TECHNICAL NOTE

PREDICTION OF PAVEMENT SURFACE SKID RESISTANCE AND THE EFFECT OF SMALLER CHIP SIZE

Authors:
Birendra Kumar, MEngSt(Transportation), Bachelor(Civil), GIPENZ
Senior Transportation Engineer
GHD Ltd, New Zealand
Email: bir.rubi@gmail.com
Douglas J. Wilson, PhD, BE (Civil), NZCE(Civil), MIPENZ, PIARC
The Department of Civil and Environmental Engineering
The University of Auckland, New Zealand
Email: dj.wilson@auckland.ac.nz

ABSTRACT

Research has demonstrated that many New Zealand natural aggregates do not perform well over an economic asset life in areas of high demand for friction. These areas require better and less variable skid resistant aggregates especially in terms of long term performance.

This paper discusses and compares the skid resistance performance of two natural aggregates and the effect of varying chip size (South Auckland Greywacke 2 Grade 4 and Grade 6, South Auckland Basalt Grade 4 and Grade 6) and one artificial aggregate (Electric Arc Furnace Grade 4) 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 the textural relationship between the minerals in the aggregate chips themselves.

The aggregate samples studied in this research have been further compared with similar fine grained Greywacke from Northland and another quarry in South Auckland in previous research projects. Among the five laboratory prepared aggregate test samples compared; the Electric Arc Furnace Grade 4 (Present Study) performed the best producing the maximum value of Equilibrium Skid Resistance (ESR). The fine grained Greywackes and the South Auckland Basalt all produced very similar values of ESR when similar sized chips were used. The effect of aggregate chip size on skid resistance performance was investigated by comparing two geologically similar sourced samples with varying chip size (Grade 4 to Grade 6). The results of both aggregates showed an approximate 24% (Basalt) to 35% (Greywacke) increase in skid resistance performance when the smaller chip size was used.

INTRODUCTION

Research over many years, for example Rogers and Gargett [1] has demonstrated that the road based transport crash rate increases as the skid resistance of road surface decreases. Research have also shown 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 [2]. 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.

This research is the continuation of a new laboratory polishing resistance test method that utilises an Accelerated Polishing Machine developed by Wilson [2]. This method includes a two-stage process:

- Stage 1: Polishing the prepared samples to an Equilibrium Skid Resistance level (ESR); and
- Stage 2: Simulating the cyclical effects of variation of the summer/ winter polishing, rejuvenation of samples through contaminants effects, rainfall and vehicle trafficking.

Background

The predominant pavement construction type used in New Zealand is classified as flexible; the majority being made up of unbound granular layers and most of the rest made up of relatively thin layers of Asphalt Mix. 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. Flexible pavements with unbound granular layers with chip seal surfaces are ideal for rural low traffic volumed roads due to their low associated construction costs.

The variables that can affect the measured level of skid resistance and their inter-relationships are many and complex. They can however be grouped under four main categories [2]:

- *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 *surface aggregate factors* and partially *load factors* can be controlled and / or taken account of by Highway Engineers. The other categories are largely outside the control of the Highway Engineers and are also difficult to predict in terms of their effects. Furthermore, recent research [3] has demonstrated that many natural aggregates (even with high 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 the task of the highway engineer to balance the prediction of long-term skid resistance performance of surface aggregates against the economic extraction, process and haulage costs of using natural aggregates. For this reason artificial aggregates that can be economically and sustainably produced and that have the potential to perform over an extended surfacing period in areas of high demand have significant potential for road surfacing in appropriate areas where transport costs do not outweigh their economic benefit.

RESEARCH METHODOLOGY

Introduction

This research compares the equilibrium skid resistance level of various natural and artificial surfacing aggregates including varying the aggregate chip size under laboratory based accelerated polishing and in response to changes in environmental conditions. Cenek [3] states that wet skid resistance of chipseal surfaces is not only a function of the polishing resistance of the aggregate, but also of its size, shape and spacing. The research also showed a positive correlation (R=0.46) of increasing measured skid resistance with increasing percentage of crushed faces. The research project continues previous research by Wilson (4) that developed a laboratory based accelerated polishing machine developed to improve the prediction of skid resistance after traffic loading of various natural and artificial aggregates.

New Accelerated Polishing Method

A controlled laboratory experiment was designed and constructed at the University of Auckland (UoA) [4] 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 surfacing utilising natural rock aggregates and the potential of artificial aggregates;
- Traffic action simulating heavy commercial vehicle polishing effects;
- Rainfall / washing cycles;
- Effects of the addition of contaminants; and
- The use of a 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 - DFT; (refer to Figures. 1(a) and 1(b)), was the critical factor that determined most of the other experiment variables.

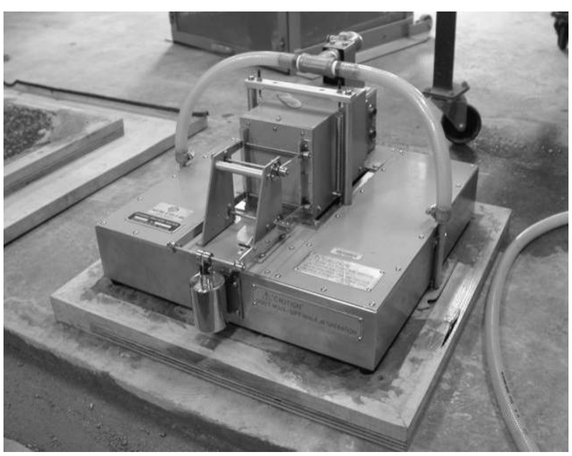

Figure 1 (a) Top View of the DFT on a prepared sample

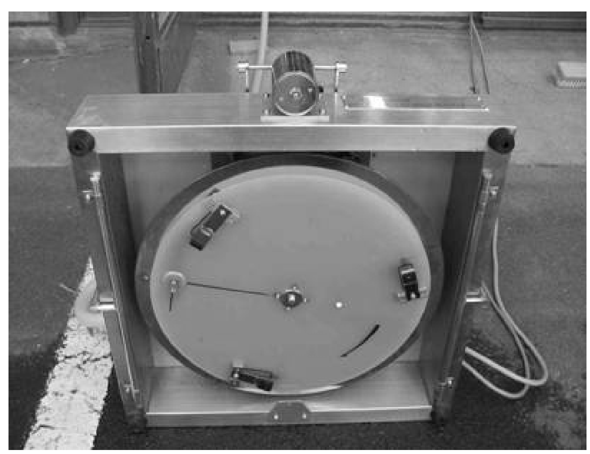

Figure 1 (b) – Bottom View of the DFT showing 3 rubber sliders

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 [4]. The modified methodology for this research included preparing large surfacing samples (approx 600mm x 600mm) with hand placed aggregate that was then bound together by the mixing of a

100:22.5 mixture (by weight) of HP33 and TP33 epoxy resins to hold the surfacing aggregate matrix in place. The prepared samples were then polished using the Accelerated Polishing Machine (Figure 2a) and b)) built specifically to polish the same diameter track and direction as the rubber sliders on the rotating disk of the DFT.

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 was without the use of contaminants and used only the accelerated polishing of rubber tyres with water. The duration of accelerated polishing was continued until an Equilibrium Skid Resistance (ESR) level was observed. Two samples of each of the aggregate type were constructed, one sample was not polished and 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 unpolished sample and the polished sample to analyse the deterioration rate.

The following sections of this paper discuss the skid resistance performance after accelerated polishing on a wetted surface and the effect of polishing on the aggregate surface on unpolished as well as polished samples with a wetted surface to ESR level (Stage 1) and further accelerated polishing with the addition of contaminants (Stage 2). The second stage of the polishing experiment considered the effect of accelerated polishing with the addition of contaminants (Oedometer clay, Leighton Buzzard sand and Emery powder) by attempting to simulate the possible extreme cyclical effects of seasonal / traffic variations with the addition of contaminants.

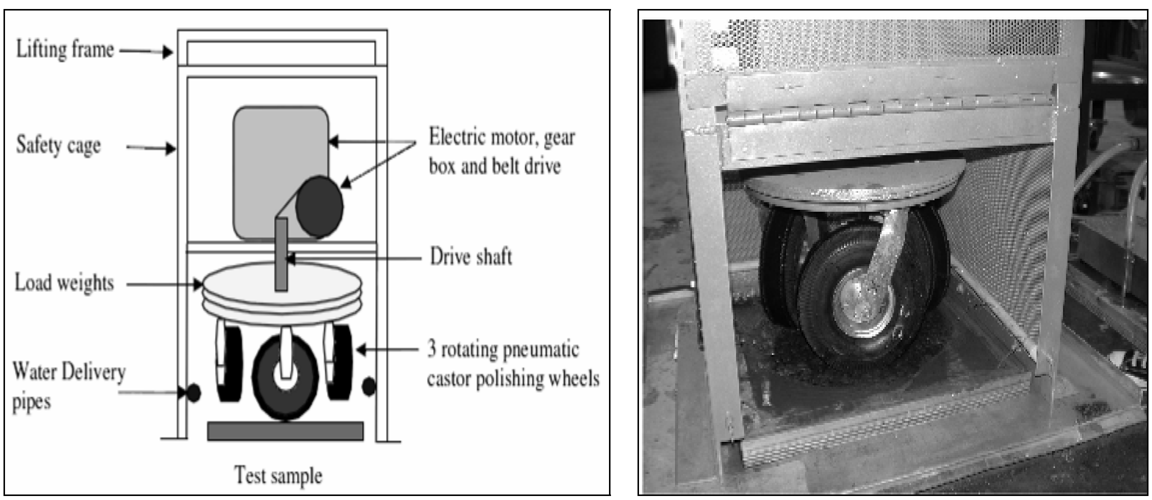

Figure 2: Schematic Front Elevation and photograph of the Accelerated Polishing Machine developed at University of Auckland

LABORATORY TEST RESULTS

One of each of the five paired aggregates (natural aggregates- South Auckland Greywacke #2 Grade 4 and Grade 6, South Auckland Basalt Grade 4 and 6 and one artificial aggregate -Electric Arc Furnace Grade 4) used in New Zealand as road surfacing chip samples were polished to an 'ESR level' whilst periodically measuring the variation of the coefficient of friction with the Dynamic Friction Tester. The test results were plotted and compared against the unpolished sample of corresponding aggregates and these are shown in the following sections. 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 until an ESR level had been reached.

Stage 1 Accelerated Polishing

The results of the Stage 1 laboratory based accelerated polishing and DF Tester friction tests for all five samples tested are shown in Figure 3. The main findings of the results are:

- The Grade 4 artificial Electric Arc Furnace performed significantly better than the two natural Grade 4 aggregates (fined grained South Auckland Greywacke and South Auckland basalt);
- The percentage reduction in measured skid resistance from the initial level of skid resistance to ESR is significantly less for the Electric Arc Furnace than the natural aggregates (South Auckland Greywacke and Basalt aggregates);
- The time to polish the Electric Arc Furnace to its equilibrium polishing level is approximately the same as the natural aggregate of similar Polished Stone Value (3-4 hours);
- The Electric Arc Furnace significantly out-performed all of the natural aggregates in terms of being more resistant to polishing;
- The greywacke and the basalt material performed similarly for the Grade 4 chip size; and
- Decreasing the chip size from Grade 4 to Grade 6 for both the greywacke and the basalt had significant benefits in increasing the skid resistance values throughout the accelerated life of the surface (this will be discussed in more detail in Section 4.3)

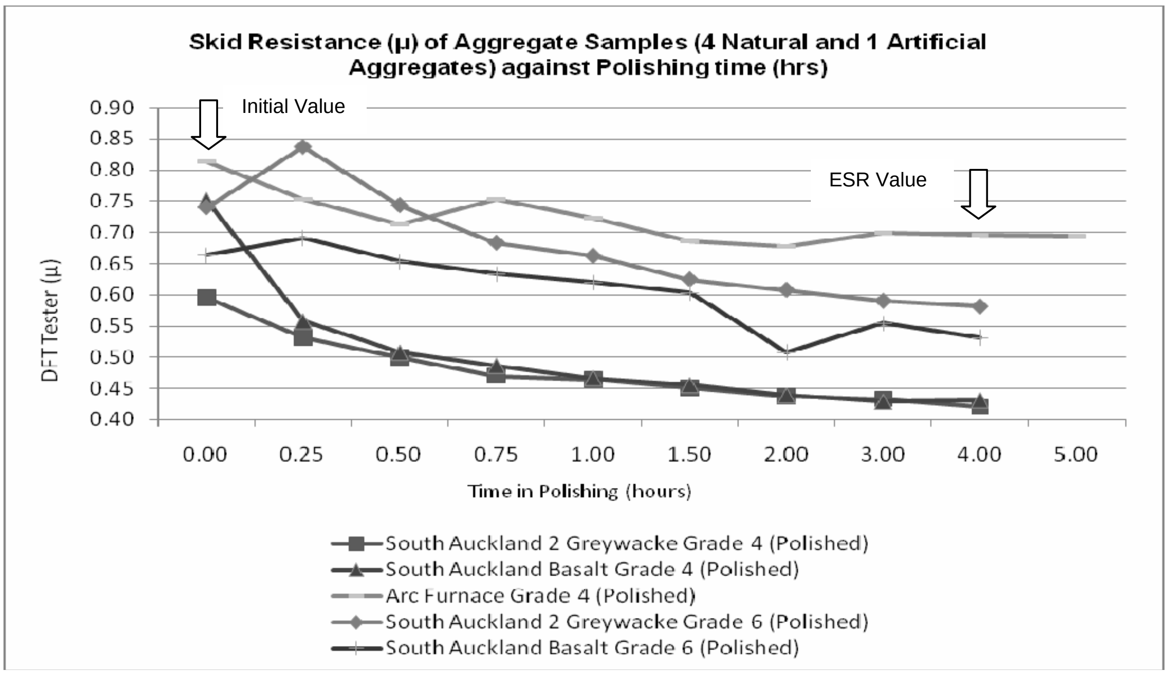

Figure 3 - Skid Resistance (µ) Performance of all Laboratory Samples to ESR (Stage 1).

- The accelerated wet polishing method developed by the University of Auckland (without any contaminant additions) can be used to polish natural as well as artificial aggregates to an "Equilibrium Skid Resistance" (ESR). However, rates at which they decrease are material dependent and a large portion of such decrease takes place in the first hour of the polishing. This shows that, in terms of field performance, most surface aggregates are expected to reach their ESR in a relatively short period of time (one or two years) when compared to their design life. However, the rate will be dependent upon the traffic load imposed,.

Stage 2 Accelerated Polishing with Contaminants

The skid resistance performance results of each polished laboratory sample, for the initial value of DFT (µ) and the ESR values (where the DFT (µ) levelled off; shown in Figure 3 above) are compared and shown graphically in Figure 4. Each progressive series of bars on Figure 4 for each tested aggregate shows the effect of the polishing intervention (e.g the effect of wet polishing without any contaminants is the difference between the first two bars). The subsequent bars shows the progressive effect of the addition of various contaminants and whether accelerated polishing was undertaken in the dry, wet or damp surface conditions.

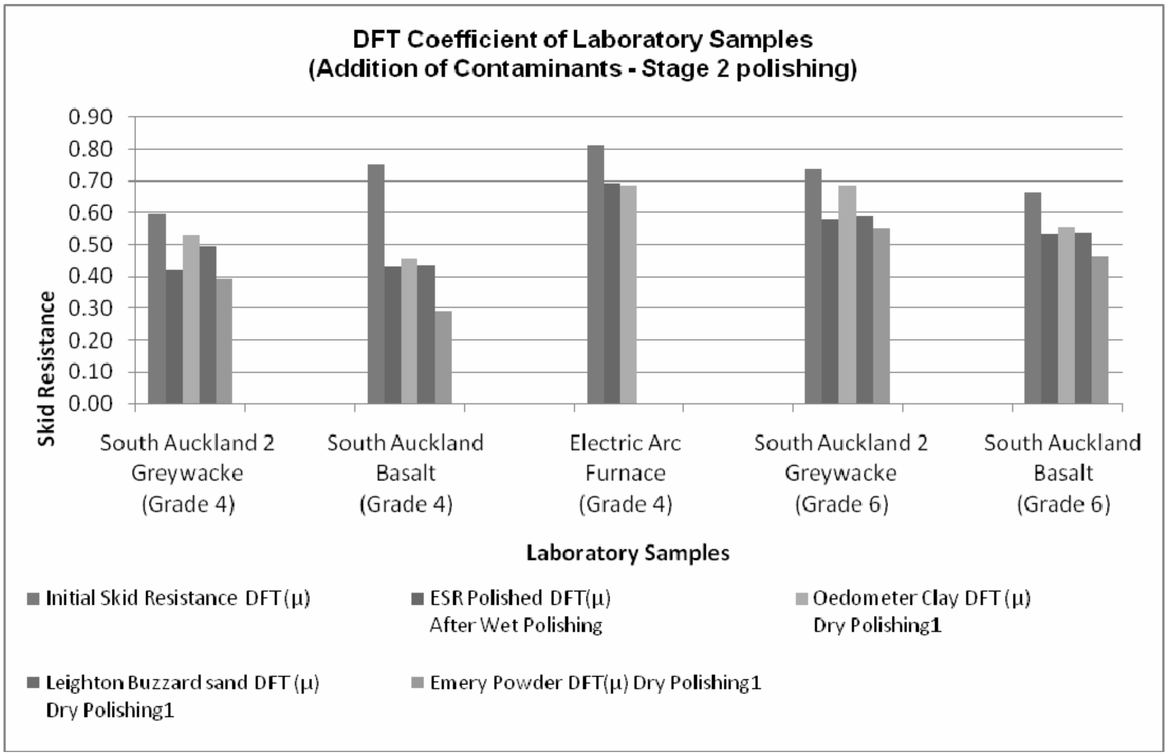

Figure 4 - Skid Resistance DFT (µ) and the Effects of the Addition of Contaminants

The data analysis and subsequent results are shown in Figure 4 for the five laboratory samples. The main findings are:

- The five laboratory samples had different initial values of DFT (µ) and decreased in measured skid resistance to an ESR level due only to wet polishing, by 15% to 43% (large variation). Also significant differences were found in the actual DFT (µ) values at ESR (0.42-0.69) between the five laboratory samples, even though their initial values featured much greater differences;
- The Electric Arc Furnace had the highest initial value DFT(µ)=0.81, this decreased by the smallest amount (15%) to an ESR level of DFT(µ)=0.69;
- The addition of oedometer clay with dry accelerated polishing, on all the aggregates (except Electric Arc Furnace), significantly increased the measured skid resistance DFT (µ). The highest increase in DFT (µ) was recorded for the greywacke aggregate with an increase of DFT (µ) of 0.20. The greywacke aggregates, increased the skid resistance DFT (µ) almost back to the initial measured values prior to any polishing. However, there was a negligible effect of oedometer clay on the Electric Arc Furnace.
- The Leighton Buzzard sand (LBS) when added to the samples, with dry polishing with the accelerated polishing machine, generally increased the measured skid resistance DFT(µ) on greywacke aggregate and South Auckland basalt grade 6; but in the case of South Auckland basalt grade 4 and greywacke grade 6 there was a smaller increase in DFT(µ).
- The addition of emery powder (hard and fine) significantly decreased the measured skid resistance DFT (µ) on all laboratory samples from the prior level which existed after the

Leighton Buzzard Sand had coarsened the microtexture. The DFT (µ) level decreased to a much lower level than that obtained at ESR. The maximum decrease occurred for the South Auckland basalt Grade 4 and Grade 6.

Effect of chip size on measured Skid Resistance performance:

The DFT (µ) results of each polished laboratory samples for the value at which the DFT (µ) levelled off, are shown graphically in the following figures. Each progressive series of bar charts given in Figure 5 and 6 respectively shows the effects of using smaller greywacke and basalt chip sizes for the same geologically sourced material (Grade 6 vs Grade 4).

South Auckland 2 Greywacke (Grade 4 vs. Grade 6):

The comparative effect of reducing chip size from Grade 4 to Grade 6 for the South Auckland 2 Greywacke for the various stages of polishing are shown in Figure 5. The main results for the Greywacke aggregate are:

- Both the initial Skid Resistance DFT (µ) as well as the ESR Polished DFT (µ) is significantly higher for the smaller chip size (Grade 6) when compared to the Grade 4 material;
- The larger Grade 4 chip size appears to be more susceptible to the contaminants as compared to the smaller Grade 6 chip size. This is most likely to be due to the increased polishing tyre / aggregate contact area on the Grade 4 sample. in comparison to the Grade 6 sample.

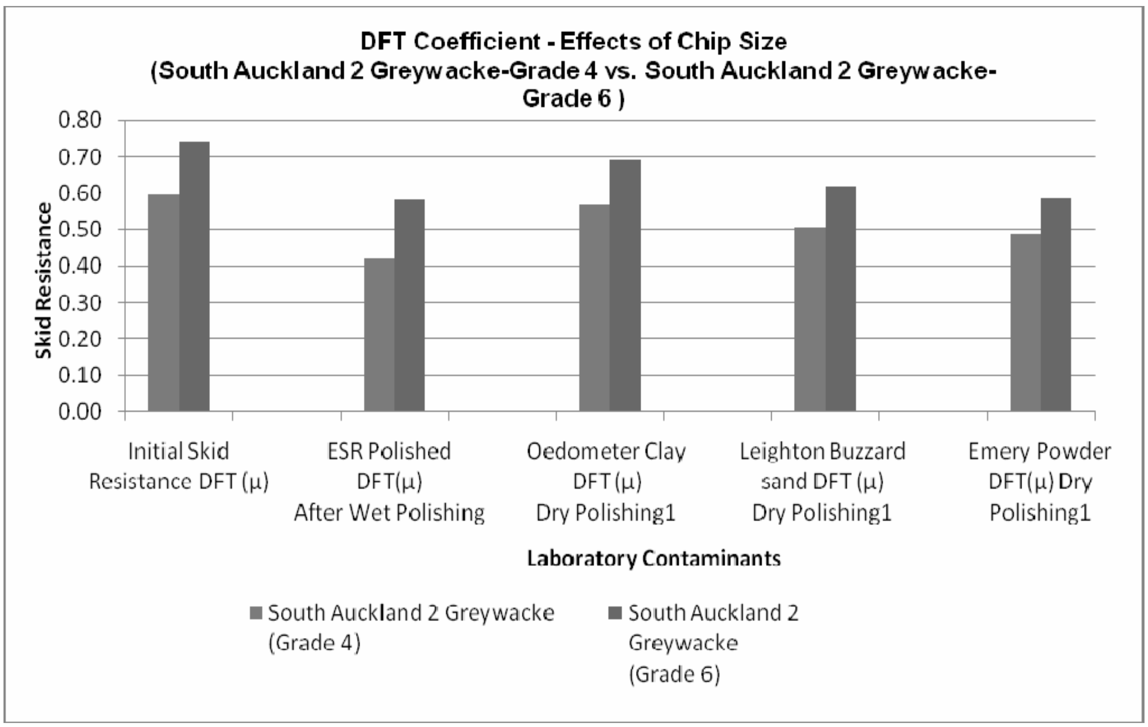

Figure 5- South Auckland 2 Greywacke (Grade 4 vs. Grade 6):

South Auckland Basalt (Grade 4 vs. Grade 6):

The comparative effect of reducing chip size from Grade 4 to Grade 6 for the South Auckland Basalt for the various stages of polishing are shown in Figure 6.

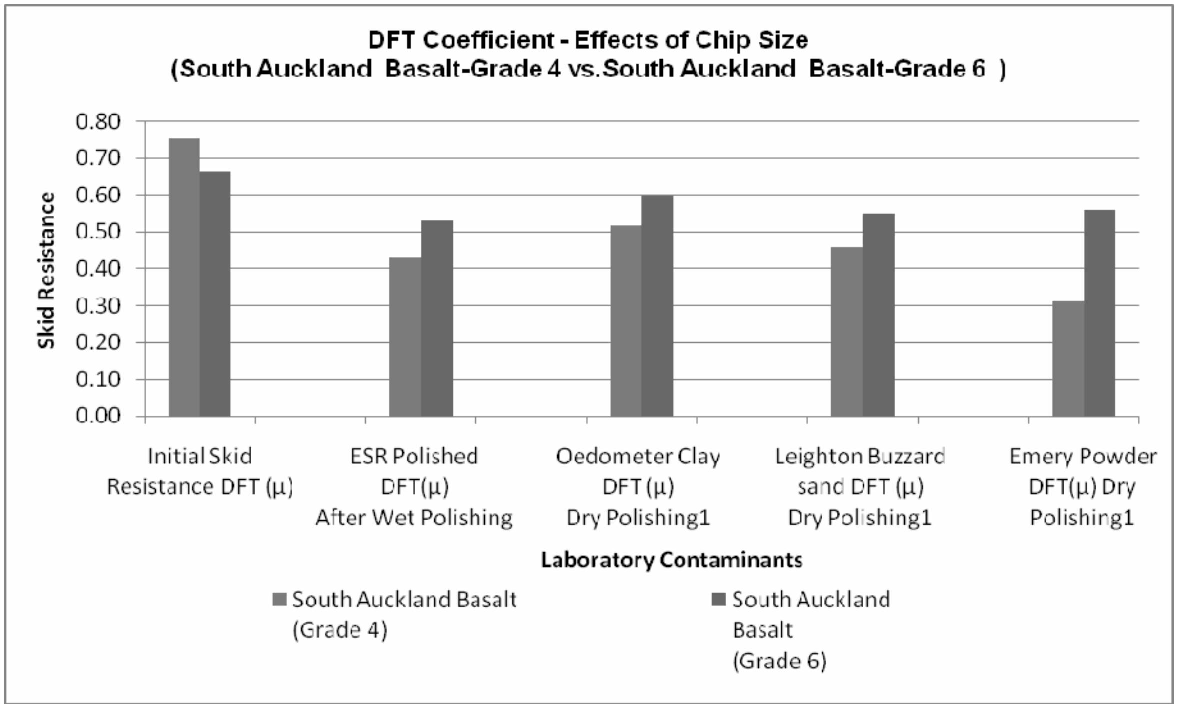

Figure 6- South Auckland Basalt (Grade 4 vs. Grade 6)

The main research findings for the basalt aggregate are:

- Although initial Skid Resistance DFT (μ) of the smaller Basalt (Grade 6) is lower than the initial Skid Resistance DFT (μ) of the larger Basalt (Grade 4), its ESR Polished DFT (μ) is significantly higher for the smaller Basalt (Grade 6) size than the Grade 4.
- The larger Grade 4 Basalt chip size appears to be more susceptible to the contaminants as compared to the smaller Grade 6 chip size. This is most likely to be due to the increased polishing tyre / aggregate contact area on the Grade 4 sample. in comparison to the Grade 6 sample.

Comparison of current results with previous Research:

In this study, a relatively fine grained South Auckland Greywacke was tested as part of the selected aggregates. Previous research by Wilson (3) had tested two other fine grained greywackes (one in Northland and the other also from the South Auckland area but a different quarry and operator). The results of the polishing to ESR of all three greywacke samples from different quarries but similar fined grained nature are shown in Figure 7.

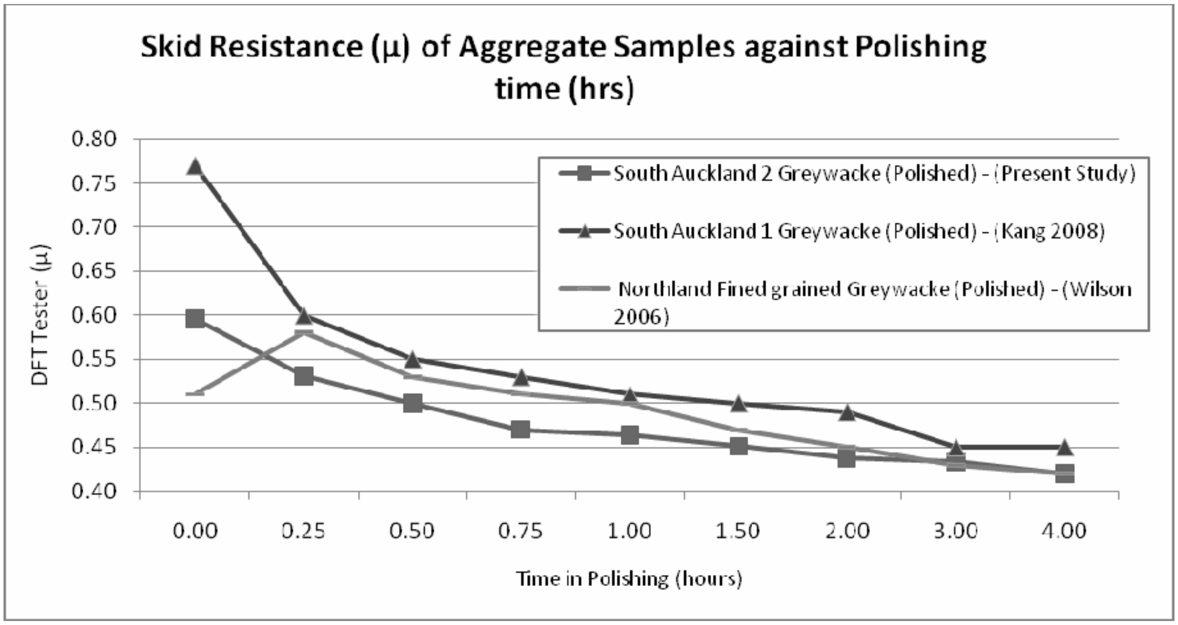

Figure 7: Stage 1. Polishing on Greywacke (Present Study, Kang [5] and Wilson [4])

After some surprising differences for the initial measured skid resistance, all three samples polished in very similar patterns to produce an ESR for all three samples within a coefficient of friction range of 0.04 (0.41 to 0.45µ). The very similar polishing trend (rate of decrease) and the end ESR result is expected as the geological source material and the grain sizes within the sedimentary matrix are all very similar. The differences in the initial skid resistance value is thought to be related to the quarry crushing process and/or the method of construction of the laboratory sample and that three different technicians built the samples. Once initial polishing or roughening up phases are complete, the three fine grained greywackes have performed very similarly.

Figure 8 shows the differences between the three greywacke aggregates during the second stage of polishing with the addition of contaminants. Once again after the initial skid resistance differences was polished away very similar end results for each stage of polishing with contaminants occurred.

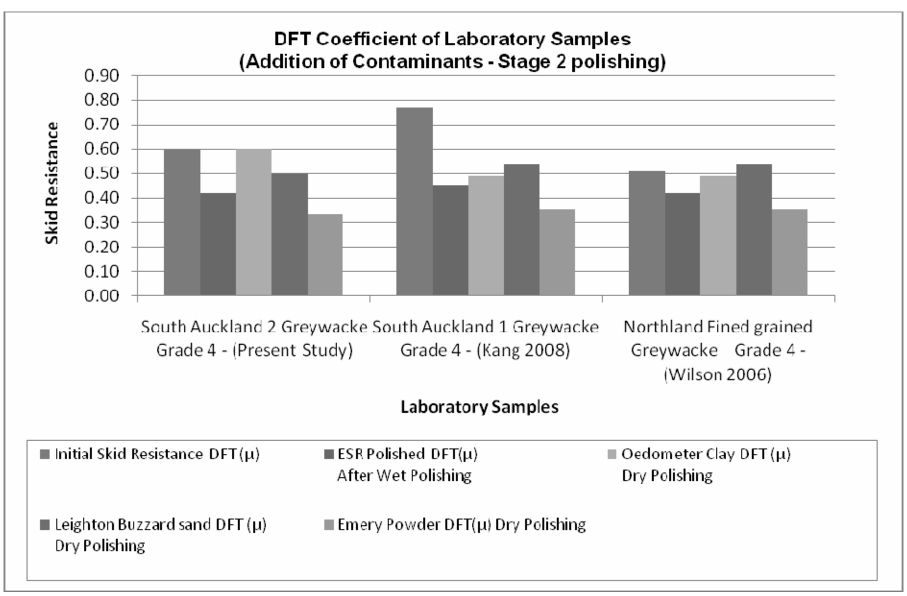

Figure 8: Stage 2 Polishing on Greywacke (Present Study, Kang [5] and Wilson [4])

SUMMARY AND CONCLUSIONS

This paper discusses the results of a student based research project undertaken at the University of Auckland that investigated the effect of decreasing the surfacing chip size from Grade 4 to Grade 6 of two natural South Auckland aggregates (a greywacke and a basalt) and compares their results with the performance of an artificial electric arc furnace aggregate. The laboratory prepared surfaces were polished under accelerated polishing in the laboratory and periodically tested with a Dynamic Friction Tester. The research findings were:

- The accelerated wet polishing of aggregates (without any contaminant additions) can be used to polish natural as well as artificial aggregates to an “Equilibrium Skid Resistance” (ESR). However rates at which they decrease are material dependent and a large portion of such decrease takes place in the first hour of the accelerated polishing. This shows that, in terms of field performance, most surface aggregates (depending upon traffic loads) will reach their ESR in relatively short periods of time (one or two years) compared to their design life;
- Under stage 2 polishing with the addition of contaminants, the research has reconfirmed earlier research by Wilson (2006) that found that the ‘approximately sinusoidal’ effect of the variation in measured skid resistance is neither a repeatable, nor a predictable, phenomenon but the nature of extremes can be predicted. A better understanding of what causes the variation to occur is required. If the causal effects are known, this will enable better decision making by road managers that will lead to better road management in terms of surfacing techniques and practices;
- Under controlled laboratory based conditions, the variations observed and measured in the field (both decreases and increases from ESR) can be simulated;
- Essentially, the significant variation in measured skid resistance observed in the field is primarily due to both the geological properties of the aggregates, the traffic and geometric loadings as well as the contaminants used in the polishing process;
- By decreasing the chip size from Grade 4 to Grade 6 for the same geologically sourced material (South Auckland 2 Greywacke and the South Auckland Basalt material) the Skid Resistance DFT (μ) increased significantly (approx 25% and 35% for the basalt and greywacke respectively);
- Overall, the Grade 4 Greywacke and Grade 4 Basalt were more susceptible to the contaminants as compared to the smaller Grade 6 materials.

In summary, by combining the recent aggregate samples and the previously tested fined grained greywacke samples together (1 from the present study and two previous studies, Wilson (4) and Kang (5)), the ranked ESR value with their respective chip grade sizes that best describes an equilibrium level for the aggregate can be summarised in the Table below:

Table 1: Comparative Ranking

Aggregates and Research project	Chip Size (Grade)	Time for ESR (Hour)	ESR (μ)	Ranking
Electric Arc Furnace (Present Study)	4	4	0.70	1
South Auckland 2 Greywacke (Present Study)	6	4	0.58	2
South Auckland Basalt Grade 6 (Present Study)	6	4	0.53	3
South Auckland 1 Greywacke (Kang [5])	4	4	0.45	4
South Auckland Basalt (Present Study)	4	4	0.43	5
South Auckland 2 Greywacke (Present Study)	4	4	0.42	6=
Northland Greywacke (Wilson [4])	4	4	0.42	6=

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