Comparison of Skid Resistance Performance between Greywackes and Melter Slag Aggregates in New Zealand

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ABSTRACT

Research has clearly shown that as the skid resistance of a road surface decrease, the road based transport crash rate increases. However, recent research (Wilson, 2006) has demonstrated that many natural aggregates (with supposedly high quality properties) do not perform well or predictably over an economic asset life in areas of high demand for friction. These areas require better and less variable (in terms of long term performance) skid resistant aggregates.

This paper discusses and compares the skid resistance performance of three natural greywacke aggregates and an artificial melter slag aggregate used in New Zealand as road surfacing chip. The comparison includes surface friction test results of the accelerated polishing of laboratory prepared samples and the coefficient of friction as measured by the Dynamic Friction Tester. Furthermore the paper shows what occurs to the microtexture of the aggregate surface by the use of Scanning Electron Microscope (SEM) photographs and how the performance in terms of ‘polishing’ and measured skid resistance relates to the aggregate mineralogy, grain size and, in the case of greywackes, to their degree of lithification and diagenesis.

The paper concludes that the PSV test cannot be reliably used as a predictor of an aggregates performance. However, the newly developed accelerated polishing method and subsequent surface friction testing developed at the University of Auckland, when combined with an understanding of the aggregates microscopic properties and the geological forming processes of the aggregate, can explain long term skid resistance performance.

1. INTRODUCTION

Research has clearly shown that as the skid resistance of a road surface decrease, the road based transport crash rate increases. Studies have also demonstrated the significant safety benefits of a targeted approach of improving skid resistance in high risk areas where frequent braking takes place rather than attempting to improve skid resistance to high levels over the whole network (Austroads, 2005). In recognising the importance of providing safe pavement surfacing for travel during wet weather, most highway controlling authorities in developed countries have skid resistance standards.

However, recent research has demonstrated that there is significant variation in field performance amongst natural aggregates, where supposedly high quality surfacing aggregates (as measured by the Polished Stone Value (PSV) test) have not performed well or predictably over an economic asset life in areas of high demand for friction. This paper compares the skid resistance performance after accelerated polishing of three natural greywacke aggregates and an artificial melter slag aggregate (an iron making by-product of a steel mill) from New Zealand.

1.1 BACKGROUND

The resistance to skidding of a road surface is one of the fundamental requirements that highway engineers must consider in pavement and road surfacing design to provide a safe travelled surface. Whether the surfacing is the wearing course of an asphalt mix or a chip sealed surfacing, the skid resistance is largely governed by the properties of the aggregate.

The resistance to sliding (i.e. a measured coefficient of friction) available at any particular time, either to the road user or as tested by a friction tester depends upon many variables. It is also not constant or easily predictable over time. The variables that can affect the measured level of skid resistance and their inter-relationships are many and complex. They can be grouped under four main categories:

- *Surface aggregate factors,* (e.g. geological properties of the aggregate, surface microtexture and macrotexture, chip size and shape and type of surfacing);
- *Load factors,* (e.g. surface age, traffic intensity, composition and flow conditions, and road geometry);
- *Environmental factors,* (e.g water film thickness, surface contamination, temperature, seasonal and short-term rainfall effects); and
- *Vehicle factors,* (e.g. vehicle speed, angle of tyres, wheel slip ratio, tyre characteristics, tread depth and patterns).

Of these four categories only the first category (surface aggregate properties) and the surface age can be controlled by the Highway engineer. The other categories are mostly outside the control of the engineer and are also difficult to predict in terms of their effects. Furthermore, recent research (Cenek et al. 2003 and Wilson, 2006) has demonstrated that many natural aggregates (even with supposedly high quality properties as measured by the Polished Stone Value) do not perform well or predictably over an economic asset life in areas of high demand for friction in the field. It is therefore an unenviable task for the highway engineer who must balance the prediction of long-term skid resistance performance of surface aggregates against the economic extraction, process and haulage costs of using natural aggregates.

This paper compares the performance of three natural greywacke aggregates with an artificial melter slag aggregate used in New Zealand (NZ) as road surface dressing. The comparison includes surface friction test results of prepared samples that have undergone accelerated polishing using a newly developed laboratory test method at the University of Auckland. The paper also shows the effect of accelerated polishing at the microscopic level by the use of Scanning Electron Microscope (SEM) photographs by the comparison of 'before' and 'after' aggregate photographs.

2. RESEARCH METHODOLOGY

2.1 OVERVIEW OF THE PSV TEST

Wilson (2006) compared in-field skid resistance performance and the repeated traffic loads with the published Transit NZ PSV (Transit NZ, 2004) test results of various surfacing aggregates from the northern regions of New Zealand and demonstrated two important points:

- A higher published PSV aggregate did not necessarily lead to a high initial skid resistance value as measured by the GripTester skid testing device;
- The published PSV of the aggregate also did not necessarily reflect the level of 'polished' skid resistance as measured in the field.

These results corroborate the research by Cenek et al. (2003) undertaken in New Zealand that showed there is very little relationship between the PSV of the aggregate and the in-field skid resistance as measured by SCRIM network surveys (even on straight and level sections of road).

Thus it was postured that, in itself, the PSV can not be reliably used as a predictor of the initial, nor the 'polished' state of skid resistance of the aggregate, without taking other factors into consideration. One of these factors is the heterogeneity of natural aggregates and especially greywacke sandstone. Whilst some variation is to be expected for aggregates derived from quarries in sedimentary rocks, aggregates sourced from a single lava flow should show only very minor variations in PSV. Other important factors relate to the methodology used (e.g. the PSV test is an end of test result after a specified time period (6hours of polishing)) and no indication is given whether the result has reached an equilibrium level or would polish further under continued polishing.

Road asset managers require reliable data to predict how aggregates would perform over time and under specific traffic, geometric and braking stresses for good decision making. As a result, a new test method was developed to investigate the long-term surface friction performance of the aggregates and to compare the results against the established PSV test method to see whether it could better reflect in-field measured skid resistance.

2.2 NEW ACCELERATED POLISHING METHOD

A controlled laboratory experiment was designed and constructed at the University of Auckland (UoA) (Wilson, 2006) to simulate the in-field skid resistance performance of surfacing aggregates. The laboratory experiment required the control and simulation of the effects of the following variables:

- Road pavement surfacings utilising natural rock aggregates commonly used in practice;
- Traffic action simulating heavy commercial vehicle polishing effects;
- Rainfall / washing cycles;

- Effects of the addition of contaminants; and
- Stationary skid tester able to be used in the laboratory on prepared specimens.

The experiment required laboratory testing equipment and surfacing samples to be constructed that were compatible with each other. A stationary skid tester (The Dynamic Friction Tester - DFTester; (refer to Figures. 1(a) and 1(b)), was the critical factor that determined most of the other experiment variables. The Dynamic Friction Tester participated in the PIARC World Road Association friction testing harmonisation experiment of 1992 and proved, under controlled testing conditions, to correlate very well against continuous friction measurement devices such as the SCRIM and GripTester devices (Wambold et al. 1995).

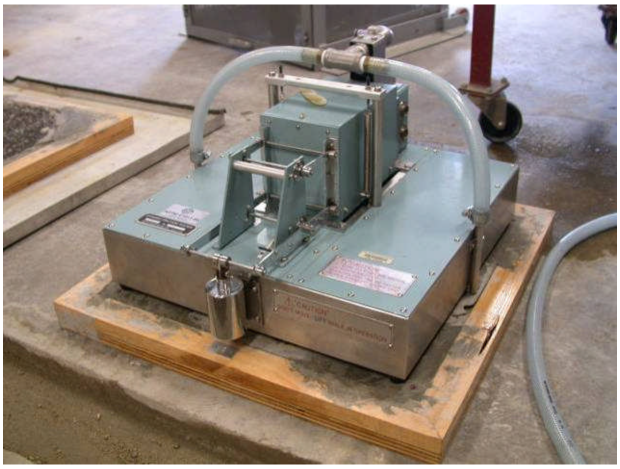


Figure 1(a) The DFTester on a prepared sample

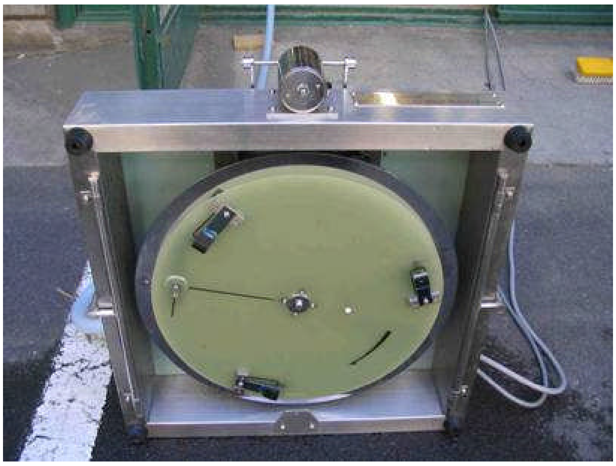


Figure 1 (b) Rubber sliders and rotating disk of DFTester

A more detailed description of the controlled experiment methodology including the laboratory equipment for the required accelerated polishing and skid testing is given in Wilson & Dunn (2005) and Wilson (2006). The methodology included preparing large surfacing samples (approx 600mm x 600mm) with aggregate chips that were sieved through a 9.5mm sieve and all flaky aggregate chips removed by the use of a slotted sieve and/or rejected by hand. The prepared surface samples were then fixed in a cement / sand mortar and polished using the Accelerated Polishing Machine (Figures 2(a) and 2(b)) built specifically to polish the same diameter track and direction as the rubber sliders on the rotating disk of the DFTester.

To examine and simulate the variation of measured skid resistance over the expected life of a surfacing, a two stage accelerated polishing laboratory test method was developed. The initial stage of accelerated polishing (as reported in this paper) was without the use of contaminants (detritus) and used only the accelerated polishing of rubber tyres with water. The duration of accelerated polishing was not arbitrarily set (c.f. the 6 hour end of life PSV test that has set 2 x 3 hour cycles of polishing of corn emery and subsequent emery powder), but continued until a steady state level of polishing was observed (nominally called an Equilibrium Skid Resistance (ESR) level). Two samples of each of the aggregate samples were constructed, one to be the master control sample that was not polished and the other sample polished by the Accelerated Polishing Machine. The accelerated polishing process was halted at regular intervals and a friction test undertaken on both the master control sample and the polished sample to enable the rate of deterioration to be analysed and considered.

The following sections of this paper discuss the geological properties of the aggregates used in this experiment, the skid resistance performance and the SEM photographs taken 'before' and 'after' accelerated polishing. A second stage of the polishing experiment (not reported in this paper and the subject of continuing research) simulates the cyclical effects of variation of the summer, winter polishing, rejuvenation of surface samples through the effects of contaminants, rainfall and vehicle trafficking.

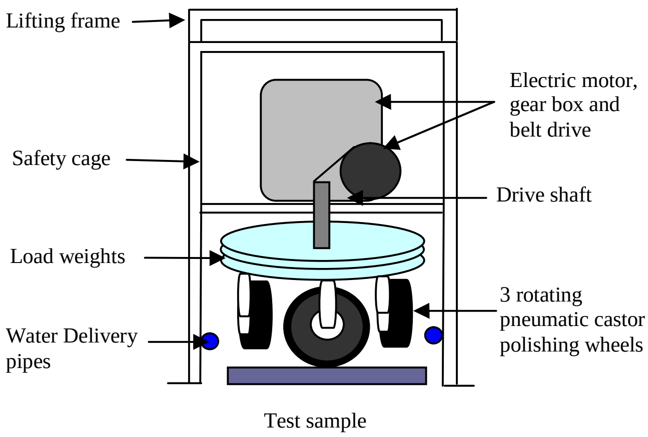


Figure 2(a) Schematic of UoA Accelerated Polishing Machine

Figure 2(b) The Accelerated Polishing Machine wheel assembly unit in operation

3. GEOLOGICAL PROPERTIES OF THE AGGREGATES

3.1 OVERVIEW

The selected samples of sealing aggregates used in the controlled laboratory experiments were chosen on the basis of comparing three quite different greywacke aggregates commonly used in the North Island of New Zealand of varying geological properties and comparing these with an artificial melter slag aggregate. A range of low, medium and high reported PSV for the greywacke aggregates were chosen as being desirable for the test matrix and compared to the artificial melter slag aggregate:

- *3 Greywackes*, (G1, G2 and G3) with a range of grain sizes and from low to high Transit NZ (2004) reported PSV (G1=51 (52)[1], G2=55, G3=65 (63)[1]);
- *1 Melter slag aggregate,* (MS1) artificial by-product from the Glenbrook Steel mill, Transit NZ (2004) reported PSV (MS1=58 (55)[1])

Descriptions of the aggregates are given in the following sections.

3.2 GREYWACKE AGGREGATES

Greywacke sandstone chips from three quarries from the North Island of New Zealand were tested in the laboratory experiment. They are all volcaniclastic clast-supported greywacke

[1] The values in brackets denote the result of a PSV test on the sample used (where these were available). It is interesting to note that in some cases there are significant differences between the Transit New Zealand reported results and the sample used in the experiment demonstrating either variability in the material source from the quarry or the variability (or repeatability) in the test method itself.

sandstones in which the clastic grains are angular to subangular. The three greywacke samples show variations in grain size – G1 is the finest and G3 the coarsest, and in degree of lithification.

Two of the greywackes (G1 from Whangarei and G2 from Auckland, NZ), of Triassic - Jurassic age, are strongly lithified and have experienced prehnite-pumpellyite facies metamorphism. In thinsections these sandstones (Figures 3a and 3b) show angular to subangular quartz grains, albitised feldspar and abundant lithic debris. The matrices of these greywacke sandstones have been totally recrystallised to albite, quartz, chlorite, illite, pumpellyite or prehnite assemblages and the individual sand grains are held in place by the recrystalised matrix. White veins of prehnite and quartz are evident cutting some grains. The two sandstones differ in that G1 is overall a finer grained sandstone, has more matrix and commonly contains lenses of silt.

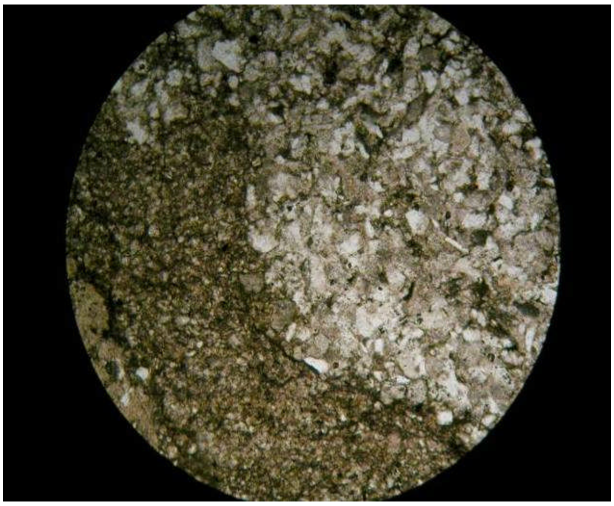


Figure 3(a) Microphoto of typical texture of greywacke sandstone (G1) Thinsection plane polarised light (diameter field of view is 2mm)

Angular grain-supported sandstone composed of quartz, albitised feldspar and lithic grains top and centre right, and siltstone lens bottom centre left.

Figure 3(b) Microphoto of typical texture of greywacke sandstone (G2) Thinsection plane polarised light (diameter field of view is 2mm)

Well sorted angular grain-supported sandstone composed of quartz, albitised feldspar, lithic grains and detrital hornblende and augite crystals.

The third greywacke aggregate (G3), from the eastern North Island of New Zealand, is of Cretaceous age and has only experienced diagenetic zone metamorphism (rather than low-grade metamorphic) and is therefore typically weakly lithified sandstone in that individual mineral and lithic grains are coated with clay minerals. The clay often swells and thus the grains are not well cemented and are easily dislodged and removed from the rock.

Sealing chips from this sample (G3) show a variety of colours (refer to Figure 4(a)) indicating different degrees of weathering. However, they all appeared to be coarse well sorted, uniform grain size sandstones as shown in Figure 3(b). The matrix constitutes about 10-20% of the sandstone and X-ray diffraction shows the matrix consists largely of chlorite and illite with minor smectite. Some chips also have calcite cement. Veining of the rock with the zeolite laumontite is common.

Figure 4(a) Greywacke sandstone G3 aggregate chips (diameter of field of view 3.5cm)

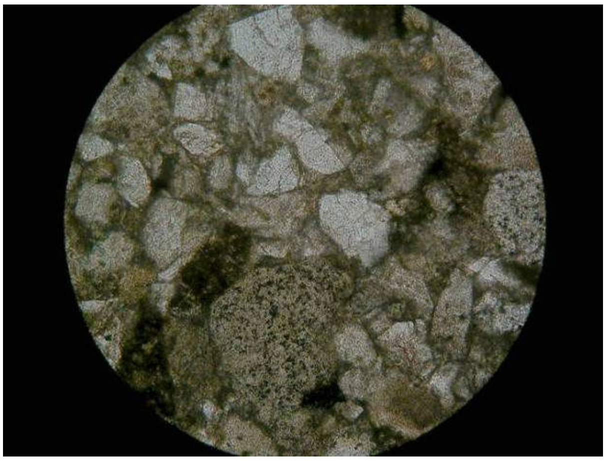


Figure 4(b) Thinsection microphoto of texture typical of greywacke sandstone G3 (diameter of field of view 2mm)

3.3 MELTER SLAG AGGREGATE

The melter slag is an artificial aggregate that is an iron making by-product of a New Zealand Steel Mill from titanomagnetite sands and is therefore much enriched in titanium. The melter slag chips are black with some reddish-brown patches. They appear metallic with reddish-brown patches on the surface and they contain many gas vesicles. Figure 5 shows an example of a chip thinsectioned that contains large cubic crystals of blue-green magnesium (Mg) rich spinel mantled with a red-brown pseudobrookite (a Ti-rich oxide). The matrix of the slag showed a typical quench texture consisting of interlocking dendrites of extremely small grains of perovskite ($CaTiO_3$) enclosed in pyroxene (colourless material). Many chips have vesicles and show brown oxidation effects. Figure 5 shows large crystals in the centre field view that are magnesium - spinel surrounded by pseudobrookite.

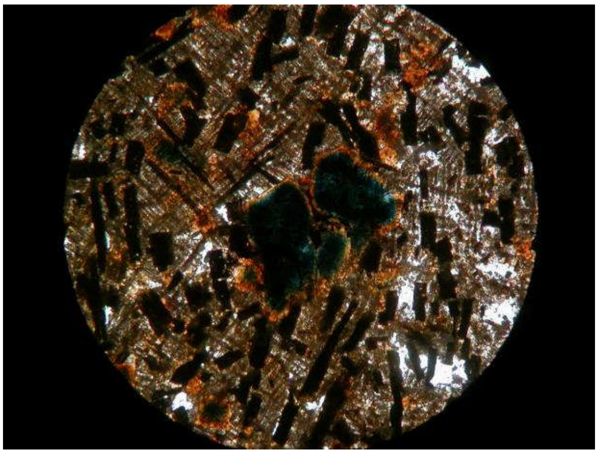


Figure 5: Microphoto of Typical Melter Slag Thinsection (diameter field of view is 2mm)

The next section shows and compares the results of the accelerated polishing and the surface friction tests for the three greywacke aggregates and the artificial melter slag aggregate.

4. LABORATORY TEST RESULTS

The prepared surface samples chosen for polishing were polished to an 'equilibrium level' whilst periodically measuring the variation of the coefficient of friction with the Dynamic Friction Tester. All four paired aggregate samples were tested and the results plotted and compared against the sample that did not undergo accelerated polishing. The results are shown together for the three greywacke aggregates and the melter slag aggregate. Each data point represents the mean of three test coefficients of friction (μ) for an average slip speed of between 20 and 40km/h as measured by the DFTester for the first 6 hours of accelerated polishing or until an equilibrium level had been reached.

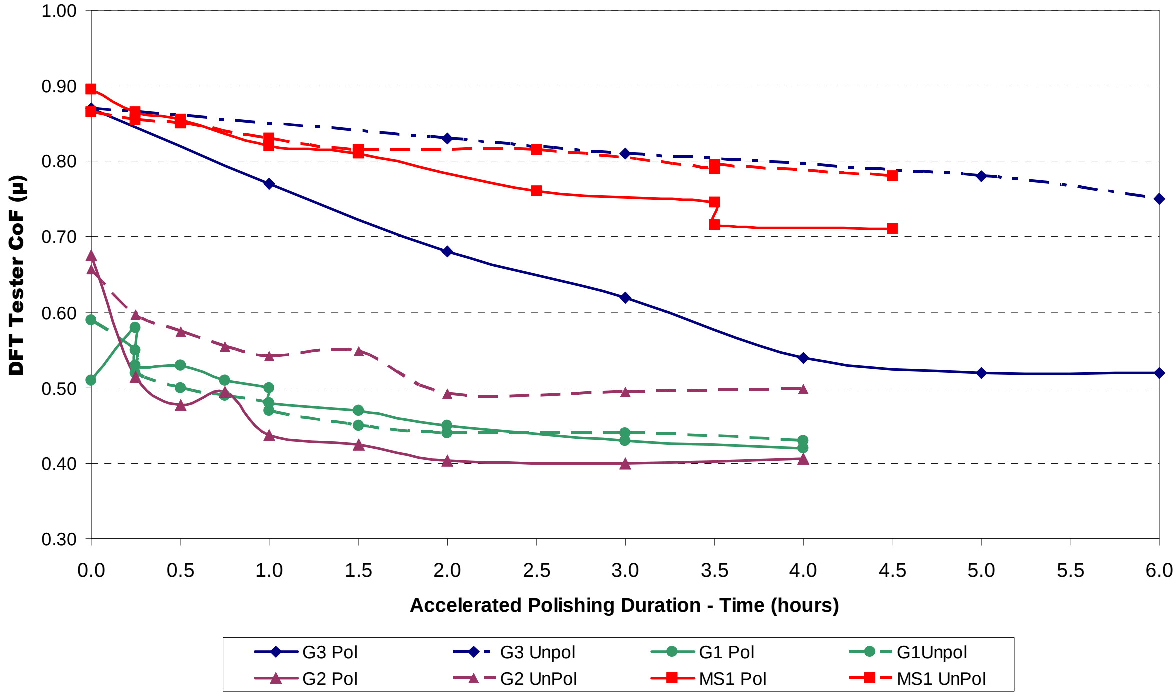


Figure 6: Skid Resistance (µ) Performance of Greywacke Sandstone (G1, G2, G3) and Melter Slag (MS1) Aggregates

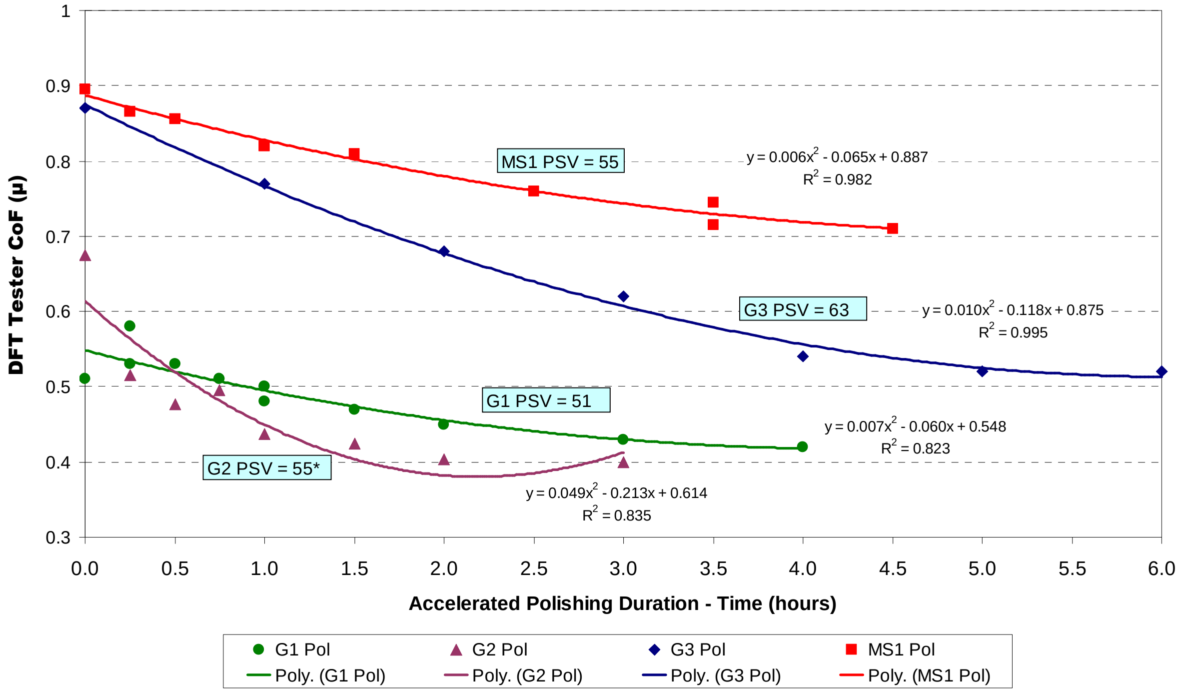
The results of the three greywacke samples (Figure 6) clearly reflect the differences seen in the thinsection photographs. The G1 and the G2 greywackes that had relatively similar grain sizes and degrees of lithification performed relatively similarly in terms of skid resistance. They both began with a moderate level of skid resistance (0.60 to 0.65µ): however, they polished relatively quickly to a level of 0.40-0.42µ after only approximately 2.0 hours of accelerated polishing (a total loss of approximately 0.20µ). It is also interesting to note that both 'unpolished' samples that were not subject to the accelerated polishing also polished by approximately 0.15µ. This reduction was due to the polishing effects of the DFTester itself that initially spins at 60km/h and spins down onto the surface, thereby undertaking some polishing. By the end of the polishing phase each sample has had over 30 DFT Tests performed on the surface.

In contrast, the G3 eastern North Island greywacke that was less lithified and significantly larger in grain size initially performed much better with a high measured level of skid resistance (0.87µ). Under accelerated polishing, it reduced measured skid resistance (µ) at a similar rate to the other two greywackes although continued to loose skid resistance (µ) for a longer period of accelerated polishing; loosing 0.35µ, being a higher percentage (40%) of its initial skid resistance value in comparison with the other two greywackes with 24 to 38%

loss. The G3 Greywacke also took 5.0 hours of accelerated polishing (c.f. 2.0 hours for the other greywackes) to reach an 'equilibrium skid resistance' (ESR) level under constant laboratory polishing conditions and levelled off at approximately 0.52µ which was higher than the other two greywackes by approximately 0.10-0.12µ.

The results of the laboratory accelerated polishing and DFTester friction tests on the artificial melter slag (MS1) show that the initial level of skid resistance for the slag (0.90µ) was slightly higher than the G3 greywacke (0.87µ) even though the tested PSV was significantly lower than the G3 greywacke. Furthermore, the melter slag polished at a lesser rate than all three of the greywackes and the percentage reduction in measured skid resistance from the initial level of skid resistance to an equilibrium level was significantly less than the natural aggregates (16% c.f. 24% to 40% for the greywackes). The melter slag took a similar time to reach an equilibrium level as the G3 greywacke (approximately 5.0 hrs) and levelled off around 0.71µ which was higher than the best performing greywacke (G3) by 0.19µ.

The result being that the melter slage aggregate (MS1) significantly out-performed all of the natural greywacke aggregates in terms of resistance to polishing even though the tested PSV was significantly lower than the G3 greywacke (PSV=55 c.f. PSV 63 for the G3 greywacke). Figure 7 shows second order polynomial equations fitted to each of the four polished sample data results with correlation coefficients (R^2) ranging from 0.82 to 0.99 (demonstrating very good to excellent data fitting was achieved). The tested or reported PSVs are also shown on the four test sample results (Figure 7) and this clearly demonstrates that there is very little correlation between the PSV test results and the results from the newly developed UoA accelerated polishing method. However, the UoA test method confirmed results observed, tested and reported in the field by Wilson and Kirk (2005) who concluded that melter slag placed on high stressed highway corners in Northland, New Zealand had similar long lasting skid resistance performance and significantly out-performed locally available natural aggregates that included G1 and G3 greywacke aggregates.



Note: * Transit NZ Reported PSV – actual sample used was not tested

Figure 7: Skid Resistance (µ) Performance of Greywacke Sandstone Rock (G1, G2, and G3) and Melter Slag (MS1) Aggregates

5. SEM PHOTOGRAPHS OF SURFACE TEXTURES

5.1 OVERVIEW

SEM photographs of surface textures of the unpolished (as received from the quarry) and polished aggregate chips (selected from the samples that underwent accelerated polishing) were taken at various magnifications. The selected chips were first washed in distilled water and then placed in water in an ultrasonic bath to shake loose any dust adhering to their surfaces before being dried, mounted and sputter coated with platinum for SEM study. Sample photographs using x200 magnification are shown in Figures 8 to 11, for each of the aggregate samples in both an unpolished and polished state. This magnification was chosen as it shows both a significant area of the surface and features of interest at a scale that is readily recognisable. The figures show significant differences in the surface textures after polishing compared to the unpolished samples, especially the greywacke aggregates, although lesser difference for the melter slag aggregate.

5.2 GREYWACKE AGGREGATES

Figure 8(a) and 8(b) show photographs of fine grained G1 greywacke aggregate in an unpolished and polished state respectively. It can be clearly seen in Figure 8(a) and in the top left corner of Figure 8(b) where the surface profile is lower, and has therefore not undergone polishing, that the surface is rougher and harsher in surface texture. In contrast, the lower half of Figure 8(b) shows clear smoothening of the surface texture and less harshness due to the accelerated tyre polishing. The sandstone matrix also clearly shows strong cementation due to the metamorphic recrystallisation.

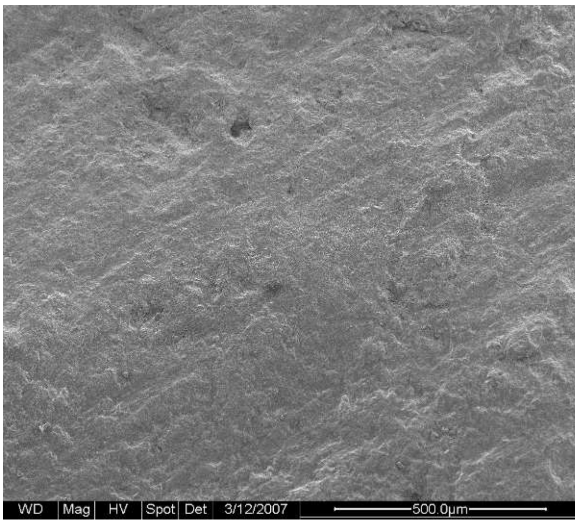


Figure 8(a) Fine grained greywacke sandstone G1 : unpolished surface x 200mag

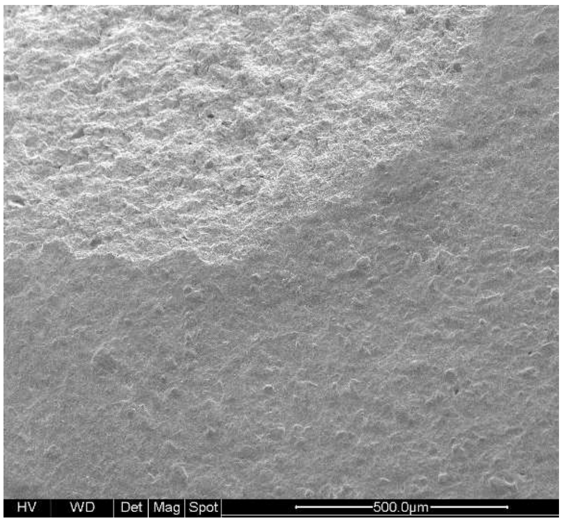


Figure 8(b) Fine grained greywacke sandstone G1 : polished surface x 200mag

Figure 9(a) and 9(b) show photographs of medium grained G2 greywacke aggregate from the Auckland region of New Zealand in an unpolished and polished state respectively. The larger grain sizes than the G1 greywacke are clearly visible in Figure 9(a) with greater surface texture roughness. Figure 9(b) shows after polishing a much more even surface texture with less roughness and clear polishing of the protruding grains. The right top corner of Figure 9(b) with a lower relief also shows the original harsh surface texture without the polishing effects. Similar to the G1 greywacke, the G2 sandstone matrix also clearly shows strong cementation due to the metamorphic recrystallisation.

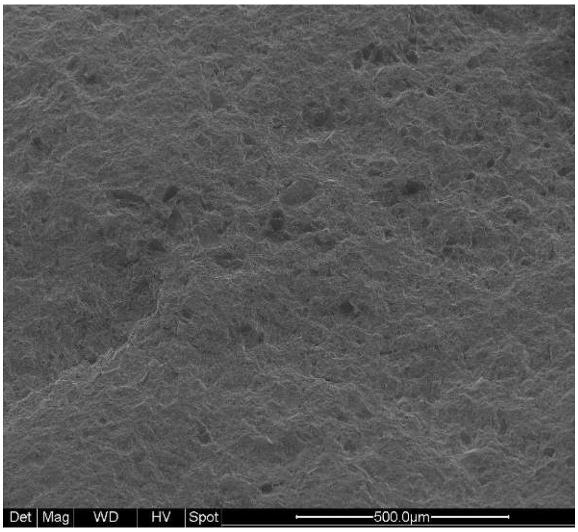


Figure 9(a) Fine grained greywacke sandstone G2 : unpolished surface x 200mag

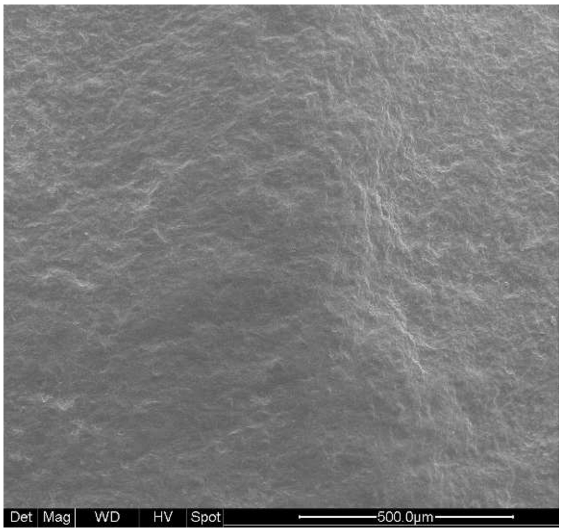


Figure 9(b) Fine grained greywacke sandstone G2 : polished surface x 200mag

Figure 10(a) and 10(b) show photographs of a coarse grained and less weathered greywacke aggregate (G3) from the east coast of the North Island of New Zealand in an unpolished and polished state respectively. As can be clearly seen from Figure 10(a) the coarse grained greywacke is weakly lithified and has significantly greater grain sizes than both the G1 and G2 greywackes (Figures 8 and 9). The G3 greywacke is diagenetically altered rather than low grade metamorphic alteration (G1 and G2) and therefore the individual mineral and lithic grains are coated with clay minerals. The grains are subsequently not well cemented in the sandstone matrix and are easily dislodged and removed from the rock leading to much higher aggregate abrasion (loss of material). This is clearly seen in the Figure 10(b) where it can be seen that coarse grains have been plucked away during polishing as the overall texture relief is much less than the unpolished surface texture (Figure 10(a)). However, where the grains have remained in the sandstone matrix clear polishing and rounding of the grains has occurred.

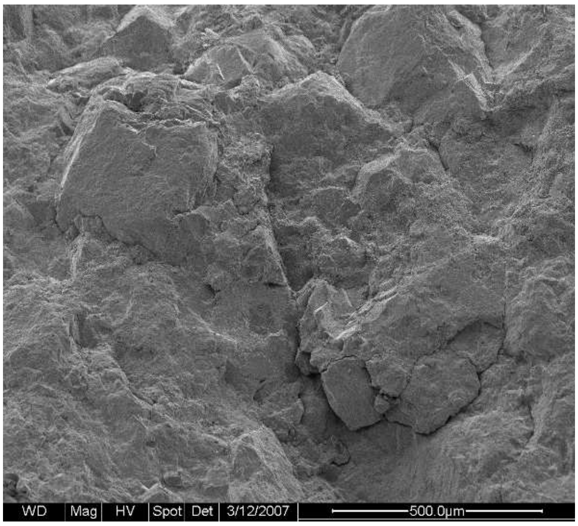


Figure 10(a) Coarse grained greywacke sandstone G3 : unpolished surface x 200mag

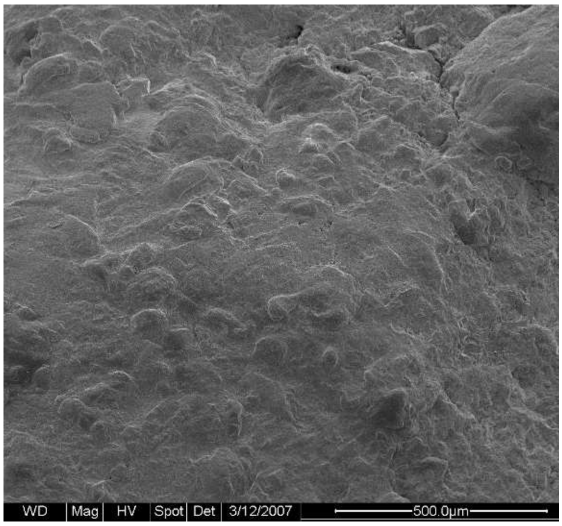


Figure 10(b) Coarse grained greywacke sandstone G3 : polished surface x 200mag

5.3 MELTER SLAG AGGREGATE

Figure 11(a) and 11(b) show SEM photographs of the titanium enriched melter slag in an unpolished and polished state respectively. The gas vesicles and harsh surface texture are clearly visible in both the unpolished and polished states and whilst some smoothening of the elevated surface in the polished sample is evident (Figure 11(b)) it is clear that the matrix of the aggregate is well cemented and not able to be plucked from the surface. Furthermore the minerals in the melter slag (e.g. spinel, pseudobrookite, ilmenite, perovskite and armalcolite) are relatively hard (Mohs hardness 5-8) and are therefore more resistant to polishing. This combined effect explains why the accelerated polishing has less effect than the greywackes and why the melter slag retains a higher surface friction (refer to Figures 6 and 7).

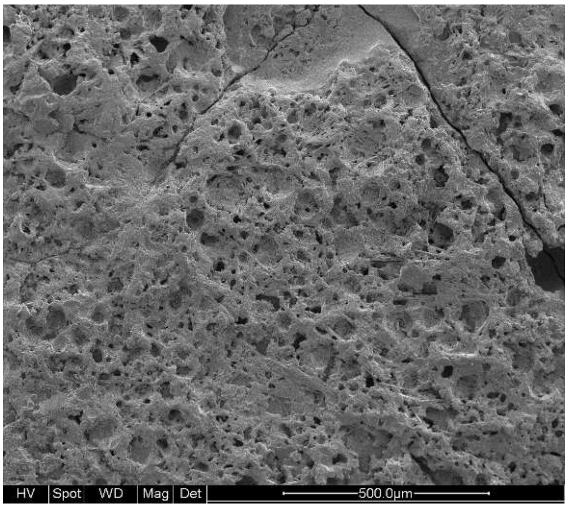


Figure 11(a) Melter slag : unpolished surface x 200mag

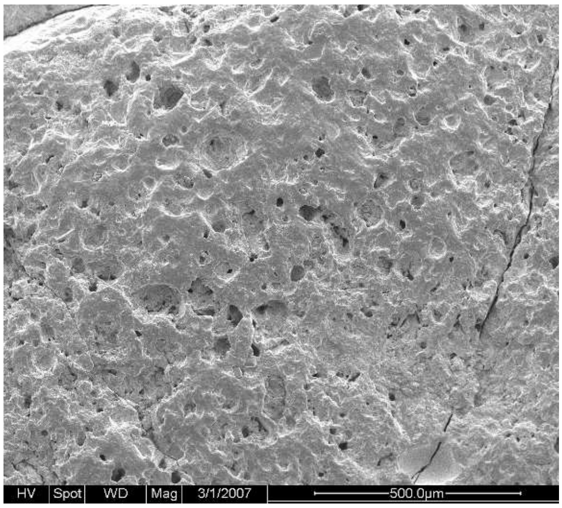


Figure 11(b) Melter slag : polished surface x 200mag

5.4 AGGREGATE COMPARISONS

The surface studies comparing the unpolished and polished surfaces of the greywackes (Figures 8, 9 and 10) show very clearly that they polish to give surfaces on which there are significant elevated features, which have been developed over the clastic grains (particularly over quartz grains), while the matrix of the sandstone has been polished away.

Natural greywacke rocks (and in this case also slags) are heterogeneous materials composed of several different minerals which frequently have different grain sizes and shapes as well as different chemical and physical properties. Further, there are differences in the nature and strength of the cement that bonds the constituent mineral grains.

The difference in the polishing properties of the greywackes and the melter slag appears to be related to the hardness of the minerals and to the way in which individual components of the rock are held together. In the greywackes the matrix enclosing the clastic grains is composed largely of phyllosilicates, such as clay minerals, chlorite and micas, and there are also differences in the degree of lithification of the rocks. The G1 and G2 greywackes have been lithified by prehnite – pumpellyite metamorphism usually bound together by silica cement. Figure 12(a) shows an SEM photograph at a much higher magnification (x 10,000mag) displaying the texture of a weakly metamorphosed G2 greywacke (at circa 250° C) and the bonding of the matrix with sand grains.

However, the G3 greywacke is less strongly lithified and bound together by clay. The G3 greywacke also has greater variation in mineral hardness and the large clastic grains are less strongly held in the matrix meaning the grains are more easily 'plucked' out during polishing (refer to Figure 12(b) – an SEM photograph x 12,000mag) that shows the smectite and kaolinite clay flakes that coat the grains). When these grains 'pluck' out they probably contribute initially to re-roughening of the surface of the sample, resulting in higher surface friction due to good microtexture. This higher surface friction remains higher for longer than other more fine grained well cemented sandstone matrix greywackes (e.g. G1 and G2), that are better cemented together but polish more quickly. The G3 greywacke does however begin with a higher measured skid resistance due to the mixture of soft and hard minerals in its matrix that are more difficult to polish. However it looses a greater proportion of this surface friction during accelerated polishing and therefore the material polishes to only a little better level than other greywacke samples. Additionally, as the grains are more easily 'plucked' the aggregate is more susceptible to wearing and weathering and therefore is more likely to require resurfacing at more regular intervals.

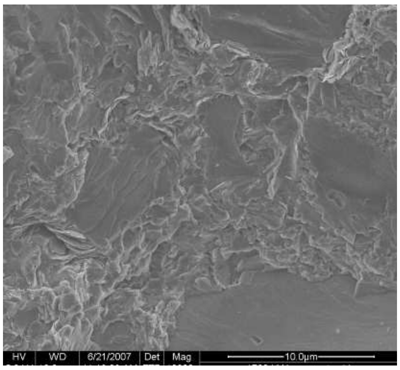


Figure 12 (a) Fine grained greywacke sandstone G2 : unpolished surface x10,000 mag

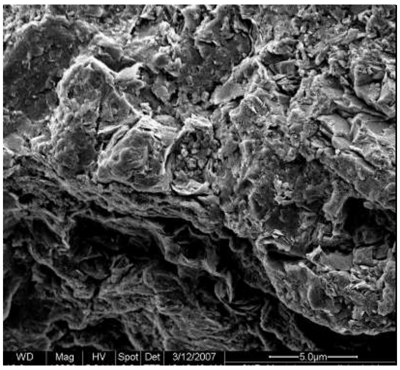


Figure 12 (b) Coarse grained greywacke sandstone G3 : unpolished surface x12,000 mag

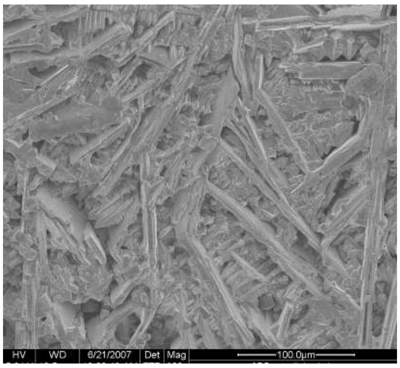


Figure 12 (c) Melter slag : unpolished surface x 800 mag

The melter slag aggregate is crystallised due to quenching at high temperatures and the individual mineral grains (that are relatively hard) are very well welded together or cemented. Figure 12(c) shows an SEM photograph (at x 800 mag) that clearly show the long needles of armalcolite and quench textured pyroxene granules and perovskite growing in the spaces between the armalcolite needles. These hard and well bonded minerals are therefore more resistant to polishing; abrasion and plucking than the greywacke aggregates and therefore deteriorate at a slower rate, retaining for longer their original microtexture harshness and correspondingly measured skid resistance (refer to Figures 6 and 7).

6. SUMMARY AND CONCLUSIONS

Controlled laboratory experiments were required to simulate on prepared samples the observed variation and unpredictable nature of skid resistance in the field. A new method of accelerated polishing and surface friction testing was developed at the University of Auckland, New Zealand. The experiments were developed to investigate the effects of accelerated wet polishing, rainfall and contaminants on measured skid resistance. The initial stage consisted of accelerated wet polishing to an 'equilibrium skid resistance' (ESR) level without any additives.

The paper discusses and compares the results of three greywacke sandstone surfacing samples and one melter slag aggregate. The three greywacke sandstone samples were different in age, degree of metamorphism (lithification) and nature. The G1 and G2

Greywackes were finer and medium grained sandstone respectively and strongly lithified by low grade metamorphism. Metamorphic prehnite was found in the matrix of both G1 and G2 greywackes and in white veins cutting the rock. These differences in degree of lithification, mineral content and grain size provide explanations for the different polishing and skid resistance properties found of the three greywackes.

The G3 Sandstone is from the Cretaceous period and is more uniform in its properties although has a mixture of soft and hard minerals. It has a coarser grain size, and is inherently less lithified than the older late Triassic / Jurassic greywackes (G1 and G2). The different colours of the chips (greenish, brownish and grey, (refer to Figure 4(a)), indicates different degrees of oxidation, together with a lack of veining, that shows the G3 greywacke still retains some permeability with respect to water and is therefore more susceptible to weathering.

The Melter Slag, which has an inherently irregular surface with many vesicles, is composed dominantly of metal oxides. Spinel, which is a substantial component of the slag, is an exceptionally hard mineral (Moh's scale 7.5 – 8) and the other Titanium oxides (pseudobrookite and ilmenite) are also very cohesive and hard. None of these metal oxides have cleavages. The micro-texture of the rock is formed by interlocking large crystals of the metal oxides which provide cohesion to the material and therefore good surface friction. Since they polish hard, these oxides effectively protect the smaller perovskite and pyroxene crystals located between them from abrasion in the polishing process, while still providing a surface relief that has rough microtexture and therefore high skid resistance. Thus, it is not surprising that the slag has a reasonably high initial skid resistance and out-performs, over time, the tested natural greywacke aggregates in terms of skid resistance.

The laboratory based experiments have reflected similar results and degrees of variation to those shown at field sites with normal heavy traffic conditions. The conclusions regarding the accelerated polishing of the three natural greywacke aggregate and the melter slag samples using the Accelerated Polishing Machine developed at the University of Auckland are:

- The actual PSV of the aggregate sample generally predicts the same ranking order of the initial level of skid resistance of the three greywacke aggregates tested with the DFTester prior to any accelerated polishing, however does not predict well the equilibrium skid resistance as reflected in-field;
- The percentage reduction in the measured skid resistance from the initial level of skid resistance to ESR reduces as the aggregate PSV reduces (from 40% for the G3 greywacke to 24% for the G1 Whangarei greywacke);
- There is very little difference in the final level of ESR as measured by the DFTester obtained for the two fine and medium grained greywacke aggregate samples (range from 0.40 to 0.42(μ) for the G2 and G1 samples respectively;
- Whilst the less lithified and more coarse grained G3 greywacke remained a little higher with an ESR of 0.52(μ), it is expected that it would wear away more quickly, thereby loosing macrotexture faster than more lithified greywackes. The result being the aggregate surfacing would have a shorter life span and require resealing earlier.
- The melter slag significantly out-performed the three greywacke aggregates in terms of being resistant to accelerated wet polishing, including the G3 greywacke which had a significantly greater PSV;
- The greywacke sandstone and the melter slag aggregate polish by different mechanisms and therefore the deterioration rates vary under the same accelerated polishing loads;

- The time to a polished state and the ranking order of the final level of ESR for the greywacke and melter slag samples tested by the new laboratory method discussed in this paper are not the same as the PSV ranking;
- SEM photographs and thinsections have shown that the original grain size, texture, mineral makeup and hardness and the type of bonding of the grain matrix of the rock determines its resistance and method of 'polishing' to an ESR level;
- For greywackes their degree of lithification is also an important factor. SEM photos of polished greywacke surfaces show clastic grains persisting as protuberance above an otherwise subdued surface; and
- The newly developed test method using large surface samples, an accelerated polishing machine and the DFTester better reflects in-field polishing in comparison to the historical PSV test.

From the above results, it is concluded that the Polished Stone Value (PSV) test method gives results that, without taking other factors into consideration, cannot be reliably used as a predictor of the initial skid resistance of the aggregate nor of the level of Equilibrium Skid Resistance (ESR) after polishing. Other methods, such as the use of the accelerated polishing machine developed at the University of Auckland, and coupled with an understanding of the geological source and makeup of the aggregates, are required for road asset managers to ensure good decision making. This will enable better predictions of how aggregates will perform over time and under specific traffic, geometric and braking stresses.

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