Polishing Aggregates to Equilibrium Skid Resistance

Douglas Wilson
The Department of Civil and Environmental Engineering
The University of Auckland
Email: dj.wilson@auckland.ac.nz

Roger Dunn
The Department of Civil and Environmental Engineering
The University of Auckland
Email: rcm.dunn@auckland.ac.nz

ABSTRACT

This paper discusses the results of a current Transfund NZ research project being undertaken by the Department of Civil and Environmental Engineering at the University of Auckland in conjunction with Works Infrastructure Limited on the “Effects of contaminants and rainfall on measured skid resistance”.

The ‘approximately sinusoidal seasonal’ effect of low skid resistance in the summer and high skid resistance over the winter period is well known. This relates to the measurement of skid resistance in New Zealand by SCRIM over the summer period that is reported by the Mean Summer SCRIM Coefficient (MSSC). However, the cause of this ‘approximately sinusoidal’ effect is little understood.

Recent research undertaken by the University of Auckland in the Northland Transit New Zealand PSMC 002 Region and in Auckland has clearly shown that the ‘approximately sinusoidal’ effect of the variation in measured skid resistance is neither a repeatable, nor a predictable, phenomenon. Clearly, 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 which will lead to more appropriate road management in terms of surfacing techniques and practices. This will ultimately lead to a safer road network for all road users.

The paper reports on Stage 1 of the project that developed a controlled laboratory experiment using the Dynamic Friction Tester, and an accelerated polishing machine to simulate in-field variation of measured skid resistance. The paper discusses the development of testing procedures, methodologies and laboratory equipment and presents results to date in simulating the in-field polishing of road surface aggregates to equilibrium skid resistance levels for a range of high to low PSV aggregates. The experiments were undertaken on prepared chip sealed surface samples that were subjected to cycles of polishing and periodic skid testing.

1. INTRODUCTION

This paper discusses some preliminary results of a current Transfund NZ research project being undertaken by the Department of Civil and Environmental Engineering at the University of Auckland (UoA) in conjunction with Works Infrastructure Limited (Works) on the "Effects of contaminants and rainfall on measured skid resistance".

1.1 BACKGROUND

The 'approximately sinusoidal seasonal' effect of low skid resistance in the summer and high skid resistance over the winter period is well known. This relates to the measurement of skid resistance in New Zealand by SCRIM over the summer period that is reported by the Mean Summer SCRIM Coefficient (MSSC). However, the cause of this 'approximately sinusoidal' effect is little understood.

Recent research undertaken by the UoA in the Northland Transit NZ PSMC 002 Region and in Auckland has clearly shown that the 'approximately sinusoidal' effect of the variation in measured skid resistance is neither a repeatable, nor a predictable, phenomenon. Furthermore, skid resistance has been shown to vary significantly within relatively short periods of time (i.e. days rather than months) and to such a degree that significant proportions of the network can be 'drifting" in and out of requiring intervention. Road asset managers, therefore, have an unenviable task of making appropriate asset management decisions on variable data with limited financial options for long term low-risk improvements. Clearly, 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 which will lead to more appropriate road management in terms of surfacing techniques and practices. This will ultimately lead to a safer road network for all road users.

This paper discusses the development of equipment, a methodology for testing and some preliminary results of controlled laboratory experiments undertaken on prepared laboratory based chip sealed surface samples. The prepared samples of various levels of Polished Stone Value (PSV) were then subjected to cycles of polishing to Equlibrium Skid Resistance (ESR) levels. The skid resistance was measured periodically with a static skid tester, the Dynamic Friction Tester.

1.2 SEASONAL VARIATION

Studies in the UK (Salt, 1977), US (Jayawickrama and Thomas, 1998) and New Zealand (Cenek et al, 1999) all indicate an 'approximate sinusoidal' variation in skid resistance with seasonal change. This variation has been found to be as high as 0.15 MSSC (Mean Summer SCRIM Coefficient) between winter and summer months.

As discussed by Jayawickrama and Thomas (1998), there is general consensus among researchers regarding the following mechanism causing seasonal variation:

> "*Prolonged periods of dry weather in the summer allow the accumulation of fine particles that assist in polishing of the pavement surface. The combination of polishing and particle accumulation, together with the contamination from vehicles such as oil drippings and grease, results in a loss of microtexture and macrotexture during the summer months. In winter, the aggregate surface is rejuvenated with chemical reactions from the rainwater exposing new particles. The increased rain flushes out the finer particles responsible for polishing and*

> *other debris increasing macrotexture. The coarser aggregate surface and the increased macrotexture in turn lead to an increased skid resistance of the pavement."*

Some researchers also suggest that the water film covering the pavement for longer periods in winter acts as a lubricant and reduces the polishing effect of vehicles on the surface aggregate. Cenek et al (1999) suggest a better understanding of the effects of rainfall on long-term skid resistance is required to enable accurate modelling of these seasonal fluctuations.

Wilson and Kirk (2005), reported results from GripTester surveys over a two year monitoring programme on a straight and level control site (Hikurangi), that had reached equilibrium skid resistance levels (now six years old). The results were surprising due to the degree of variation over such short time durations, demonstrating that variations of up to 30% of measured skid resistance (a difference of 0.20 GN or approx 0.15 SFC) were possible within a three-week period. The concern arising from this research meant that sites that have been surveyed and have passed, can fail within weeks and sometimes even days later and vice versa. The possibility of such large variations was also reported in an earlier paper by Haydon and Hutchison (2002) who compared two successive years of SCRIM network surveys that were in one case only days apart and the other a few months apart.

These findings led the authors to apply successfully for Transfund NZ Research funding in 2004 to investigate the effects of contaminants and rainfall on the variability of road surfacing skid resistance.

2. THE RESEARCH PROJECT METHODOLOGY

2.1 RESEARCH OBJECTIVES

The primary objective of the research project was a better understanding of the factors that cause significant changes in skid resistance with time. Answers to the following questions were sought:

1) What was causing the variability in measurement and especially the mechanism for replenishment of the chip and over what period of time did this occur?
2) How would one know when the chip had reached its worn-out state and could this be predicted?
3) What surfacing treatments would last the desired asset life-cycle.

It was recognised that if these questions could be answered and understood by road asset managers, then improved skid resistance asset management would occur enabling better decision making.

The Transfund New Zealand Research Project firstly, and most importantly, allowed continued testing of the five monitoring sites in the Northland PSMC 02 network, on a minimum monthly basis for a further year. The previous year's monitoring had been funded by Works Infrastructure Ltd and the UoA. Furthermore, it enabled the development of laboratory equipment and procedures for the simulation of the in-field variation of skid resistance within a controlled laboratory setting. This paper reports specifically on the laboratory methods and procedures developed and discusses some of the laboratory test results.

2.2 THE LABORATORY EXPERIMENT

A controlled laboratory experiment was required to simulate the in-field skid resistance variation as shown by a time series of skid testing obtained using the GripTester in the Northland Region at the Hikurangi control site (refer to Figure 1). The laboratory experiment required the control and simulation of the effects of the following variables:

- Road pavement surfacings utilising the same materials used in practice;
- Temperature control;
- Traffic action simulating heavy commercial vehicle polishing effects;
- Contaminant loading;
- Rainfall / washing cycles;
- Stationary Skid Tester able to be used in the laboratory.

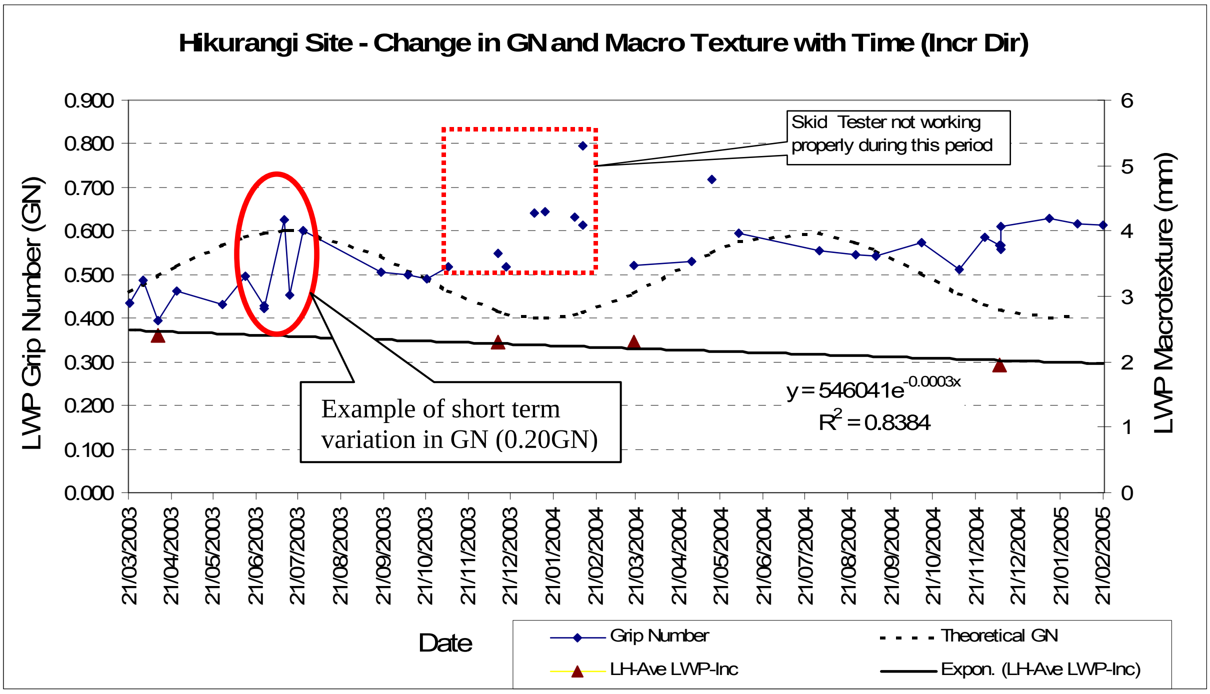

Figure 1: Variation of Skid Resistance (GN) at PSMC002 Control Site - Hikurangi

The experiment required laboratory testing equipment and surfacing samples to be constructed that were compatible with each other. As the UoA had recently purchased a stationary skid tester, this became the critical factor that determined most of the other experiment variables. The following sections discuss the methodology and laboratory equipment developed and / or chosen to undertake the controlled experiment.

2.3 THE DYNAMIC FRICTION TESTER

2.3.1 An Overview

The UoA in collaboration with Pavement Management Services (PMS) purchased a Dynamic Friction Tester (DFTester) in late 2003. The DFTester is a stationary skid testing device that complements the GripTester (a mobile fixed slippage and continuous friction measurement device) used by the UoA for skid resistance research and monitoring since late 2002.

The DFTester was designed mainly to measure the dynamic coefficient of friction on road surfaces. It can also be used as a static device to determine the friction on paved surfaces of footpaths, promenades, amusement parks and on floor surfaces of buildings and gymnasiums. It has been found to be very stable with time and to give highly reproducible measurements and has recently been chosen as the standard reference in the recently revised IFI ASTM International Standard (Henry, 2003). The testing procedure and methodology is described in ASTM Standard Test Method E-1911 (ASTM, 2003).

The DFTester (refer to Figures 2 and 3) is an easy-to-use portable device for use in obtaining friction data (dynamic coefficients of friction) on two surfaces in sliding contact. The measuring principle of the DFTester is based upon three standard rubber mounted slider pads fitted to the underside of a horizontal rotary disk of diameter 284mm. The disk bears on a wetted road surface through its rubber slider under a constant load W. It is orientated perpendicular to the surface and is rotated to set the pad in sliding motion up to a set speed. The force F required to overcome the dynamic friction is measured, and the linear speed V of the pad is determined from the rotary speed of the disk. The coefficient of friction μ is calculated as follows:

$$\mu = \frac{F}{W}$$

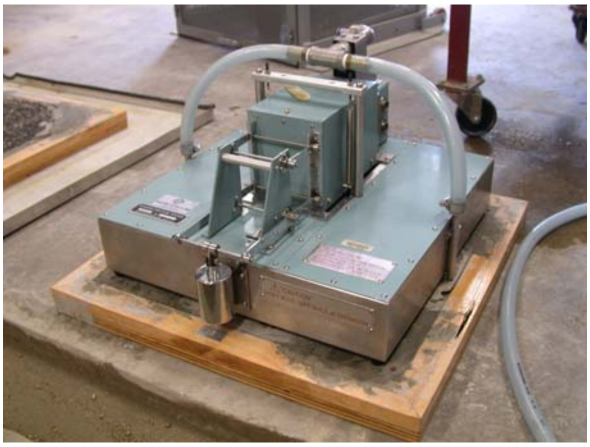

Figure 2: The DFTester on a Prepared Sample

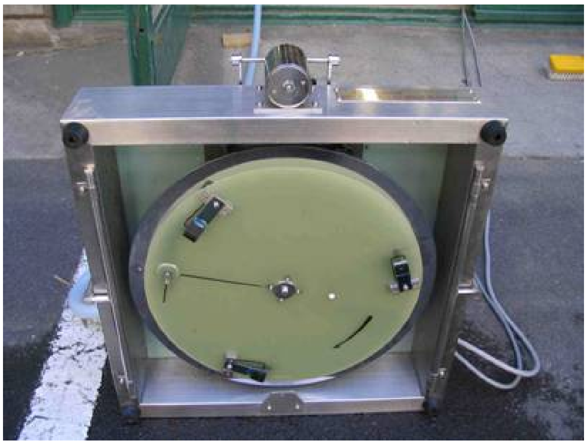

Figure 3: Rubber Sliders and Rotating Disk of DFTester

A significant benefit of the DFTester is that whilst being a stationary device, it has a significantly larger contact area than the British Pendulum Tester (and is less affected by individual chips). It has been found to produce stable and highly repeatable measurements over time. These benefits enable the use of this device as a calibration device for other Continuous Friction Measurement devices such as the GripTester and ROAR (PIARC, 1995).

2.3.2 Temperature Trials

Temperature is known to affect the measured coefficient of friction and various testing devices. Some are more sensitive than others (Wilson et al, 2003). Some skid testing devices (such as SCRIM and the British Pendulum Tester) apply temperature correction factors and others do not (such as the GripTester and the DFTester). As the DFTester was used for controlled laboratory experiments, it was decided to undertake a series of experiments on the prepared samples for a wide range of temperatures to determine the sensitivity of the device to temperature changes. At the same time the effect of changing the DFTester rubbers from worn rubber sliders to new rubbers was undertaken. Figure 4 shows the results of these tests. The numbered positions of the graph are consistent for each sample tested and relate to the following variations in the testing methodology:

Position 1: Test sample and water used for testing both refrigerated to 4°C prior to testing - New rubbers.

Position 2: Test sample refrigerated to 4°C however normal tap water temperature used for testing (approx 17-17.5°C) – New rubbers.

Position 3: Test sample tested when sample surface, air temperature and water temperature all range between 18.5 and 20°C - Old rubbers.

Position 4: Test sample tested when sample surface, air temperature and water temperature all range between 19 and 20°C - New rubbers.

Position 5: Test sample tested when sample surface had been heated in an oven up to 55°C and the air temperature and water temperature ranged between 19 and 20°C - New rubbers.

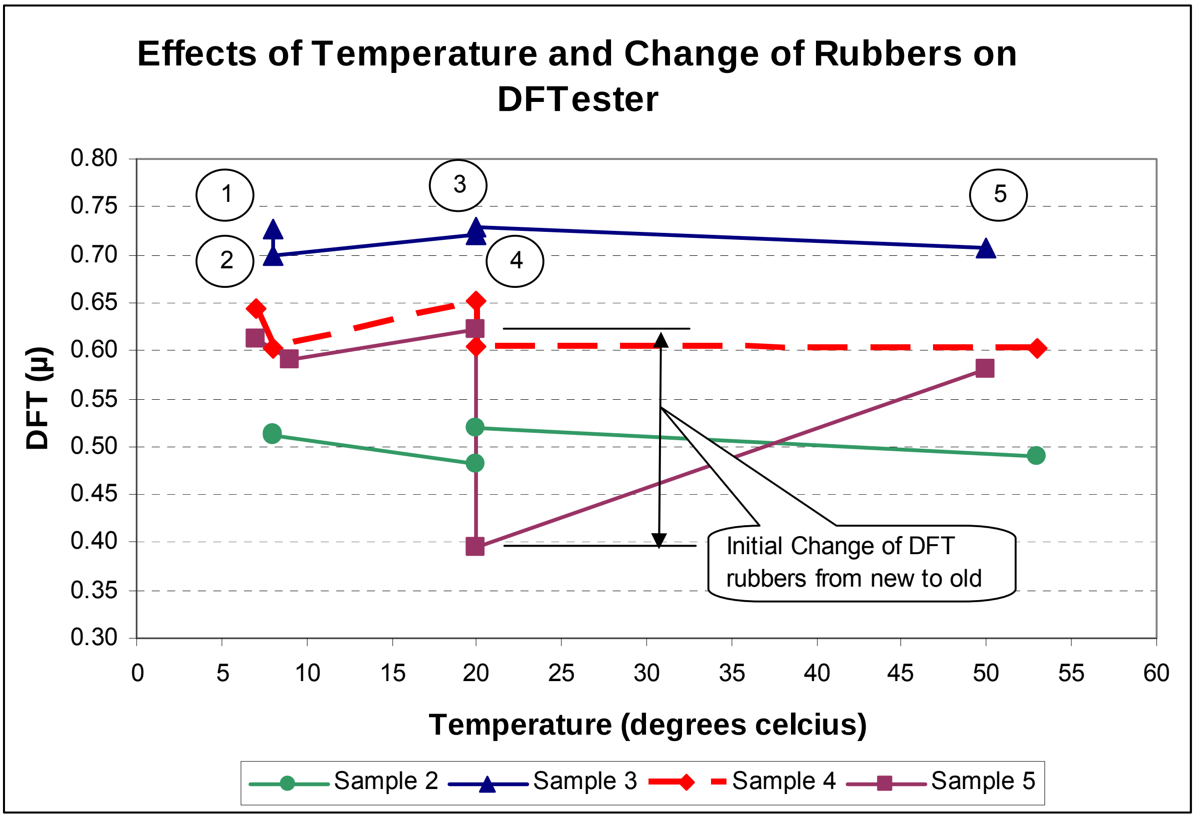

Figure 4: The effects of Temperature and Change of Rubber Sliders on DFTester Results.

The results of the temperature trials using the DFTester are shown in Figure 4 and demonstrate that:

- The measured coefficient of friction is very insensitive to change in surface and / or air temperature for the normal ranges that could be expected in New Zealand (difference between positions 1,2,4 and 5);
- Using very cold water temperatures for the skid testing slightly increases the measured coefficient of friction (difference between positions 1 and 2);
- Changing the DFTester rubbers significantly reduces the first few test results (refer to Sample 5), however this effect quickly wears off as the rubber sliders roughen and become conditioned (difference between positions 3 and 4 of Samples 2,3 and 4).

2.3.3 Correlating the DFTester with the GripTester

Figures 5 and 6 show a comparison of a GripTester survey measuring the coefficient of friction every 1m and a stationary DFTester coefficient of friction measured at intervals of 1m. The site being measured is an asphalt mix surface (Mix 14) and the surface is now approximately three years old. The location of the survey was at an intersection of a carpark entrance where the turning movements had polished the pavement surface to a greater extent than the approaches. A significant correlation between the two friction measurement devices is achieved with an R^2 of 0.81 with 35 data points. This gives some confidence that the DFTester could be used in the laboratory and could be correlated against in-field results of the GripTester on similar surfaces.

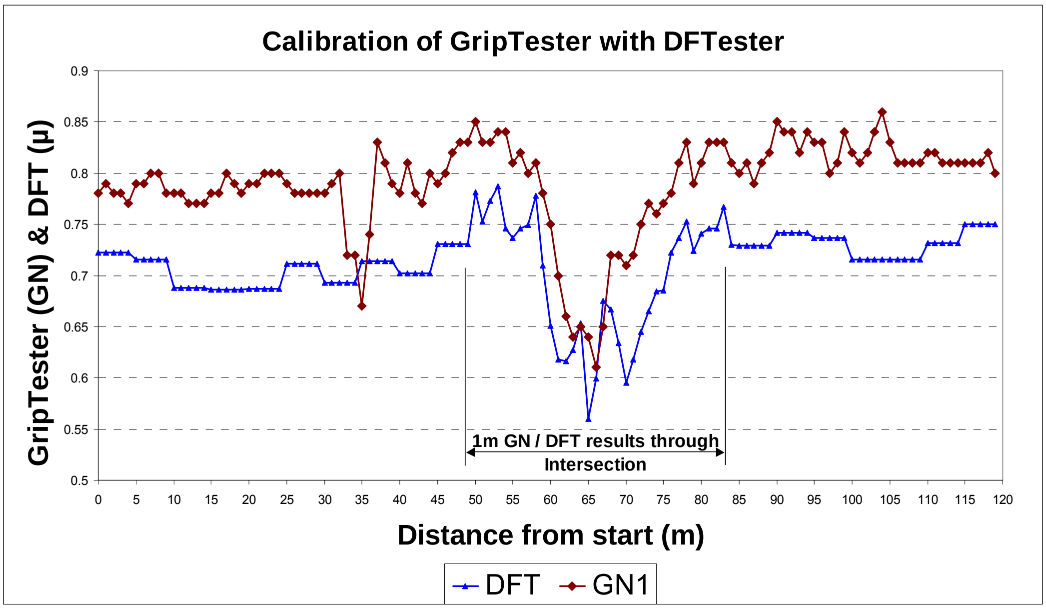

Figure 5: A comparison of the GripTester and the DFTester through an Intersection

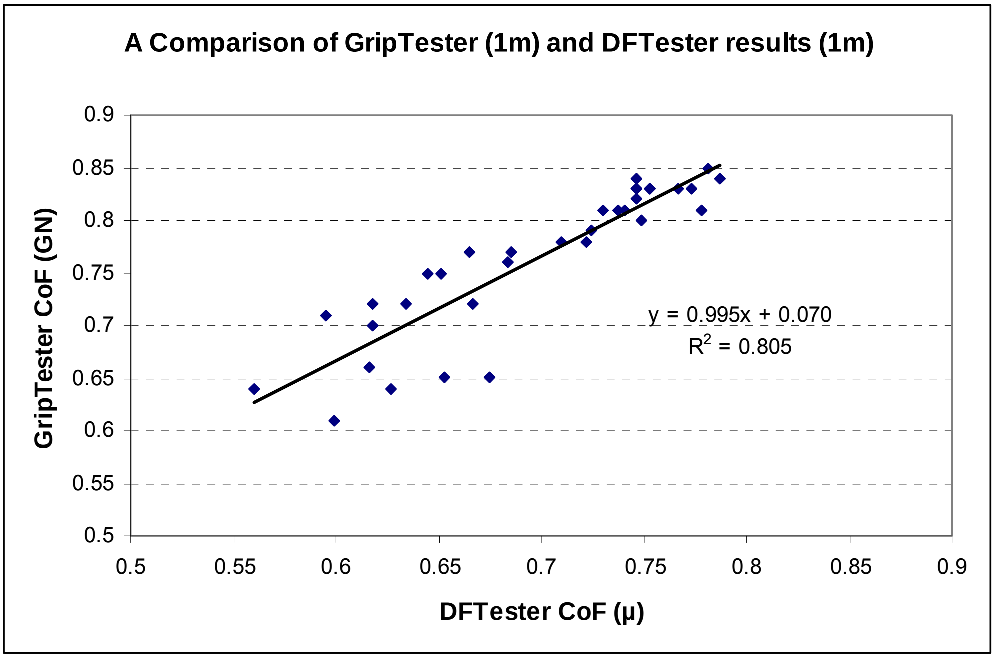

Figure 6: GripTester – DFTester Correlation Results through Intersection

2.4 The Accelerated Polishing Machine

To enable the simulation of the 'approximately seasonal' skid resistance effect required a method of simulating heavy vehicle traffic action on prepared chip seal surfacing samples. Furthermore, this variation occurs only after an 'equilibrium level of skid resistance' (ESR) has been reached. This depends upon the:

- resistance of aggregate to polishing, traditionally measured by the Polished Stone Value (PSV) test, and
- number of passes of heavy commercial vehicles.

An international literature review was undertaken to consider various options for polishing, testing and analysing pavement surface frictional properties in the laboratory. A laboratory device was required to polish a prepared surface sample to ESR. The device also needed to be compatible with the DFTester and therefore polish on a circular track at the same diameter as the DFTester rotating disk, that is, 284mm diameter to the centre of the rubber sliders. Testing methods considered in the review were:

- The accelerated polishing machine used in the PSV test in conjunction with the British Pendulum Tester (AS1141.40, 1999);
- A scuffing wheel apparatus developed by the TRL for determining the resistance to wear by scuffiing of high friction surfaces at elevated temperatures (Nicholls, 1997, Appendix G);
- A 'road machine' apparatus (with standard car tyres) developed by the TRL for determining the resistance to wear by repeated turning wheels of a high friction surface at low temperatures (Nicholls, 1997, Appendix H);
- National Centre for Asphalt Technology (NCAT) 'slab polishing machine' developed in the US to specifically wear samples at an appropriate diameter for the DFTester (McDaniel and Coree, 2003).

A number of devices, such as the accelerated polishing machine used in the PSV test, were ruled out due to the surface sample size required by the use of the DFTester and the expense and timeframe required to develop and assemble the apparatus.

A decision was made to proceed with developing a device similar to the NCAT slab polishing machine method. This device was developed specifically for use with the DFTester and polishes the prepared sample in the same circular motion as the DFTester. This was seen to be of benefit as it would simulate in-field traffic action that occurs in the wheel paths. The developers of the NCAT device and Purdue University, who developed a similar machine, were contacted and permission was gained to design and build an accelerated polishing machine based upon the principles of the NCAT device. Some modifications were made to the mechanical operation to better control the loads on the wheels whilst also taking account of the higher macrotexture and irregularities of chip seal samples common in New Zealand. This is in contrast to the concrete or asphalt mix samples that the NCAT apparatus was developed for in the US.

The main features of the accelerated polishing machine developed at the UoA are:

- Three castor wheels with rubber tyres, filled with rubber to a constant tyre pressure of 20 psi and rotating on a diameter of approximately 284mm;
- A loaded wheel assembly weight of approximately 57kg over the three wheels;
- A variable drive electric motor and gearing to enable a maximum speed of 47 rpm at a motor speed of 50 Hz.

Figures 7 and 8 show the UoA accelerated polishing machine and the wheel assembly unit in operation on a prepared sample.

Figure 7: The UoA Accelerated Polishing Machine

Figure 8: The Accelerated Polishing Machine wheel assembly unit in operation

2.5 TEXTURE MEASUREMENT

Ideally, the macrotexture could have been tested utilising the CTMeter which is a companion apparatus to the DFTester and measures the two dimensional texture of the surface by laser. The CTMeter features the same circular diameter as the

DFTester and gives Mean Profile Depth (MPD). However, this apparatus was unavailable to the project and therefore the volumetric texture depth was measured by the Sand Circle Test as set out in TNZ specification T/03 (1981). This method determines the average texture depth (TD) at the centre of a surface sample by measuring the diameter of the circle formed when a known quantity of sand (50ml) to a specified grading is spread evenly over the surface.

2.6 BUILDING THE SURFACE SAMPLES

A stable and robust method of constructing a chip seal surface sample was required to be large enough to be polished and then tested by the DFTester. A number of trial construction methods were attempted before settling upon a surface sample method prepared by:

- Selecting Grade 4 aggregate samples sieved through a 9.5mm sieve, with any flaky aggregate either sieved out with a slotted sieve and / or rejected by hand;
- Hand placing selected cubically shaped chip seal aggregate upside down on a glass surface embedded in a thin layer of sieved sand through a 3 or 6 micro-millimeter sieve;
- Mixing a 1:1 mix of sand and cement and pouring the mix over the prepared sample, taking care not to move any of the aggregate chips;
- Once the mix was set (approximately one day later), turning over the sample and brushing away the excess sand and setting the circular sample in a 1:1 sand and cement mortar mix. This was placed into a prepared 600mm x 600mm timber frame mould mounted on 18mm thick plywood.
- Labelling and numbering the samples before any polishing or testing.

Figure 9 shows a surfacing sample after being hand placed and prior to being fixed in mortar and Figure 10 shows a completed sample ready for testing.

Figure 9: Hand placed Sample preparation

Figure 10: Completed sample in timber frame

3. EXPERIMENTAL DESIGN

3.1 METHODOLOGICAL APPROACH

A laboratory experiment was designed to simulate the variation of skid resistance observed for a typical range of chip-seal aggregates used in New Zealand. The aggregates tested were to specifically include, (with others) local aggregates used by Works in the Northland Region on the PSMC 002 contract. The sample variables that were initially considered for the experimental design were:

- The aggregate source and resistance to polishing as measured by the PSV test;
- Chip size (i.e. to determine surface macrotexture), and
- Traffic loading.

Due to the time and cost constraints of the project it was decided that a similar grading size would be used for all samples in an attempt to deliver a similar macrotexture for the prepared samples. The aggregate source was obtained from a TNZ Grade 4 chip stockpile that was further sieved through a 9.5mm sieve. The effects of varying texture on skid resistance measurement have been well reported by Oliver (2003), Wilson et al (2003) and the PIARC (1995) Harmonisation project and were seen as a non-essential component of this research project. For initial experiments, it was decided to keep traffic loading constant in terms of the vertical loading (57kg over three wheels). Two samples of each aggregate source were constructed, one to be the master control sample that was not polished and the other sample polished by the accelerated polishing machine. Table 1 gives the details of the samples developed for testing.

To examine and simulate the 'approximately seasonal' variation of measured skid resistance required two stages of laboratory testing, being:

Stage 1: Polishing the prepared surface samples to Equilibrium Skid Resistance (ESR) level; and

Stage 2: Simulating the cyclical effects of variation of the summer, winter polishing, rejuvenation of surface samples through the effects of contaminants, rainfall and vehicle trafficking.

This paper is focused on the results of Stage 1 and is discussed in the following sections.

Sample Number	Aggregate Source	PSV	Macro-texture TD (mm)	Comment / Descript
1	Moutohora	65	-	Prototype
2	Moutohora	65	1.0	Polished
3	Moutohora	65	1.0	Un-polished
4	Hunua	55	0.8	Polished
5	Hunua	55	0.9	Un-polished
6	Otaika	51	0.9	Polished
7	Otaika	51	1.0	Un-polished

Table 1: Laboratory Test sample details

3.2 POLISHING TO EQUILIBRIUM SKID RESISTANCE LEVELS

A procedure was developed to polish and test the skid resistance of the samples using the following steps:

1) Lightly clean the prepared samples with water.
2) Test the paired samples for the coefficient of friction of both the un-polished and the 'to-be' polished sample three times each utilising the DFTester at initial slip speed of 60km/h.
3) Polish the sample marked 'polished' for 15 mins with continual watering and no addition of contaminants.
4) Repeat Step 2 and test both samples with the DFTester.
5) Repeat Step 3 for another 15mins and once again repeat Step 2.
6) Continue polishing the polished sample at the following time intervals or until ESR is reached (0, 15mins, 30mins, 45mins, 60mins, 90mins, 120mins, 3hrs, 4hrs, 5hrs, 6hrs and 7hrs if required).

4. EXPERIMENTAL RESULTS

4.1 INITIAL AND EQUILIBRIUM SKID RESISTANCE

All three paired aggregate samples were tested by the procedure set out in Section 3.2. Table 2 shows the results for the coefficient of friction (μ) for an average slip speed of between 20 and 40km/h as measured by the DFTester.

Polishing Hours	Coefficient of Friction using DFTester					
	Moutohora PSV 65		Hunua PSV 55		Otaika PSV 51	
	S2-Pol	S3-UnP	S4-Pol	S5-UnP	S6-Pol	S7-UnP
0.00	0.90	0.90	0.60	0.61	0.51	0.59
0.25			0.65	0.57	0.58	0.55
0.50			0.60	0.59	0.53	0.50
0.75			0.57	0.58	0.51	0.49
1.00	0.77	0.87	0.53	0.58	0.50	0.48
1.50			0.50	0.58	0.47	0.45
2.00	0.68		0.46	0.56	0.45	0.44
3.00	0.62	0.83	0.44	0.55	0.43	0.44
4.00	0.54	0.81	0.41	0.54	0.42	0.43
5.00	0.52		0.39	0.56		
6.00	0.52	0.78				
7.00	0.49	0.75				

Table 2: Results of Polishing the Samples to Equilibrium Skid Resistance

Figure 11 compares the coefficient of friction of the paired sample results for the polished and unpolished samples of the Moutohora aggregate with a PSV of 65. The results show:

- A high initial measured coefficient of friction of approximately 0.87 for both samples was achieved;
- The polished sample took approximately seven hours of polishing by the accelerated polishing machine to level off to ESR;
- The coefficient of friction reduced by 46% from initial measurements to ESR for the polished sample;
- The coefficient of friction for the unpolished control sample reduced by approximately 20% with approximately 33 tests (3x11) of the DFTester;
- The polished sample ended up approximately 30% lower in measured skid resistance than the unpolished sample;

- A highly significant statistical polynomial prediction equation can be fitted to the polished sample data points with $R^2 = 0.99$;
- The variation in measured coefficient of friction after the ESR had been established for the polished sample (Sample 2) were largely due to trialing changes in loads and wet and dry polishing cycles. This indicates that laboratory simulations of in-field 'seasonal' variations in measured skid resistance after the ESR is reached is likely (this will be reported on in subsequent research).

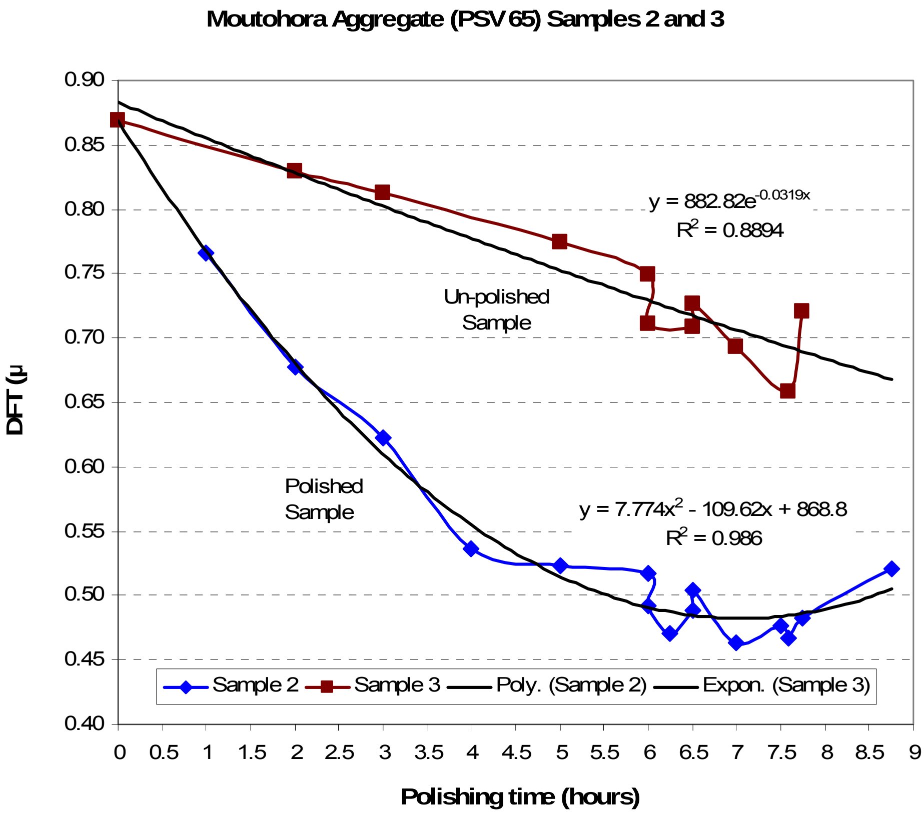

Figure 11: DFT results of Moutohora Aggregate on polished and unpolished samples.

Figure 12 compares the paired sample results of the polished and unpolished samples for the Hunua aggregate with a PSV of 55. The results show:

- An initial measured coefficient of friction of approximately 0.60 was achieved for both samples;
- The polished sample took approximately five hours to level off to ESR;
- The coefficient of friction reduced by 39% from initial measurements to ESR for the polished sample;
- The coefficient of friction for the unpolished control sample reduced by approximately 8% with approximately 30 tests (3x10) of the DFTester;
- A significant statistical polynomial prediction equation can be fitted to the polished sample data points with $R^2 = 0.95$.

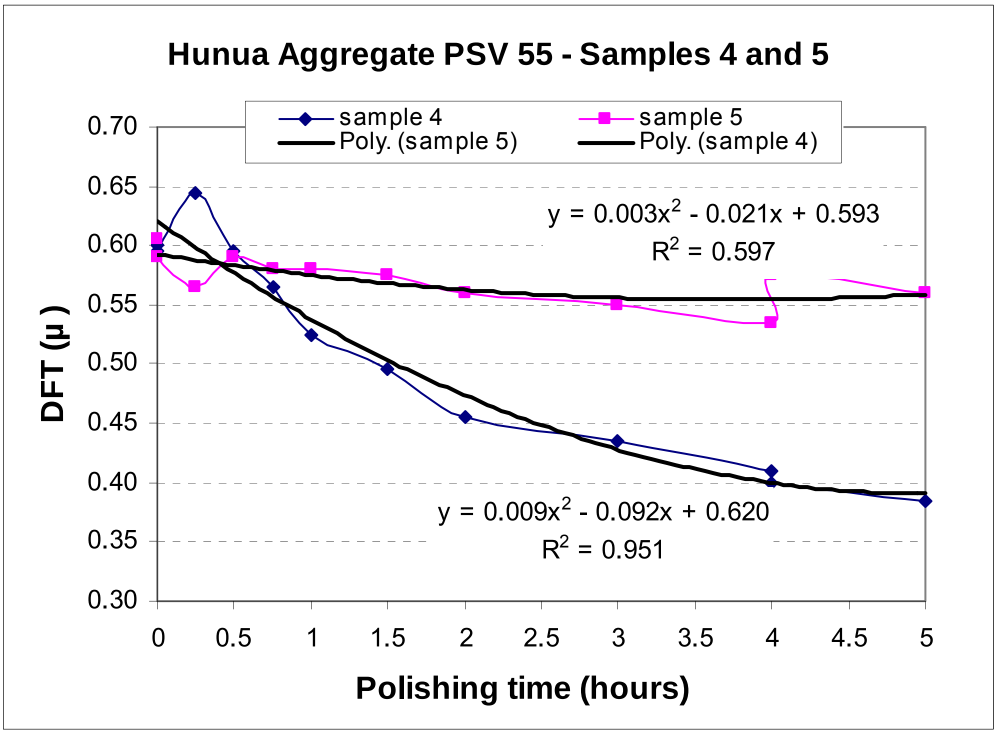

Figure 12: DFT results of Hunua Aggregate on polished and unpolished samples.

Figure 13 compares the paired sample results of the polished and unpolished samples for the Otaika aggregate (a locally sourced aggregate in the Northland Region) with a PSV of 51. It should be noted that the Otaika aggregate in terms of PSV is the lowest quality aggregate source specified for use in Transit NZ sealing aggregates (Transit NZ, 2004). The results show:

- An initial average measured coefficient of friction of approximately 0.55 for both samples although the samples demonstrated a 0.08 difference in initial measured coefficient of friction;
- Interestingly, this aggregate for both the polished and unpolished samples performed approximately the same in terms of the deterioration of measured coefficient of friction;
- The polished sample took approximately four hours to level off to ESR;
- The coefficient of friction reduced by 24% from initial measurements to ESR for the polished sample;
- The coefficient of friction for the unpolished control sample also reduced by approximately 23% with approximately 30 tests (3x10) of the DFTester;
- The polishing action of the DFTester (3x8=24 tests) for this lower PSV specified aggregate, is surprisingly, more aggressive initially than the accelerated polishing machine with two hours of polishing;
- A significant statistical polynomial prediction equation can be fitted to the polished sample data points with R^2 = 0.82.

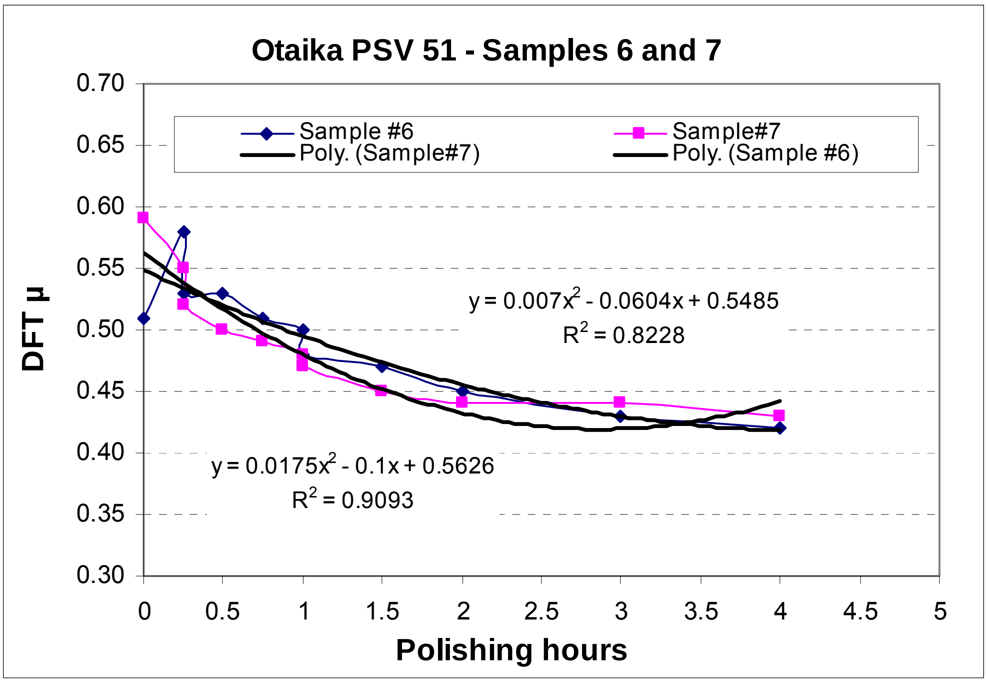

Figure 13: DFT results of Otaika Aggregate on polished and unpolished samples.

4.2 DISCUSSION OF THE EXPERIMENTAL RESULTS

A comparison of the results of the three aggregate samples that were polished to an ESR level and tested for their coefficient of friction using the DFTester demonstrates some interesting results. These are:

- The PSV of the aggregate generally predicts the ranking order of the initial level of skid resistance of natural aggregates prior to any accelerated polishing;
- The difference between the initial levels of skid resistance significantly reduces with natural aggregates as the PSV of the aggregate reduces;
- The percentage reduction in measured skid resistance from the initial level of skid resistance to ESR reduces as the aggregate PSV reduces;
- The lower the PSV of the aggregate the faster the aggregate polishes to its ESR level;
- There is very little difference in the final level of ESR obtained for the three natural aggregate samples; and
- The ranking order of the final level of ESR for the three samples is not the same as the PSV ranking.

The variations shown after ESR has been reached on Sample 2 in Figure 11 begin to demonstrate the seasonal variation effects that the Transfund research project is attempting to simulate in the laboratory as part of Stage 2. Research is continuing on this aspect with the addition of contaminants and rainfall cycles.

5. SUMMARY AND CONCLUSIONS

Experience has shown that predicting skid resistance and, therefore, time to treatment intervention, is very difficult due to the inherent variability of skid resistance measurement. The variability is due largely to environmental factors (temperature, detritus buildup, rainfall and cyclical polishing/ abrading rejuvenation cycles) and the skid testing equipment and methodology used. Separating out these factors and determining their individual statistical significance has been difficult historically.

This paper discusses the development of testing procedures, methodologies and laboratory equipment. Results are presented on the sensitivity of laboratory equipment to variables and the simulation of the in-field polishing of road surface aggregates to equilibrium skid resistance levels for a range of high to low PSV aggregates.

In terms of the Dynamic Friction Tester, the research has demonstrated that the DFTester:

- Can be correlated against the GripTester very well when using the 1m measuring mode of the GripTester;
- Is a highly repeatable device and is very insensitive to change in temperatures that could be expected in New Zealand;
- Rubber sliders need a few tests to 'roughen' and 'condition' the rubbers before measured results should be utilised.

The research and experimental results of Stage 1 of this project have shown:

- That large hand placed surface samples, whilst time consuming, can be prepared for laboratory testing using the DFTester;
- The accelerated polishing machine developed can simulate in-field polishing of aggregates to an equilibrium skid resistance level;
- That for similar macrotextures, generally the higher the PSV of the aggregate the higher the initial value of skid resistance prior to any polishing;
- The higher the PSV of the aggregate the greater the total loss of measured skid resistance to equilibrium skid resistance levels;
- Equilibrium level skid resistance was reached on most of the samples at around 4 to 6 hours of accelerated polishing with the greatest loss of skid resistance being for the higher PSV type aggregates (30% to 50% of initial skid resistance value);
- After ESR has been reached, indications are that short term 'seasonal type' up and down variations can be simulated in the laboratory;
- The final level of ESR reached for each of the natural aggregates were not that dissimilar;
- The PSV test is not necessarily a good indicator of the equilibrium level of skid resistance.

The University of Auckland has been undertaking field and laboratory experiments in conjunction with Works Infrastructure Ltd to try to better understand the causes of skid resistance variation. The research is ongoing, and the controlled laboratory experiments have recently been extended to Stage 2 to simulate the in-field seasonal changes that occur. It is hoped that the primary causal factors of skid resistance can be simulated and explained using the techniques and laboratory equipment described in this paper. This research is aimed at the development of better predictive methods and, therefore, enhancement of the management of skid resistance by Road Controlling Authorities and their respective delegated managers.

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