CORRELATION BETWEEN LABORATORY AND FIELD PERFORMANCE OF GREYWACKE AGGREGATES

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ABSTRACT

A number of studies have been undertaken to compare and correlate the skid resistance of laboratory based test methods and the in-field performance of road surface pavements with the same aggregates.

This paper presents results of research undertaken in 2010 at The University of Auckland that uses a different approach to monitoring specific sites over time. Instead, various road sections with the same source aggregates were surveyed with varying age and traffic loads using the Grip Tester. The roads tested had different age and are exposed to different traffic volumes and percentage of Heavy Commercial Vehicles (HCV). The research primarily focuses on two coat sealed pavement surfacing constructed using a South Auckland Greywacke aggregate.

The paper analyses the in-field performance of the Greywacke aggregates and demonstrates that it correlates well with the University of Auckland Laboratory based Accelerated Polishing device results. The measured variation of the skid resistance values of pavement surfacing of the same age can be better correlated when various ranges of macrotexture, traffic flow, and percentage of HCV's are taken into account. Furthermore, the results were compared to the performance of Greywacke aggregates produced by different quarries and correlated to the road crash rates, especially loss of control in wet crashes.

INTRODUCTION

Wet pavement road accidents are a major concern for highway and road safety engineers. Many researchers have shown that when the pavement is dry, the skid resistance is generally adequate to fulfill the friction demand. When the pavement is wet, however, the skid resistance is significantly reduced and sometimes results in the pavement being unable to provide sufficient friction (Pardillo Mayora & Jurado Piña, 2009). To provide safe travel for road users, it is necessary to ensure that road surfaces have an adequate level of skid resistance at all times (Cafiso & Taormina, 2007). There are several laboratory test methods available to predict the long term performance of pavement surfaces. However, laboratory based test methods do not necessarily imitate the in-field results due to the limitations of the laboratory test methods, such as the incapability to mimic the polishing action of the actual traffic (Do, Tang, Kane, & de Larrard, 2007).

Skid Resistance

Skid resistance is described as the contribution of pavement to the surface friction or more specifically, as the friction generated between the tyre and road surface or pavement (Cafiso & Taormina, 2007; Do, et al., 2007; Oliver, 2009; Pardillo Mayora & Jurado Piña, 2009; Wilson, 2006). There are two pavement characteristics that primarily influence the skid resistance, being the microtexture and macrotexture (Cafiso & Taormina, 2007; Do, et al., 2007; J. Henry & Meyer, 1984; Kokkalis & Panagouli, 1998; Oliver, 2009; Pardillo Mayora & Jurado Piña, 2009; Wilson, 2006; Yeaman, 2005).

Measured skid resistance is dependent upon various factors, which can be classified into four main sources of variables (Wilson, 2006):

- Surface aggregate

- Load factors
- Environmental factors; and
- Vehicle factors.

Out of the factors mentioned above, only the surface aggregate factors and partially the load factors are controllable by design (Kumar & Wilson, 2010). This research will focus on the surface aggregate factors.

Polishing of Pavement Surfaces

Research has shown that an aggregate's resitance to polishing can deteriorate over time; although it is still not confirmed definitively how traffic, weather, and other factors affect the aggregates performance (Henry & Meyer, 1984). Recently, a number of studies have been dedicated to improve the methods to accurately predict the performance of aggregates under in-service factor influences (Wilson & Black, 2009). The selection of aggregates influences the skid resistance performance of the road, therefore it is important to know how aggregates deteriorate thereby reducing measured skid resistance (Senior & Rogers, 1991). It would be beneficial for road engineers to be able to forecast the deterioration before the pavements are constructed so that maintenance can be planned in advance (Do, et al., 2007).

The long term skid resistance performance is assessed by the ability of the aggregates to resist polishing effects (M.-T. Do, et al., 2007). There are several laboratory based test methods available to determine the skid resistance of the pavement surfaces. One of the most popular and the oldest method is the Polished Stone Value (PSV) test. The procedure involves polishing a prepared sample using an Accelerated Polishing Wheel (APW) with added contaminant solutions and measuring the end skid resistance using the British Pendulum Tester (BPT). The results are reported as a PSV and a high PSV value (ranged between 30 and 80) of aggregate indicates good resistance to polishing (Wilson, 2006). The New Zealand Transport Agency (NZTA) publishes and updates a list of the PSVs of the various aggregates produced by different quarries throughout New Zealand (Transit New Zealand, 2004). Specifically for this research, an Auckland and Northland greywacke aggregate were researched having a PSV of 53 and 51 respectively.

More recently, the PSV test has been shown to have some significant limitations, therefore two alternative methods have been developed, one using the Accelerated Polishing Machine (APM) developed at the University of Auckland and the Wehner-Schulze device from Germany.

Correlating Laboratory and Field Results

There have been a number of research studies undertaken to predict the pavement surface deterioration over time. Determining the skid resistance of aggregates can be done through laboratory and field tests. Laboratory tests are designed to be able to mimic the factors that influence in-field skid resistance (Do, Kane, Tang, & de Larrard, 2009; Henry & Meyer, 1984). Ideally, both laboratory tests and field tests should have yielded similar skid resistance values but this is very difficult to achieve in reality because there are several factors, that cannot be perfectly simulated in the laboratory, such as weather and traffic loading (Do, et al., 2007). The PSV test is still the most common method used to measure the skid resistance of the aggregates thereby predicting the in-field performance, however there is no clear connection between the PSV and the in situ road friction (Woodward, Woodside, & Jellie, 2005).

Previous Accelerated Laboratory Tests Undertaken at the University of Auckland

Previous laboratory tests undertaken by Wilson (2006) and Kumar (2009) attempted to predict the skid resistance performance of various types of surface aggregates, including a number of greywackes, a basalt, and artificial Melter Slag and Electric Arc Furnace aggregates using the Accelerated Polishing methodology developed by Wilson (2006) (Figure 1). The samples were polished using the APM developed at the University of Auckland and the skid resistance values were measured using the Dynamic Friction Tester (DFT). The results from the laboratory tests show that the skid resistance values (μ) exponentially decreased at different rates as the laboratory samples were subjected to longer polishing time (refer Figure 2 for the Auckland Greywacke result). The samples were polished for up to six hours until the measured coefficient of friction (CoF) reached an equilibrium skid resistance level (ESR).

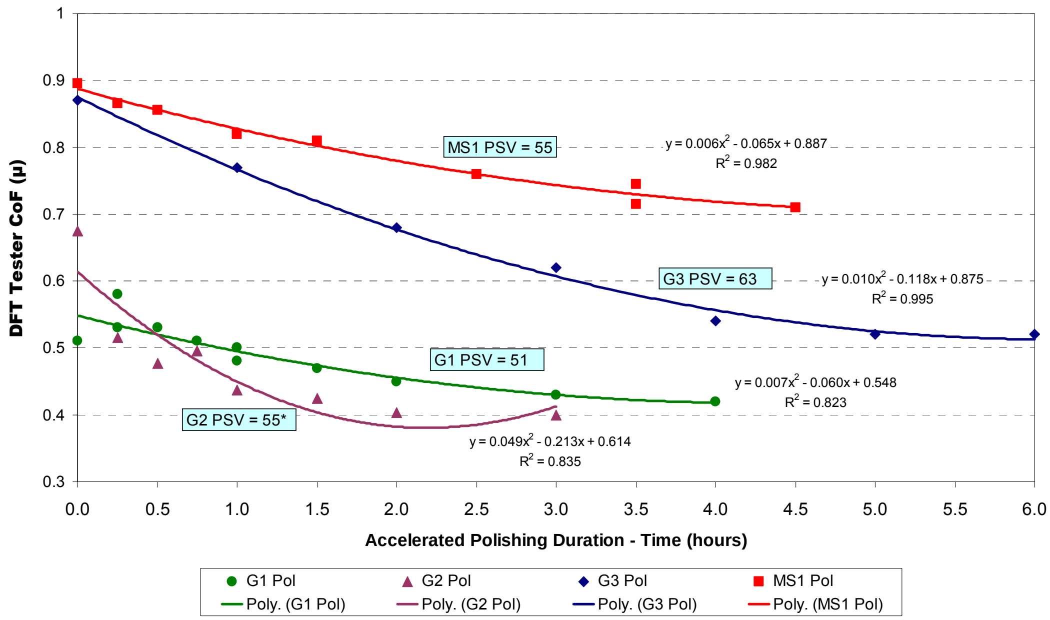

Figure 1: Laboratory Performance of three North Island of NZ Greywackes - G1, G2 and G3 and a an Artificial Melter Slag (MS1), (Wilson & Black 2008)

The relevance of this research reported in (Wilson and Black, 2008) demonstrated that whilst some aggregates performed well initially, they deteriorated at varying rates and also took different lengths of polishing duration to reach an 'equilibrium' level of skid resistance (ESR). Figure 1 shows the performance of three very different greywackes (G1, G2 and G3) in comparison to an artificial melter slag (MS1). The three greywackes were however very different in grain size range, degree of metamorphism and mineral contents and therefore toughness and would be expected to behave quite differently in both engineering mechanical tests and skid resistance performance. However, the level of ESR for the three natural greywackes (G1, G2 and G3 in Figure 1), that are the most commonly used surfacing aggregate in New Zealand, are not too different from each other. It also demonstrated that the PSV test (an end of test result) did not align well with the order expected but more reflected the initial value of skid resistance for natural aggregates but not artificial aggregates such as the NZ melter slag (MS1). The research also demonstrated that there were significant variations within aggregates of the same geological groupings (e.g. sedimentary greywackes) but that detailed geological investigations could help explain the differences in the aggregates performance. This research indicated the need for research to be undertaken at the individual quarry and aggregate level to determine not only predicted laboratory performance of aggregates but how this performed in the field with respect to measured in field skid resistance and actual crash rates.

Kumar (2009) then tested a further medium grained Greywacke (G4) that had a published PSV of 53 (refer to Figure 2) that was geologically quite similar to the G2 greywacke (PSV of 51) in Figure 1 above and had performed very similarly in the accelerated laboratory tests. As the G4 aggregate had a relatively low published PSV of 53 it had been used on mostly urban or rural roads in the Auckland region that were not State Highways. Furthermore, as the roads were non-state highways they were roads that had not been surveyed by the SCRIM device or other skid resistance measurement devices and therefore no existing skid resistance history was available to analyse.

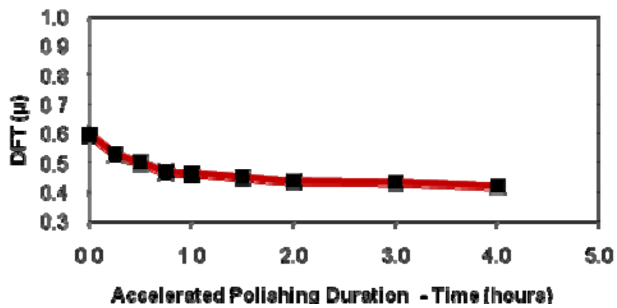

Figure 2: Laboratory Skid Resistance Performance of Auckland Greywacke (G4) Aggregate (Kumar, 2009)

Research Objectives

This research project aimed to extend the research of Kumar (2009) and Wilson (2006) by:

- correlating the laboratory and measured field skid resistance performance of the G4 Auckland greywacke aggregate,
- investigating a skid resistance related crash model for the G4 Auckland greywacke, and
- comparing the field performance between the G4 Auckland Greywacke and a greywacke aggregate (G1) from another quarry in Northland of New Zealand (NZ).

The project was limited to two-coat sealed local road surfaces in the Auckland region that were constructed using the G4 Auckland greywacke aggregates (published PSV of 53) and two-coat sealed road sections on State Highway 11 (SH 11) which were constructed by using a fine grained greywacke aggregate (G1) with a published PSV of 51 in Northland of NZ.

METHODOLOGY

A number of researchers have undertaken long term studies that have monitored the skid resistance performance of roads after the completion of road construction and over several years at regular intervals to determine the performance of the materials used in construction. As this project was undertaken as a research project at the University of Auckland and needed to be completed within an academic calendar year, an alternative methodological approach was adopted as shown in Figure 3. This research took skid resistance measurements of in-service roads with the same quarry aggregate and collected data from road sections with different surface age and traffic loading to obtain a time history of the same aggregate with various traffic loadings.

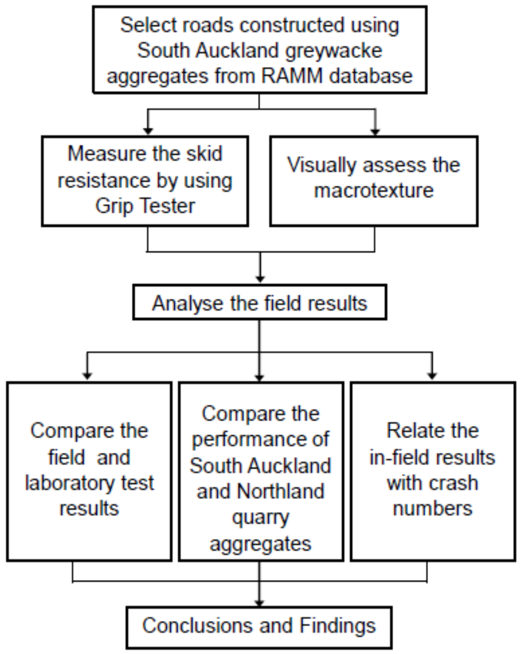

Figure 3: Overall project methodology

Note: Road Assessment Maintenance Management System (RAMM) Database is the NZ Road Inventory and Condition Database

Auckland G4 Greywacke Aggregate

There were five main stages involved in obtaining and analysing the skid resistance values of roads that were constructed using the Auckland (G4) greywacke aggregates. These stages are discussed below.

Data Extraction

The Road Assessment and Maintenance Management (RAMM) database was data mined in order to obtain applicable road inventory information related to the roads in the Auckland region that were constructed using the Auckland (G4) greywacke aggregate.

Data Selection

There were at the time five regional areas in Auckland (these have since been combined into the one Auckland Council region) to which the data was divided into and tested. Generally, the surfacing age varied up to a maximum of eleven years old.

The roads using the G4 Auckland greywacke aggregate chip seals were spread across those regions. Only geometrically level and straight sections were used in this research to determine a benchmark level of skid resistance without high demand areas. Some roads could not be tested as it was impractical to perform the testing on some very highly trafficked sections without the need for specific traffic control measures.

The roads were grouped according to their pavement surface seal type, surface age, Average Daily Traffic (ADT) (four ranges), surface depth, first chip size grade, and second chip size grade (see Table 1). At least one road was chosen for each combination of those categories. For example, one road was a three year old two-coat seal pavement surface that carried ADT of 100-500 vehicles per day. The surface depth obtained from RAMM was 8mm and the aggregate chip sizes used were Grade 4 and Grade 6 (a Grade 4 chip has Average Least Dimensions (ALD) in the range of 5.5mm to 8.0mm and a Grade 6 chip has at least 95% of chips less than

6.7mm). Another consideration that was taken into account was the distance between the selected road section in order to be more efficient travelling from one site to another site.

Table 1: The List of Categories Used In Choosing the Roads

Surface Type	Two-coat seal
Surface Age (years)	1,2,3,4,5,9,10, and 11
Average Daily Traffic (ADT)	ADT 100-500
	ADT 501-2000
	ADT 2001-4000
	ADT 4001-10000
Surface Depth (mm)	0,5,8,9,10,11, and 12
Chip Size Grade Combination	Grade 3 and Grade 5
	Grade 4 and Grade 6

Data Collection

114 road sections were tested in April (late summer), June and July (winter) in 2010 using the GripTester (GT) shown in Figure 5. Each test site was surveyed with 2 to 3 runs to obtain average Grip Number (GN) values. The measuring speed of the GT was controlled between 30 to 40 km/h. Calibration was undertaken every 2 to 3 days during skid testing to ensure the validity of data. During Grip testing, markers were inserted to indicate any noticeable road features, such as changes in seal or patches. This was required to ensure the average skid resistance was not affected by these features. The left wheel paths in both directions were tested as it is generally found that the left wheel path polishes more than the right wheel path, especially on straight sections of road with normal camber.

Many researchers have established that, seasonal variation causes variation in skid resistance (Jayawickrama and Thomas, 1998). In this project, two control sites were tested in both April and July 2010. A comparison of test results shows that the effect of seasonal variation on skid resistance in this project was not significant and therefore no adjustment has been made between the values of late April and July.

Macrotexture Assessment

For the purposes of this research project the macrotexture of each road section was visually assessed from the surface texture photographs taken during the skid testing sessions. An example of photographs taken is shown in Figure 4. This subjective method was adopted due to the unavailability of traffic control that would be needed if, for example, the Sand Patch Method or stationary Laser Mean Profile Depth (MPD) measurement were to be undertaken. Macrotexture variation was divided into three bands: good, medium, and poor. The subjective judgements were made according to the size of the chips in comparison to a ten-cent coin, the degree the chips were embedded into the bitumen, and the chip size grade distributions.

Figure 4: Photographs of Good (Left), Medium (Middle), and Poor (Right) Macrotexture.

Data Processing

All raw results generated by the GT were extracted into Microsoft Excel to be futher analysed. The GN values were checked, validated, and averaged and plotted against the surface age, macrotexture, and traffic flow.

It was important to ensure the mean skid resistance values measured were not affected by geometric road features and therefore GN values were only compared on road sections that were geometrically benign.

The University of Auckland statistical analysis software package (R) was used to analyse and generate box plots in order to show the range of GN in each macrotexture category. To assess the impacts of the traffic composition on polishing (measured skid resistance), the number of Heavy Commercial Vehicles (HCV) passing through the road section since surfacing was calculated by:

Number of HCVs = SA x ADT x D x %HCV

Where:

SA = Surface Age (year)

ADT = Average Daily Traffic

D = Number of days in a year (365 days)

%HCV = Percentage of Heavy Commercial Vehicles

Northland G1 Greywacke Aggregates

Slightly different steps were undertaken to analyse the performance of pavement surfaces constructed using Northland's G1 fine grained greywacke aggregates with a published PSV of 51. The fine grained G1 greywacke aggregate that had been tested in the laboratory under accelerated polishing by Wilson (2006) and shown in Figure 1 had been shown to be initially relatively low in skid resistance performance but furthermore did not reduce significantly more after accelerated laboratory polishing (eg. Initial skid resistance = 0.54 and ESR = 0.41). The G1 aggregate had been used on State Highways in the Northland region and SCRIM++ high speed data results were available as part of the national NZ Transport Agency (NZTA) annual skid resistance surveys. The high speed data results included skid resistance measurements using the Sideways Force Coefficient (SFC) SCRIM device and Mean Profile Depth (MPD) macrotexture measurements and therefore did not require additional skid testing with the GripTester.

Data Extraction

Road sections that had used the G1 aggregate on State Highway 11 in Northland were chosen as a case study in the Northland region. Road inventory and condition data on SH 11, including surface pavement type, chip size grades, traffic flow, surface age, MSSC (Mean Summer SCRIM Coefficient) and macrotexture depths, were extracted from the RAMM database.

Data Selection

State Highway 11 was comprised of many road sections that were constructed by using different aggregates from different quarries. Only a sample of road sections that were surfaced with a two-coat seal using the G1 aggregate were included in this research project.

Macrotexture Assessment

The MPD macrotexture of selected road sections was obtained from RAMM from the SCRIM++ device. The measurements were taken from the left and right wheel paths of each lane on SH 11 and the results were represented as MPD macrotexture depth, that was then further classified into three band categories (Table 3) similar to the subjective visual assessment bands used in the Auckland G4 case study.

Table 2: The Macrotexture Categories According to the Macrotexture Depth

Macrotexture Categories	Macrotexture Depth
Good	≥ 2 mm
Medium	> 1 mm and < 2 mm
Poor	≤ 1 mm

Data Processing

The skid resistance of selected road sections were obtained from the RAMM database that had been measured using the SCRIM++ device and represented as the Sideways Force Coefficient (SFC). The measurements were taken on both left and right wheel paths of each lane.

The SFC values and macrotexture depths from both wheel paths on both lanes were averaged and plotted against the surface age, which was calculated from the last time the roads were resealed until the skid resistance values were measured. Zero year old surfaces means that the roads were recently resealed, and within one year of construction until the skid resistance values were measured.

To assess the effect of traffic polishing action on skid resistance values, the number of vehicles passing the roads since the surfacing construction was determined.

Crash Analysis

For mid-blocks, exposure to the risk of having an accident is defined as the number of vehicle - kilometres of travel on the mid-block, measured in 100 million vehicle kilometres travelled (MVKT) per year (NZTA Economic Evaluation Manual, 2010).

The formula to calculate exposure for individual sites is given by:

$$X = \frac{L \times ADT \times 365}{10^8}$$

Where

X	=	exposure
L	=	length of site (km)
ADT	=	annual daily traffic

The Relative Crash Rate for individual sites can then be given by

$$Rate = \frac{Count \times X}{Years}$$

Where

Rate	=	relative crash rate
Count	=	count of accidents on site
X	=	exposure as above
Years	=	service life.

RESULTS

Field Performance of Auckland G4 Greywacke

Each data point shown in Figure 5 is the average GN of each road tested in the Auckland City region for the G4 greywacke aggregate. The data demonstrates an exponentially decreasing relationship between GN and surface age (Figure 5) although data points between 6 to 8 years were not available. Generally, the older the surface and in combination with the higher the HCV traffic volumes, the lower the skid resistance was due to the aggregate polishing. The difference between the 1 year old and 11year old surfaces was roughly 0.2 GN and this reflects similar results shown in accelerated laboratory tests that lost <0.2 DFT(μ) during polishing (refer to Figure 2). However, although the difference in skid resistance for this aggregate is relatively small, this is not the case for other aggregates that have both in the laboratory and in-field performance have lost a much greater proportion of the initial measured skid resistance value (eg. G3 aggregate that lost approximately 0.36 DFT(μ) however started at a higher initial skid resistance value).

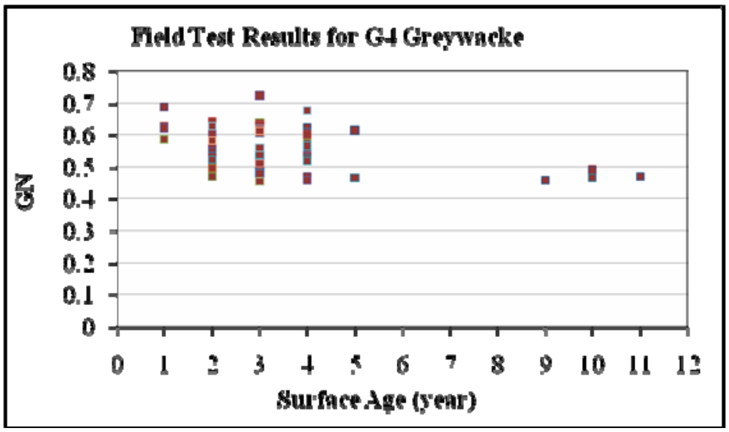

Figure 5: Field Performance of G4 Auckland Greywacke Aggregates

It was also noted that there were reasonably wide ranges (between 0.45 and 0.72) of GN in 2, 3, and 4 year old surfaces (although there were also many more data points of road sections in this age group). An explanation for this greater variation could have been related to the contributing variable of macrotexture to skid resistance measurement. This variable was investigated and the results shown in Figure 6. There were however, no definitive range for each macrotexture category and the lower and upper bands overlap one another. However, the median GNs clearly decrease with poorer macrotexture, which suggests that the better the macrotexture, the higher the GN (refer to Figure 6). This is expected due to the hysteretic component of friction.

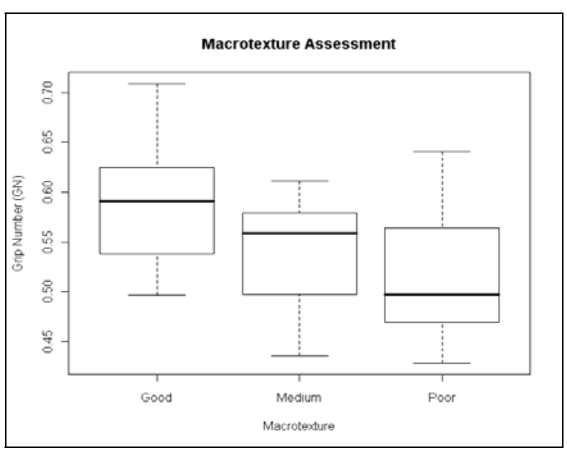

Figure 6: The Box Plots of Macrotexture Range of All Tested Roads

Analysis was also undertaken to assess the effect of traffic volume and composition of HCV's polishing action on skid resistance provided by the G4 greywacke aggregate. The number of HCV's in the past has been shown to be more important in creating the polishing forces on aggregates in comparison to lighter car based ADT. However, it can be observed in Figure 7 below for the G4 greywacke aggregate that the number of HCV passes has very little relationship with the measured skid resistance GN in the field as it did not effectively reduce with increasing HCV volume passes (refer to Figure 7). It would seem that for this G4 greywacke aggregate surface, age is more of a factor (refer to Figure 5) in the polishing of the aggregate than the number of HCV's. It should however be stated that the road sections are predominantly urban or inter-urban roads with operating speeds between 50 to 80km/h and not rural 100km/h roads.

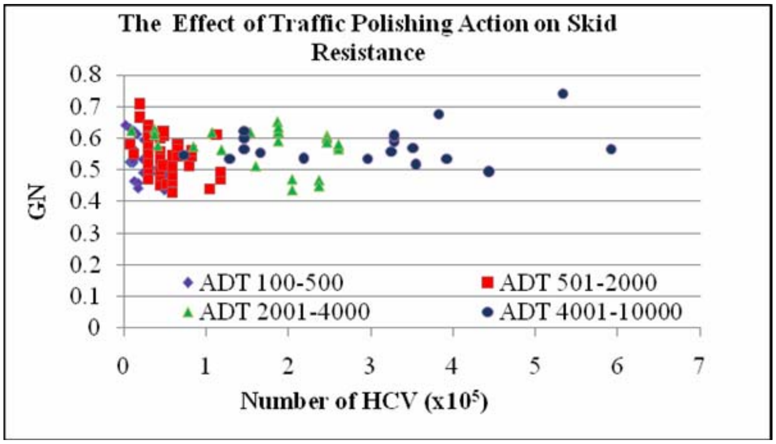

Figure 7: The Plot of Skid Resistance against Traffic Polishing Action

Field Performance of Northland G1 greywacke aggregates

As discussed previously, the performance of a fine grained Northland G1 aggregate that demonstrated similar laboratory performance as the G4 aggregate, was investigated in this research project from high speed data surveys undertaken with the SCRIM++ device on State Highway 11 in Northland. The results of the SCRIM measured SFC data for the G1 greywacke aggregate is shown in Figure 8 in comparison to Surface age. As the traffic volumes and HCV composition for this section of State Highway 11 are reasonably consistent, this has not been accounted for further in this analysis.

Each point in Figure 8 represents the average SFC for 10 meter sections of road. From this graph it is very difficult to observe any significant statistically deteriorating trend relationship with the skid resistance measurement of the G1 aggregate and age of surface. One would expect to see that older surfaces have lower measured skid resistance but there is no clear indication of this as some sections after 7 years are still performing as equally well (approx 0.6 SFC) as other sections either 1 year or less age. However, of greater concern is that some sections of road even within the first year since construction are showing a measured skid resistance value of just better than 0.3 SFC which would fail NZTA Investigatory levels. This example demonstrates that there are other issues and variables at play that mean that the in-field skid resistance value of the G1 aggregate can become alarmingly low very quickly after construction of a new surfacing.

There were a group of outliers noted in the graph in the circle that seem unusually high for this aggregate source and it is likely that these sections were incorrectly coded in the RAMM database and most likely were of a different pavement surface type.

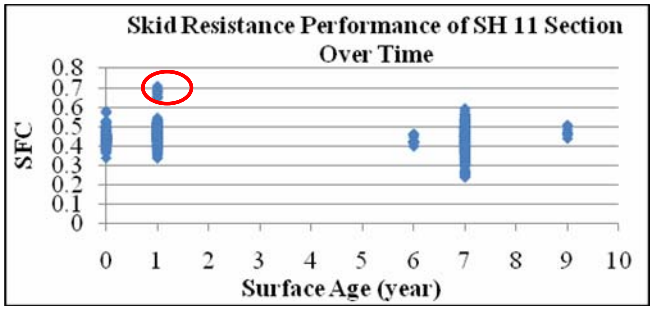

Figure 8: The Field Performance of SH 11 G1 Aggregate

These same 10m road section skid resistance values were plotted against macrotexture and a as would be expected a general increasing skid resistance trend is observed with increasing macrotexture (refer to Figure 9). This figure also clearly shows that there is a grouping of the lowest measured skid resistance areas (Circle 1) coinciding with sections that have a macrotexture less than 1.2mm in MPD. This would tend to indicate that these road section failures are more due to bitumen flushing with low measured MPD rather than microtexture polishing which could also explain why some sections that are relatively new (refer to Figure 8) have low measured skid resistance. The same group of outliers (Circle 2) which was previously noted in Figure 8, also appear in Figure 9 and are clearly not from the same aggregate source.

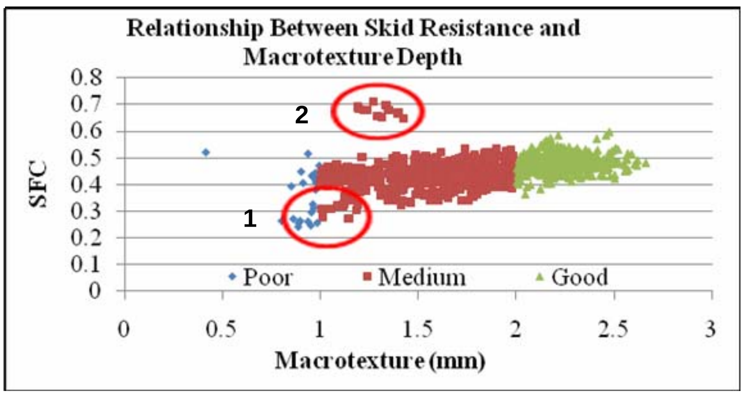

Figure 9: The Relationship between Skid Resistance and Macrotexture on SH 11 – G1 aggregate

Crash Occurrences and Factors

It is has been well established in previous research that as measured skid resistance reduces the wet loss of control crash rate increases, thereby justifying a policy to manage skid resistance levels on the road network. Crash rates were investigated for the road sections in the Auckland region that had the G4 surfacing to determine whether crash rates increased on sections with lower skid resistance. Figure 10A shows that only 35% of the road sections measured had any crashes reported by the NZ Police. Furthermore of the sites that did have crashes only 11% of the crashes were related to a combined loss of control in the wet type crash (Figure 10B). However, as the sites were chosen to be geometrically benign (mostly straight and level) it would be expected that the crash rates on these sections would be significantly lower than when horizontal curved sections are included. In most NZ regions the wet loss of control crashes account for approximately 20 to 30% of total crashes.

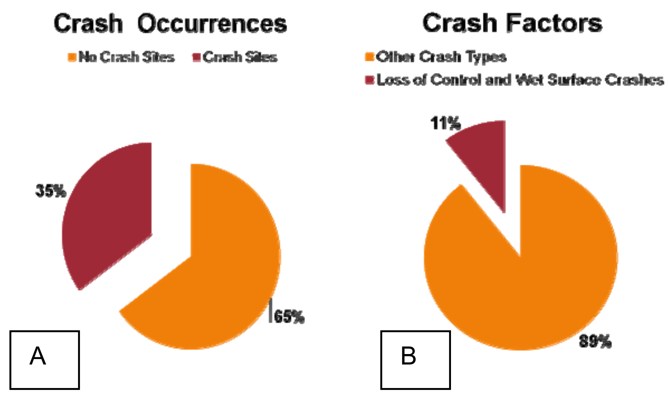

Figure 10: Crash occurrence and crash factors for road sections with G4 aggregate

Skid Resistance and Relative Crash Rate

Figure 11 shows a plot of relative loss of control in wet crash rate against measured Grip Number for the road sections tested with the G4 greywacke aggregate in the Auckland Region. Although the number of paired data points and the skid resistance range is small leading to less statistical confidence the trend indicates that the relative skidding crash rate is negative exponential in form with a lower crash rate for high values of skid resistance and a higher crash rate for low values of skid resistance. It however also indicates that of the 114 sections of road that used the G4 greywacke aggregate and investigated the sections for measured skid resistance and reported crashes, many sections did not have any loss of control in the wet crashes. The relatively narrow band of measured skid resistance again reflects that whilst the G4 greywacke aggregate does not produce very high initial skid resistance values it also does not deteriorate very much either and is relatively stable over time (in comparison to other natural aggregates).

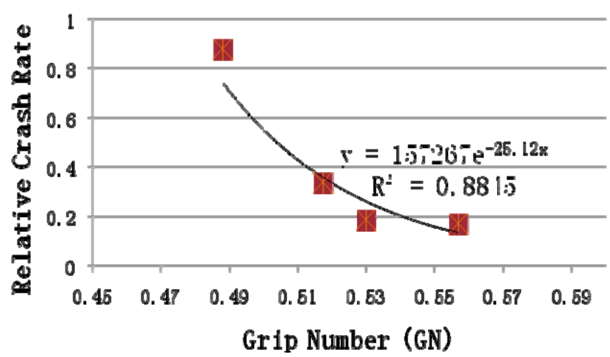

Figure 11: Relative Loss of Control and Wet Crash Rate against Grip Number

DISCUSSIONS

Limitations

Due to time and available data constraints, it was not possible to test all roads that were constructed using the G4 greywacke aggregates in the Auckland region. There were no road sections that could be found that had a surface age of 6, 7, and 8 years old in the Auckland region. However, the available data was sufficient to sample and observe the general trend of pavement surface skid resistance performance over time. More data to fill the gaps would have been useful to better determine the statistical confidence in the observed deterioration trends.

This project also considered the performance of the G1 greywacke aggregate that had been used on State Highway 11 in Northland. This data was extracted from the RAMM database and included SCRIM SFC and macrotexture MPD data but surfacing ages included 0,1,6,7, and 9 year old road surfaces. The available data can give an indication of the behaviour of aggregates over time, under different traffic loading, and with the change of macrotexture qualities. The incompleteness of data, however made it difficult to obtain clear trends from the graphs.

The performance of road surfaces is influenced by various complex factors. In this research project, the analysis only included the microtexture of the selected aggregate (G4 and G1), the in place macrotexture, the vehicle traffic volume and composition and the age of the surface. There are many other factors that contribute to the variation in measured skid resistance of road surfaces that were not taken into account in this project due to the limited scope, such as road geometry and polishing demand, seasonal variation, surface contamination, rainfall intensity and duration.

Comparison between Laboratory and Field Performance of Auckland G4 Greywacke Aggregates

An objective of this research was to compare accelerated laboratory polishing test results and the field testing results on the same G4 greywacke aggregate. However, the two devices used to measure skid resistance are quite different. The Dynamic Friction Tester (DFT) used in the laboratory is a stationary device that measures the coefficient of friction in one small 284mm diameter circular motion whereas the GripTester (GT) continuously measures at a 15% fixed slippage, a braked in line coefficient of friction. The two devices therefore function quite differently. Accordingly, a direct numerical comparison between the two devices cannot be made although previous correlation studies have shown that a very good correlation between the two devices can be achieved under controlled testing regimes.

However, a visual comparison of Figure 2 showing the performance of the G4 aggregate using the accelerated polishing method developed at the University of Auckland in comparison to Figure 5 by the GripTester measurement in the field on G4 aggregate with various surface ages, clearly shows that the two methods exhibit very similar aggregate deterioration trends. Both figures show that whilst the initial skid resistance is not that high in comparison to other aggregates and therefore should not be used in highly stressed areas (0.60 DFT(μ) and 0.65 GN) the aggregate also does not lose too much skid resistance value to an ESR level (0.41 DFT(μ) and 0.45 GN).

These research results demonstrate that the accelerated laboratory polishing and skid resistance testing procedure developed at the University of Auckland reasonably accurately reflects the in-field skid resistance performance of the G4 Greywacke aggregate surfacing. This implication needs to be tested for a range of other aggregates especially aggregates that have a much higher range of deterioration. The results are however promising, given that the PSV test method has been shown to be a poor indicator of in-field performance requiring new methods to be developed that better reflect in-field performance.

Secondly, it was observed from Figure 6 that there were wide ranges of measured GN in 2, 3, and 4 year old surfaces. These variations can be better explained by the difference in macrotexture qualities of each road surface. From the qualitative surface texture assessment, it is observed that when a pavement has good surface texture, it usually exhibits a higher measured skid resistance as it increases hysteretic friction. Two different roads with the same surface age can have variable skid resistance values due to the different quality in surface macrotexture. However, some of this observed variation could also be better explained from the contributions of other factors not considered in this research.

Thirdly, the traffic polishing effect on skid resistance is also considered in this research. In determining the effect of traffic on the pavement surface polishing, it is important to consider the composition of the traffic and the proportion of HCV's. The HCV vehicle proportion imposes a much larger load to the surfacing and underlying pavements compared to the load imposed by other vehicle types, such as Light Commercial Vehicles (LCV) and passenger cars, which, theoretically polishes road surfaces at a faster rate. Figure 7 however unusually shows that the variation observed in measured skid resistance cannot be explained by the number of HCV's that have passed over the surface, as the skid resistance values and range of observed results remain relatively constant. This result indicates that the skid resistance performance is less dependent upon HCV volume than surface age (Figure 5), implying that the skid resistance value of the G4 Auckland greywacke is less sensitive to traffic volume polishing in comparison to the environmental effects of surface age. However, this needs some qualification as the in-field skid resistance performance only found road sections with a maximum of up to 10,000 vehicles per day.

It is also observed from both laboratory and field test results that the skid resistance of South Auckland greywacke varies within a relatively narrow range of ±0.2 DFT (μ) and ±0.2 GripTester (GN) respectively. This demonstrates reasonable durability as it demonstrates a relatively small change from its original value. Although, these results reflect geometrically benign areas and it would be expected that greater polishing occurs on road sections with greater frictional demand like on horizontal curves or approaches to intersections. Additionally, the research results must be further qualified as the initial measured value of skid resistance is also relatively low in comparison to other aggregates, therefore whilst it does not lose much skid resistance with age, it also does not begin that high either (0.65 GN).

Comparison between G4 Auckland and Northland G1 Greywacke Aggregates

One of the research objectives was to compare the in-field skid resistance measurement results of the G4 Auckland greywacke measured by the GripTester device and the Northland G1 greywacke aggregate measured by the SCRIM++ SFC device. The accelerated polishing results of the two aggregates in the laboratory had shown relatively similar results and it was therefore expected that similar deterioration trends would be observed in the field. Figure 8 shows the results of measured skid resistance (SFC) with surface age with relatively similar traffic volumes and HCV content across road sections on SH 11. Relatively wide ranges of SFC values in roads with 0, 1, and 7 year old surfaces were observed, although this included sections of roads that had horizontal curvature as well and therefore one would expect that the variation would be greater than a comparison of the G4 greywacke aggregate sections that had excluded sections with horizontal curvature.

The variations observed on State Highway 11 can however be partly explained by the difference in macrotexture where Figure 9 shows a linear relationship between increasing SFC and increasing macrotexture. The greater the macrotexture, the higher the SFC is. The observed field results on State Highway showed a greater variation of results with surface age than the G4 aggregate, however when plotted against macrotexture there were a number of road sections that were young in age but were poor in macrotexture due to bitumen flushing (refer to Figure 9). As macrotexture loss was a significant issue in the skid resistance measurements for State Highway 11 no further comparison was made between the G4 and G1 aggregates as this would have adversely affect any comparisons.

Skid Resistance and Relative Crash Rate

Although the data range of measured skid resistance was very narrow and the number of data points relatively insignificant, the research confirmed previous research that had demonstrated a decreasing exponential relationship between the relative wet loss of control crash rate and the level of skid resistance measured by the GripTester for the G4 Auckland greywacke aggregate.

This comparison is only valid within the narrow range between 0.48 GN and 0.56 GN as shown in Figure 11 although most of the 114 sections tested showed no loss of control wet related crashes at all. This would tend to indicate that skid resistance related crashes are not a significant issue on these road sections – also demonstrated by the wet loss of control crashes being only 11% of total crashes, whereas this is more commonly 20 to 30% on NZ roads. However, this greater proportion would include sections with horizontal curvature and therefore greater frictional demand that would also provide additional polishing forces.

In order to make valid comparisons outside the data range shown in this research, it would be necessary to extend the research to include a lot more road sections and to then compare against the performance of other types of aggregate. It would then be possible to populate crash points with a much wider range of aggregates and their relative crash rates, therefore result in a better crash prediction method. It must also be remembered that vehicle crashes are multi-factor events and that often have a number of contributory crash factors and it is therefore often difficult to isolate individual statistical factors that are causal in crashes occurring.

CONCLUSIONS

This research has shown that the accelerated laboratory polishing prediction methodology developed at the University of Auckland by Wilson (2006) can adequately reflect the field performance as measured by the GripTester for an individual Auckland G4 greywacke result. This method shows continuing promise as a predictive method that better reflects in-field skid resistance measurement than the more established PSV test method that has proven to be a very poor indicative test method.

Similar relationships are also indicated between the accelerated laboratory polishing method and the in-field measured skid resistance results by the SCRIM++ device for the G1 greywacke aggregate on State Highway 11 in Northland. However the variation shown in the data is much greater due to a number of road sections with poor macrotexture due to bitumen binder rise (flushing). More conclusive comparisons were not able to be undertaken in this University student based research project without further on-site investigations to remove sections from the data set that had 'failed' due to poor macrotexture.

The research has also shown that the wet loss of control relative crash rate on the road sections tested with the G4 Auckland greywacke aggregate is relatively low (11%) of the total crashes that occurred, although this does not include sections with significant horizontal curvature. It has also shown (although the data range was very narrow and the number of data points very small) that the relative wet and loss of control crash rate increases exponentially as the level of measured skid resistance decreases.

Furthermore, it has shown that both macrotexture measurement and microtexture measurements are important to adequately describe skid resistance field measurements. Correspondingly, it is important for practitioners to clearly understand whether a skid resistance treatment intervention is required due to microtexture polishing or macrotexture loss.

Further research is required with a wider range of geologic aggregate sources (including natural and artificial aggregates), grain size, microtextural harshness and toughness (a balance between the hardness of grain sizes and the binding of the grain size in the rock matrix at a microtextural level) to better determine the relationship between predictive laboratory methods and in-field skid resistance performance.

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