ASSESSMENT OF RECYCLED AGGREGATE FOR USE IN THE PAVEMENT SURFACE LAYER

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ABSTRACT
Skid resistance is a key factor in road safety. However, over time the pavement surface is polished by vehicle tyres, reducing the micro-texture of aggregates and macro-texture of the road surface. This results in reduced levels of skid resistance to a point where it can be the trigger to require re-surfacing or in some way rejuvenated. While the surface aggregates in asphalt mixes are often recycled for use in lower value layers of pavements, the aggregates in most cases have properties that meet much higher value specification requirements.

This research forms part of a doctoral research programme undertaken at the University of Auckland and is funded by MBIE - the primary project objective being the better and more economic utilisation of mineral aggregate resources in New Zealand. This element of the research will assess the possibility of recycling the high value aggregates (e.g. melter slag) for re-use in the surface layer, given that only one face of the aggregate has been polished and, in the case of hot mix asphalt (HMA), aggregates further down in the surface layer have not been subjected to polishing at all. In particular, this research focusses on aggregates salvaged from Open Graded Porous Asphalt (OGPA) surfaces used on the Auckland motorway network. This paper discusses the results of both in-field macro and micro texture testing prior to milling on four sites on the Auckland Motorway network.

INTRODUCTION
Skid resistance is the frictional force that is produced between the road surface and the tyres (Wilson 2006, Nataadmadja, Wilson & Costello 2012). This friction has a direct impact on a vehicle's ability to manoeuvre and stop safely. Many studies have confirmed that the rate of crashes increases if the skid resistance level is reduced lower than critical levels of service (Cenek et al. 2004, Perry, Woodside & Woodward 2001).

These critical levels (intervention levels) vary depending upon the site category (NZTA T/10, 2010) Not surprisingly, improving skid resistance in high level risk areas is a key target for providing safe pavement surfaces, especially during wet conditions. A study by Mayora and Piña (2009) showed that the coefficient of friction on the road surface is significantly reduced during wet conditions. For this reason, wet skid resistance standards are provided by managing authorities in developed countries to try and balance crash risk with varying skid resistance intervention levels across varying road sections (Kumar, Wilson 2010).

Over time, the pavement surface is polished by vehicle tyres, reducing the micro-texture of aggregates and macro-texture of the road surface. This results in reduced levels of skid resistance to a point where the surface may need to be replaced or in some way rejuvenated due to poor skid resistance performance. While the surface aggregates in asphalt mixes are often recycled for use in the lower value layers of pavements, the aggregates in most cases have properties that meet much higher value specification requirements.

The ongoing research project will assess the possibility of recycling these high value aggregates (e.g. melter slag) for re-use in a surfacing layer, given that only one face of the aggregate has been polished and, in the case of hot mix asphalt (HMA), aggregates further down in the surface layer have not been subjected to polishing at all. In particular, this research focusses on aggregates salvaged from Open Graded Porous Asphalt (OGPA) surfaces used on the Auckland motorway network.

This paper discusses the first step of that research, the in-field testing results of skid resistance and mean macro-texture depth testing on four sites on the Auckland Motorway network prior to milling. The skid resistance and macrotexture were measured by the Dynamic Friction Tester and Circular Texture Meter, respectively.

BACKGROUND

In New Zealand, the majority of roads are flexible unbound pavements, constructed with a chip seal or thin asphalt surface (Nataadmadja et al. 2015a, Kumar, Wilson 2010). Maintaining adequate skid resistance on these surfaces is a key component of safety on the road network. However, there are several factors that influence skid resistance as follows:

- 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, only the surface aggregate factors and, to an extent, the load factor can be controlled by pavement engineering (Kumar, Wilson 2010).

One of the main factors that has a direct effect on skid resistance is the aggregate texture (Nataadmadja et al. 2013). According to the wavelengths, aggregate texture can be divided into four categories: microtexture, macrotexture, megatexture and unevenness (Nataadmadja et al. 2015b). In road surface aggregates, just microtexture and macrotexture are considered for skid resistance. Microtexture is the small-scale texture in the aggregates that can be felt by the fingertips. The size of wavelengths for this texture is less than 0.5 mm (British Standards 2002). Skid resistance in low speed environments is provided predominantly by this texture on the road surface by way of adhesion friction (Dookeeram et al. 2014).

Macrotexture can be seen by the naked eye and is the texture of the road surface created by the gaps between the aggregates. The wavelengths size for this texture is between 0.5mm and 50mm. Macrotexture reduces the potential for aquaplaning and increases the level of skid resistance by hysteretic friction in high speed environments (Nataadmadja et al. 2015b). Repeated traffic loading on the surface will result in the microtexture starting to polish and the level of measured skid resistance reducing. In addition, the macrotexture can also reduce due to a combination of wear and flushing. When the skid resistance is reduced below the intervention standard, the surface is usually planned to be replaced.

RESEARCH METHODOLOGY

This section discusses the methodology used for collecting the in-field skid resistance and macrotexture data using the Dynamic Friction Tester (DFT) and the Circular Track Meter (CTM), respectively. Four sites on the Auckland Motorway network were tested in line with the work instructions to the contractor undertaking the milling and paving works on the motorway network. Although records exist regarding the aggregate types used in the OGPA mixes, preliminary assessment of the aggregates suggests some inconsistency in the records. Consequently, the aggregate types from the historical information will need to be confirmed through mineralogical analysis as part of future research.

The first site is located in Penrose, on the Southern Motorway in Auckland. The road name is 01N-0431-D and the treatment length name is Penrose - SEART (1B2). This site has been given the code PAV 104 by the contractor (Figure 1). All DFT and CTM tests were undertaken in the T2 lane.

Figure 1: PAV 104, Penrose, Southern Motorway

The location of the second site is in Grey Lynn, on the Auckland-Kumeu Motorway. The road name is 016-0000-I and the treatment length name is Kingsland - Western Springs. This site has been given the code PAV 108 by the contractor (Figure 2). At this site, all the tests were undertaken in the slow lane.

Figure 2: PAV 108, Auckland-Kumeu Motorway, Grey Lynn

The third is located on the Auckland-Waiwera Motorway. The road name is 01N-0398-I and the treatment length name is Silverdale. This site has been given the code PAV 120 by the contractor. At this site, as for PAV 108, all the DFT and CTM tests were undertaken in the slow lane. The location of PAV 120 is shown in Figure 3.

Figure 3: PAV 120, Auckland-Waiwera Motorway

The fourth, and last, site location was on the Southern Motorway, near Karaka. The road name is 01N-0448-D and the treatment length name is Pahurehure Box Cul-Slippery Crk. This site has been given the code PAV 123 by the contractor (Figure 4). All the tests were undertaken in the slow lane.

Figure 4: PAV 123, Southern Motorway, Karaka

MEASURMENT OF THE ROAD SURFACE FRICTION: DYNAMIC FRICTION TESTER

The DFT tester measures the dynamic coefficient of friction on the surface layer of a road surface. This device can also be used to measure the surface friction on promenades, footpaths, cycleways and laboratory prepared samples. The DFT has been chosen as the standard reference by IFI ASTM International Standards (Henry 2000). All testing was carried out according to ASTM Standard Test Method E-1911 (Standard 1911).

Three standard rubber mounted slider pads are fitted to the underside of a lateral rotary disk with a diameter of 284 mm (Figure 5). The device wets the road surface prior to measurement. The force F needed to overcome the dynamic of friction is measured by a constant load W on the rubber sliders and also with the linear speed V of the pads (Wilson, Dunn 2005). In this research, the initial rotating speed of the DFT device was set at 60 km/h at all sites.

Figure5: Dynamic Friction Tester (DFT) device

According to Wilson and Dunn (2005), the DFT tester has a number of advantages compared to other devices for measuring the coefficient of friction. One of the significant benefits of this device is it has a larger contact area for measuring skid resistance, compared to, for example, the British Pendulum Tester (BPT). Skid resistance results from the DFT tester are very stable and are highly repeatable.

MEASUREMENT OF THE ROAD SURFACE MACROTEXTURE: THE CIRCULAR TRACK METER

The Circular Texture Meter (CTM) measures the Mean Profile Depth (MPD) of a pavement surface. The testing procedure and methodology is described in ASTM E2157 (Hanson, Prowell 2004). This device uses a laser to measure the profile of a circle with a 284 mm diameter (the same as the DFT) and is divided into eight same size segments. The Mean Depth of each segment is calculated and stored within a notebook computer that is connected to the CTM device. The average for each segment is calculated within the supplied software. However, for estimating the MPD it is best to have the average of all eight segments together (Abe et al. 2001). The CTM device is shown in Figure 6.

Figure 6: The Circular Track Meter (CTM) device

IN-FIELD TEST RESULTS

The results of the DFT and CTM for the four sites on the Auckland Motorway network are presented in this section. Testing at each site was undertaken at five locations within the traffic lane as shown in Figure 7. Two of them in the wheel paths (a and b - one in each wheel path), one in the centre of the lane between the wheel paths (c) and two locations between each wheel path and the road lane markings (d and e). This testing pattern allows comparison between the less polished areas of the road surface, between the wheel paths for example, and the highly polished areas, on the wheel paths.

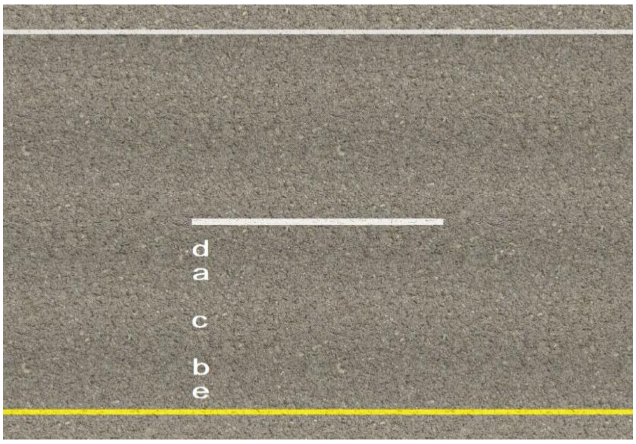

Figure 7: Test locations at each site

DYNAMIC FRICTION TESTER RESULTS

The results of the in-field Dynamic Friction Tester for all four sites and in all five locations are shown in Figures 8, 9, 10 and 11. Each dataset presents the average of three test results at each location. A Visual Basic Application (VBA) was used for processing the DFT tester data. The template plots the coefficient of friction measurement (μ) against the measure slip speed by taking three DFT tester runs. The three DFT test results are calculated by the template at 20 km/h, 40 km/h and the average slip speed between this range of speeds.

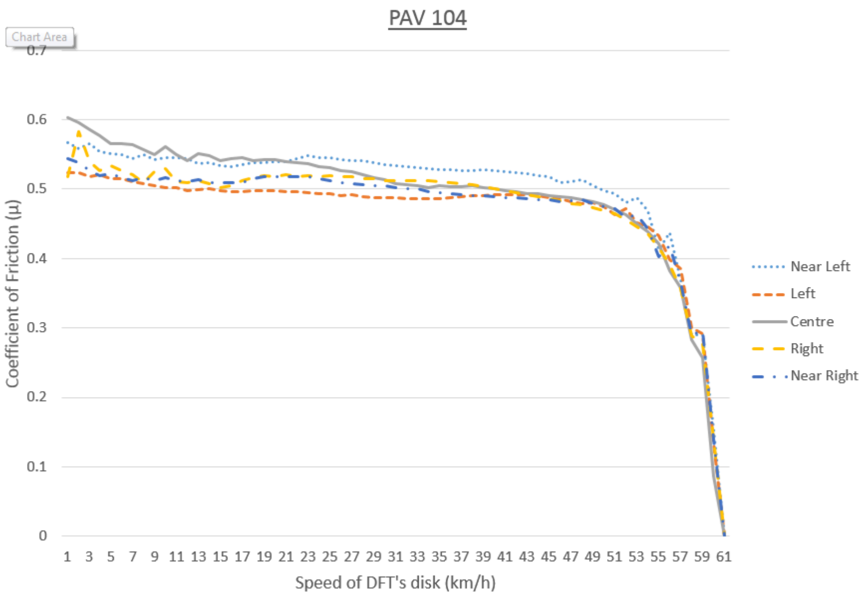

Figure 8: Dynamic Friction Tester results in PAV 104

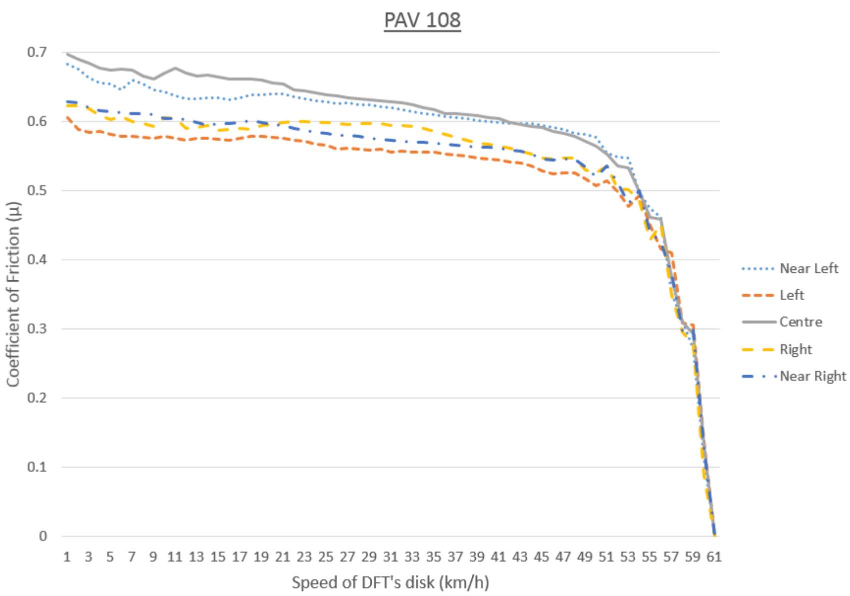

Figure 9: Dynamic Friction Tester results in PAV 108

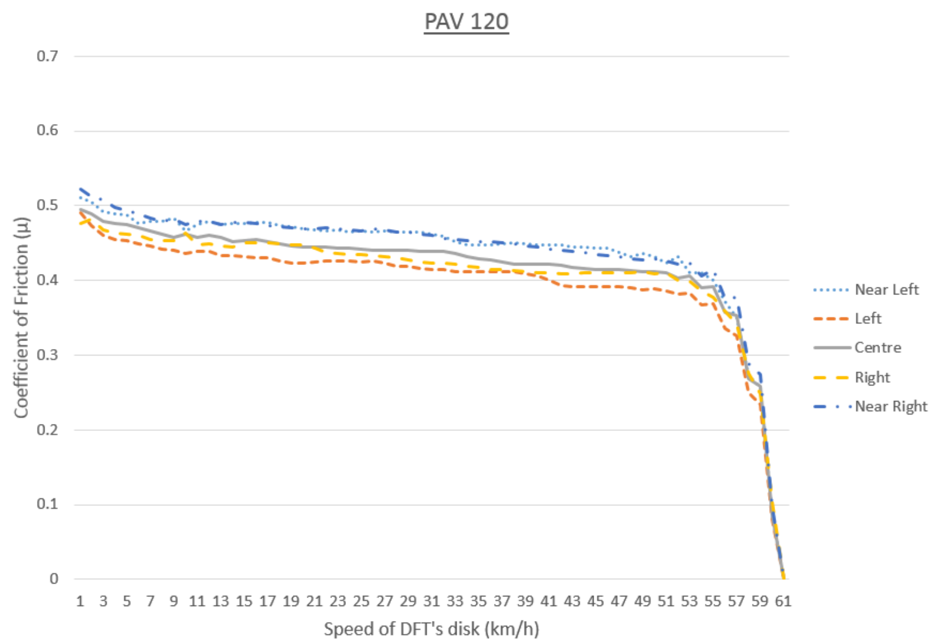

Figure 10: Dynamic Friction Tester results in PAV 120

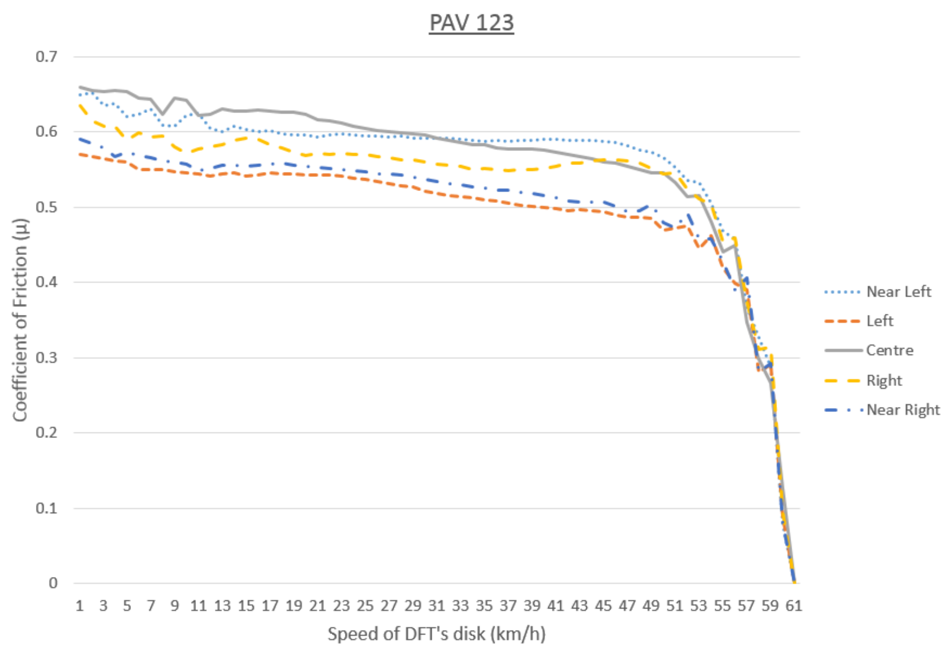

Figure 11: Dynamic Friction Tester results in PAV 123

Table 1 shows the average of the friction results for all four sites.

Table 1: Friction results for all five locations at all four sites

Site Name	Average of Coefficient of Friction Results (μ)			
	PAV 104	PAV 108	PAV 120	PAV 123
Centre of Left Wheel Path and Road Lane	0.594	0.732	0.556	0.593
Left Side Wheel Path	0.552	0.634	0.517	0.521
Centre of Wheels path	0.628	0.730	0.514	0.599
Right Side Wheel Path	0.564	0.659	0.507	0.560
Centre of Right Wheel Path and Road Lane	0.560	0.647	0.548	0.534

The main findings of the results are as follows:

According to NZTA T/10 (NZTA, 2010), skid resistance investigation levels (IL) for highway and motorway junction areas including on/off ramps should be between 0.40 μ and 0.45 μ, as measured by the Sideways-force Coefficient Routine Investigation Machine (SCRIM). However, the coefficient of friction for all sites, as mention in the Table 1, is above the IL. The minimum and maximum coefficients of friction, across all locations, are 0.507 μ and 0.732 μ, respectively, as measured by DFT. Although not exactly the same, correlation trials have shown SCRIM and DFT results to be very similar and highly correlated. Given the above values, this would suggest that none of the sites are being resurfaced due to skid resistance failures.

Also, the results suggest that recycling the milling aggregates for use in the surface layer is not an unreasonable proposition, due to high levels of skid resistance retained by the polished aggregates on the surface. In OGPA, of course, many aggregates are not polished at all as they are further down in the surface layer.

CIRCULAR TRACK METER RESULTS

The Mean Texture Depth results of each site are shown in Table 2, which is the average of three CTM test results in the same location. These results are for four sites and each site was tested in five locations as explained in the previous section.

Table 2: Mean Texture Depth results for all four sites

Site Name	Mean Profile Depth Results (mm)			
	PAV 104	PAV 108	PAV 120	PAV 123
Centre of Left Wheel Path and Road Lane	1.31	1.45	1.23	1.88
Left Side Wheel Path	1.35	1.45	1.28	1.48
Centre of Wheels path	1.21	1.65	1.41	1.14
Right Side Wheel Path	1.51	1.54	1.06	1.39
Centre of Right Wheel Path and Road Lane	1.85	1.35	1.28	1.13

The main findings of the results are as follows:

The NZTA T/10 has two sections for minimum macro-texture requirements; the terms Investigatory Level Macro-texture (ILM) and Threshold Level Macro-texture (TLM) are used to indicate the macro-texture requirement. As all test results were located on the Auckland Motorway network and the surface layer was asphalt concrete, the minimum macro-texture requirements for speeds more than 70 km/h is set at 0.9 mm for ILM and 0.7 mm for TLM.

The minimum and maximum mean profile depth, across all locations, are 1.06 mm and 1.88 mm, respectively. Comparing these results with NZTA T/10 minimum macro-texture requirements, all the areas were in reasonable condition.

SUMMARY AND CONCLUSION

This paper discusses the effect of vehicle tyre polishing and surface wear on the pavement for four Open Graded Porous Asphalt (OGPA) sites on the Auckland motorway network. The four sites are: Penrose, Southern Motorway (PAV104), Auckland-Kumeu Motorway, Grey Lynn (PAV 108), Auckland-Waiwera Motorway (PAV 120) and Southern Motorway, Karaka (PAV 123). Dynamic Friction Tester (DFT) and Circular Track Meter (CTM) devices were used for measuring the coefficient of friction and mean texture depth, respectively.

Interestingly, none of the sites appeared to have failed the NZTA T/10 requirements for skid resistance or macrotexture. This would suggest that even the surface aggregates still retain high value specification requirements for skid resistance, which further backs up the need to recycle such aggregates for use in the surface layer. The remaining faces of the aggregate have not been polished at all, similarly for aggregates further down in the surface layer of HMAs.

FUTURE PLAN

This research forms part of a doctoral research programme undertaken at the University of Auckland and is funded by MBIE. Further research will assess the possibility of recycling the high value aggregates (e.g. melter slag) for use in the surface layer, given that only one face of the aggregate has been polished and, in the case of hot mix asphalt (HMA), aggregates further down in the surface layer have not been subjected to polishing at all.

There is a plan to increase the number of the sites from four to eight on the Auckland motorway network. In-field DFT and CTM testing will be undertaken at the additional sites, as described above. The skid resistance performance of laboratory prepared samples that use the milled aggregate from the test sites will be part of future research. The mineralogy of the milled aggregates will also be determined.

Potential devices that will be used in the laboratory include, Polish Stone Value (PSV) and Auckland Pavement Polishing Device (APPD) for polished samples, the British Pendulum Tester (BPT) and DFT for measuring the microtexture, Infinite Focus (Alicona device) for determining the level of microtexture and Wehner/Schulze (WS) for polishing and measuring the coefficient of friction.

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