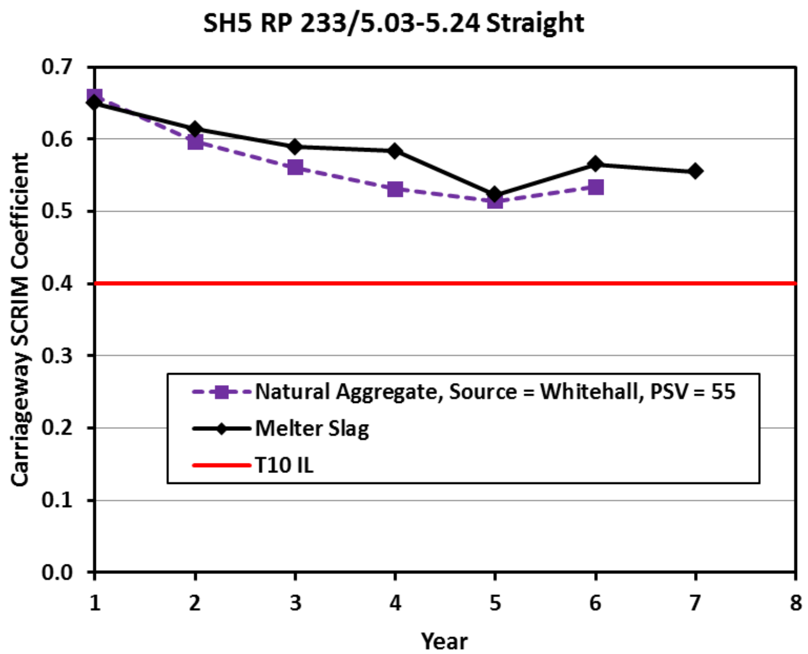
APPENDIX: SKID RESISTANCE TRENDING PLOTS FOR ALL INVESTIGATED SITES

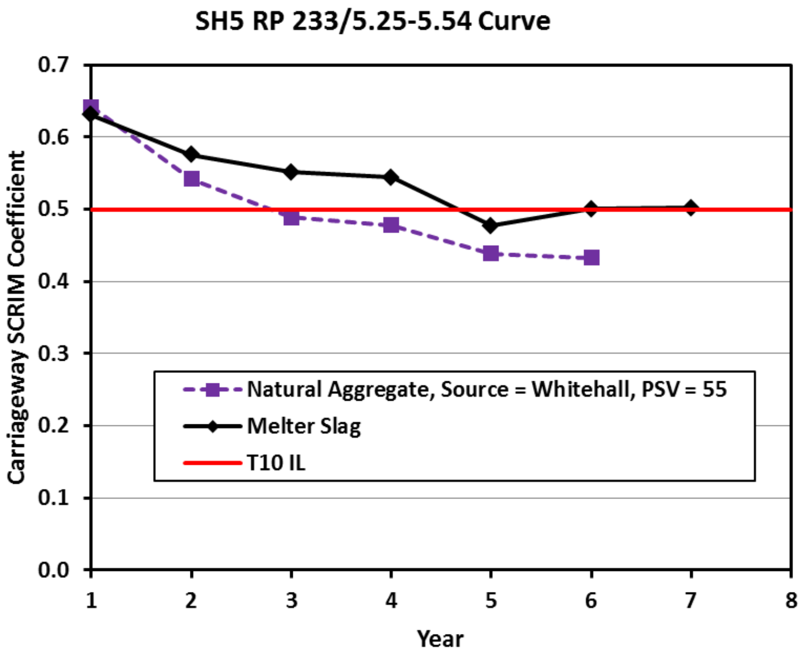
The full set of ten plots of comparisons between natural aggregate and melter slag is presented below, and also the plot for the additional natural aggregate site SH5 RP 239/3.21–3.39.

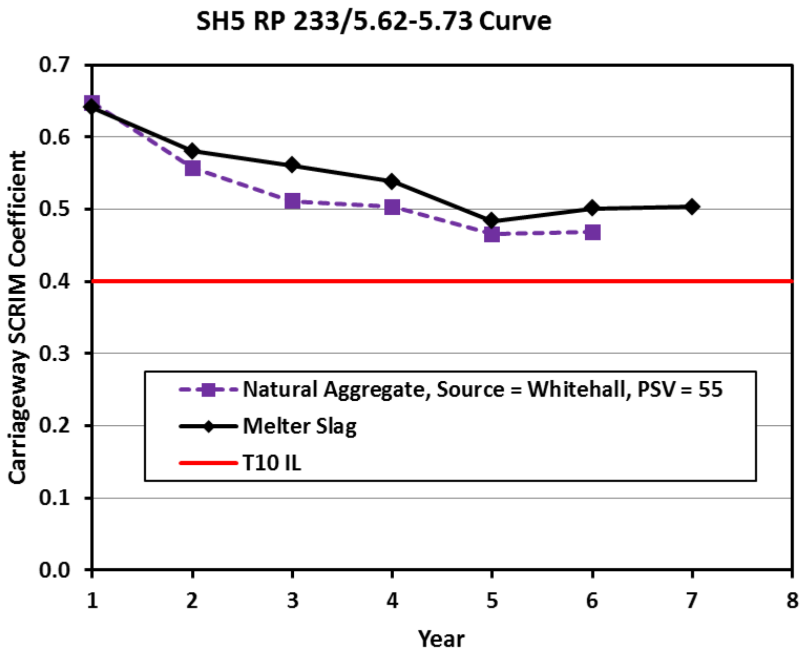


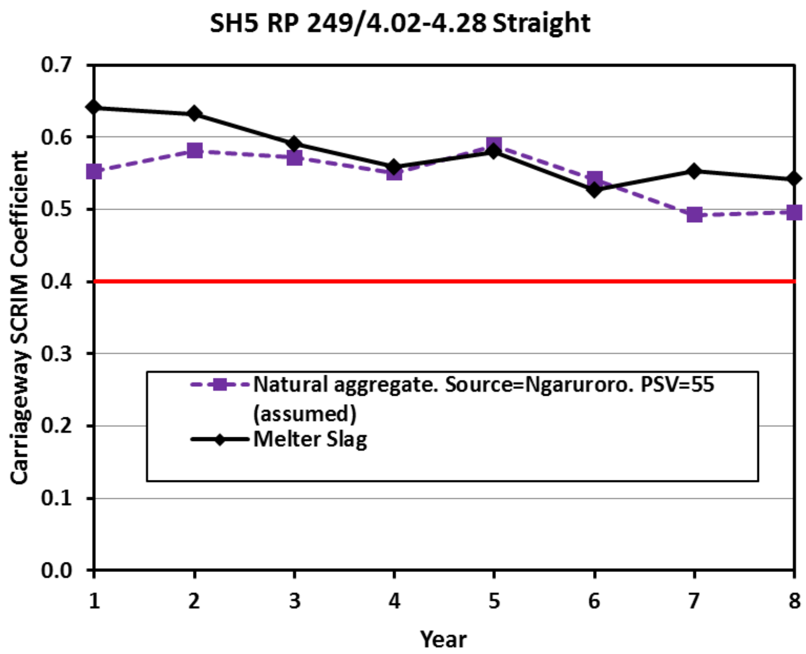


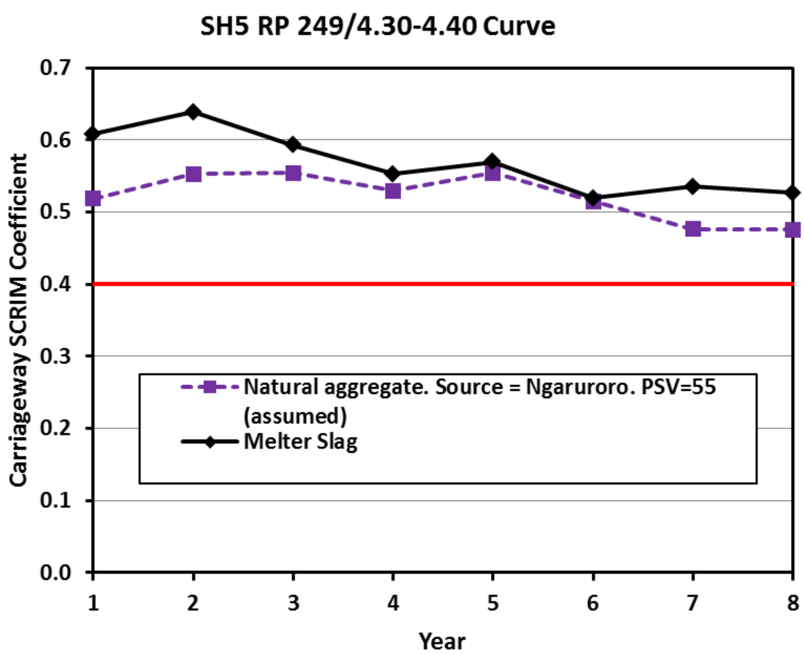

SH5 RP 190/ 3.78-3.88 Curve
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Whitehall, PSV = 55
Melter Slag
T10 IL

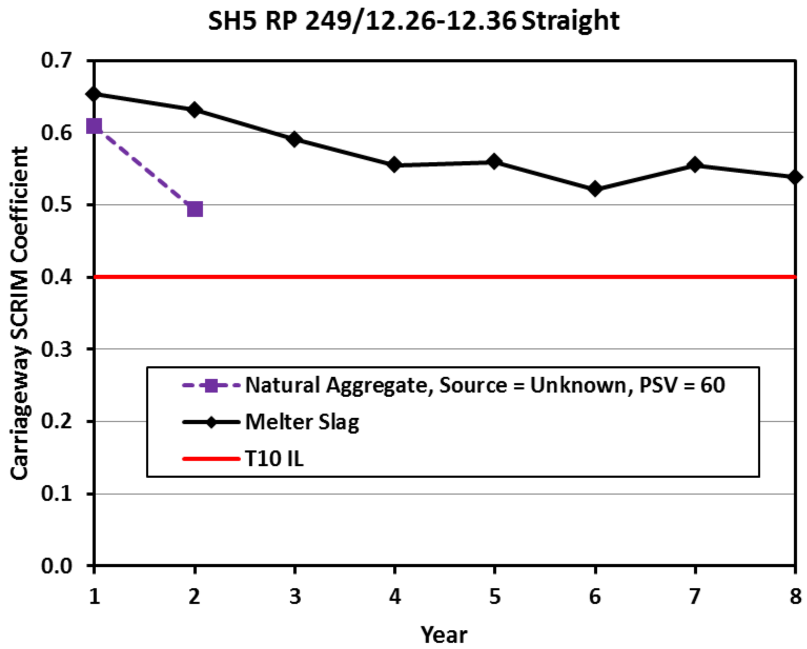

SH5 RP 233/5.03-5.24 Straight
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Whitehall, PSV = 55
Melter Slag
T10 IL

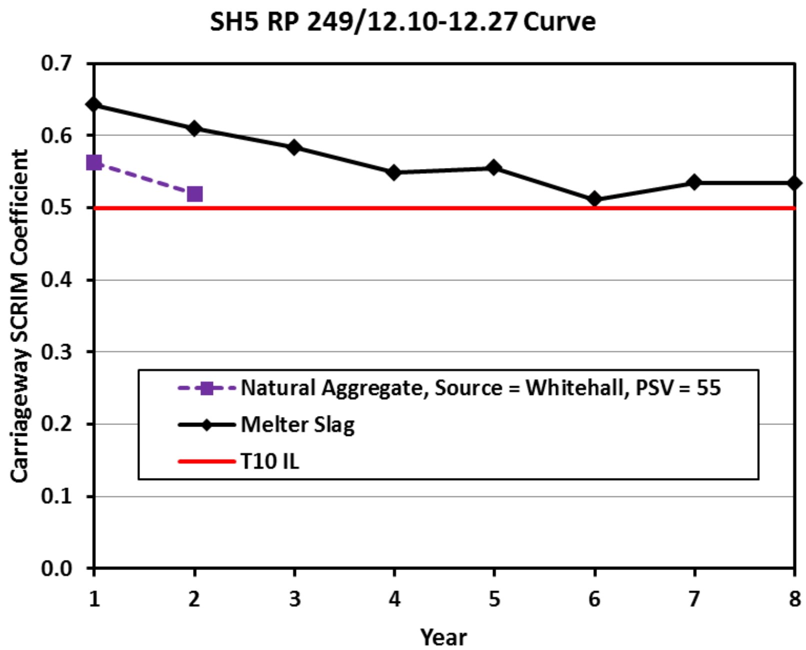

SH5 RP 233/5.25-5.54 Curve
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Whitehall, PSV = 55
Melter Slag
T10 IL

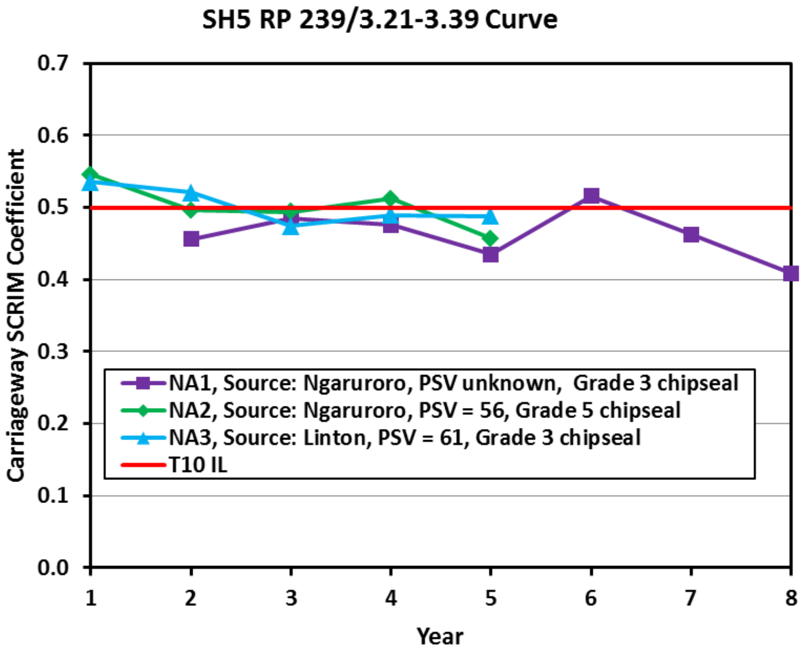

SH5 RP 233/5.62-5.73 Curve
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Whitehall, PSV = 55
Melter Slag
T10 IL


SH5 RP 249/4.02-4.28 Straight
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural aggregate. Source=Ngaruroro. PSV=55 (assumed)
Melter Slag


SH5 RP 249/4.30-4.40 Curve
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural aggregate. Source = Ngaruroro. PSV=55 (assumed)
Melter Slag


SH5 RP 249/12.26-12.36 Straight
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Unknown, PSV = 60
Melter Slag
T10 IL


SH5 RP 249/12.10-12.27 Curve
Carriageway SCRIM Coefficient
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
Year
Natural Aggregate, Source = Whitehall, PSV = 55
Melter Slag
T10 IL


SH5 RP 239/3.21-3.39 Curve
Carriageway SCRIM Coefficient
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1
2
3
4
5
6
7
8
Year
NA1, Source: Ngaruroro, PSV unknown, Grade 3 chipseal
NA2, Source: Ngaruroro, PSV = 56, Grade 5 chipseal
NA3, Source: Linton, PSV = 61, Grade 3 chipseal
T10 IL

Author Biography

David Cook

David holds the position of Senior Surfacing Engineer working in National Office of NZTA. He has over 40 years' experience in a wide range of roading issues from construction supervision, major project development and roading maintenance and construction. He has been involved in a variety of roles relating to the development of the state highway skid resistance policy. He managed the initial High Speed Data Collection contract that included skid resistance. Recently he retired as chairman of STAG (Skid Technical Advisory Group), the group responsible for overview and management of the state highway skid resistance policy, following a period of 8 years as chairman. He currently works for New Zealand Transport agency on skid resistance, surfacings and associated safety areas.