USE OF CLOSE RANGE PHOTOGRAMMETRY TO ASSESS THE MICRO-TEXTURE OF ASPHALT SURFACING AGGREGATE

Grainne McQuaid
Research student, Highway Engineering Research Group, University of Ulster, Northern Ireland

Phillip Millar
Lecturer in Civil Engineering, University of Ulster, Northern Ireland

David Woodward*
Reader in Infrastructure Engineering, University of Ulster, Northern Ireland
* Shore Road, Newtownabbey, Northern Ireland, BT37 0QB wdh.woodward@ulster.ac.uk

Shaun Friel
Engineer, Mouchel, Sutton Coldfield, West Midlands B72 1PH, England

ABSTRACT: The micro-texture of aggregate used in surfacing asphalt mixes plays an important role in wet skid resistance as it helps to cut through the film of water between the aggregate particle and the tire rubber. Non-contact three dimensional modelling is now being used to better understand tire / asphalt surfacing interaction. This paper considers the application of 3D modelling to better understand aggregate particle surface micro-texture. Six different aggregates were investigated i.e. Carboniferous sandstone, two Carboniferous limestone's, Tertiary basalt, Quartz Dolerite and Silurian greywacke. These rock types provide a range in wet skid resistance. They were subjected to simulated trafficking using the Polished Stone Value test method. Triangular Irregular Networks were created for each rock type before, during and after simulated trafficking. These were obtained using Close Range Photogrammetry and modelled using Imagemaster Software. Change in micro-texture was investigated using Digital Surf Mountains 6 software. Differences in 3D areal parameters are discussed for the six rock types. This study shows that this non-contact technique can be used to better understand the relationships between aggregate properties and tire / asphalt interaction.

KEYWORDS: Polished stone value, close range photogrammetry, triangular irregular network, Abbott-Firestone Curve, volume parameters

1. INTRODUCTION

This paper uses a non-contact method of 3D surface recovery and measurement known as Close Range Photogrammetry (CRP) to quantify the micro-texture of aggregate particles during the Polished Stone Value (PSV) test method [1]. The PSV test was first introduced as a British Standard in1960 in order to provide a means of establishing an aggregate's resistance to polishing under the action of trafficking by vehicle tyres. The PSV test is now a European Standard and used in many other countries around the world. Close Range Photogrammetry (CRP) is a non-contact method of assessment. The micro-texture of aggregate used in surfacing asphalt mixes plays an important role in wet skid resistance as it helps to cut through the film of water between the aggregate particle and the tire rubber. Non-contact three dimensional modelling offered a possible means of better understand tire / asphalt surfacing interaction.

2. LITERATURE REVIEW

Although much has been written about the polishing of aggregates, the use of PSV as a specification requirement for aggregates can be over emphasised. However, its ability to predict in-service performance has been questioned. Woodward [2] investigated the effect of longer polishing cycles on different aggregate types and found a typical reduction in PSV of 10% when compared to standard testing. Perry [3] and Jellie [4] investigated increased stressing during PSV testing by offsetting the angle of the test wheel 6^o with respect to the standard alignment. The findings indicated a reduction in PSV of up to 24% when compared to the standard testing.

Roe and Hartshorne [5] investigated the relationship between PSV and in-service skidding resistance. Their findings highlighted the weaknesses of specifying aggregate based on PSV. They suggested that PSV does not adequately reflect in-service performance for skidding resistance particularly at locations of higher stressing, such as approaches to roundabouts or places where there is additional deceleration or acceleration expected. Two research projects known as SKIDPREDICT [6] and SKIDGRIP [7] sought to investigate further in-service skidding resistance. Modified testing regimes based on the PSV test equipment were designed to imitate the conditions that an aggregate would be subjected to in a real highway surfacing material.

SKIDPREDICT [6] identified that a single aggregate could deliver a range of skidding resistance under apparently similar conditions. This suggested the requirement for a simple way of assessing aggregates and their limitations as compared with current test procedures. SKIDGRIP [7] investigated the early life skid resistance of highway surfacings. It started with the SKIDPREDCT modified versions of the PSV method and developed additional methods such as assessing the effect of applied bitumen coatings on PSV moulds. This concluded that the standard PSV is not a measure of an aggregates ultimate state of polish but simply an equilibrium value that relates to the test conditions. The overall findings of both projects suggest that a change in PSV test conditions results in an aggregate behaving in different ways. This also implies that an asphalt surfacing material will also behave in different ways in terms of skidding resistance in-service.

Additional texture information from the test specimen may help explain the process taking place during testing. This paper proposes that this texture data may be attainable though a non-contact method i.e. Close Range Photogrammetry (CRP). Although used in other areas, Georgopoulos et al. [8] was one of the first researchers to use CRP in the context of highway engineering when an algorithm was developed to approximate the expert's judgement in evaluating roadway surface defects from digital images. Development of camera technology has since expanded the potential of the method when combined with proprietary post processing software. Chandler et al. [9] found that a consumer grade digital camera could produce images from which Digital Elevation Models (DEM) may be generated to sub-millimetre accuracy at close range.

DEMs are generally recognised as raster datasets of elevations typical of those used in proprietary geographical information systems. Studies by Slimane et al. [10], Flintsch et al. [11] and Neaylon [12] have explored the application of stereo vision to pavement textures but the level of surface detail recovered appears somewhat variable and smoothed. Practically speaking, the achievable accuracy will depend to some extent on the individual set-up adopted by the user and the properties of the lens optics. The ability therefore to portray finely textured surfaces is possible provided specific photographic criteria are met such as appropriate exposure time, aperture setting and depth of field.

The direct application of CRP as applied to asphalt surfacings was investigated Millar et al. [13]. This comprised an initial feasibility study of a single area of asphalt surfacing. The models constructed from the transformed stereo pair allowed extraction of areas and volumes of a selected area of interest and demonstrated that the rate of volumetric displacement could be measured using the photogrammetric method. Field studies [14, 15] demonstrated a robust correlation of mean texture depth estimated from the sand patch test and mean model texture depth from photogrammetric models. This type of analysis allows additional information to be obtained about the surface. Millar et al. [16] showed that the 3D models could be used to delineate areas of potential water entrapment. Millar et al. [15] showed that spatially adjusting pressure distributions to topographic models provided additional insight into tyre surface interaction and draping.

Dunford et al. [17] looked at 3D characterisation at the microtexture scale using an Alicona Infinite Focus microscope at the National Physical Laboratory (NPL). The resolution for small areas of aggregate is impressive but recovery of the entire specimen surface proved impracticable. This reinforces the challenge confronting researchers attempting to model surfacings at the microtexture scale. It would appear therefore that recovery of a surface within the microtexture scale is a challenge using close range photogrammetry.

3. METHODOLOGY

The methodology consisted of the following stages: selection and preparation of aggregates for testing, polishing using the accelerated polishing machine, determination of pendulum value at 4 stages during accelerated polishing, 3D modelling of a single PSV test specimen and 3D modelling of single aggregate particles using the CRP method. Six different aggregates were selected for study and represent a range of rock types available in the British Isles in relation to their skid resistance. They consisted of Carboniferous sandstone, Silurian greywacke, Tertiary basalt, quartz dolerite and two Carboniferous limestone's. Aggregate which passed the 10mm test sieve and retained on the 7.2mm grid sieve was washed and dried. Four test specimens were made for each aggregate.

The skid resistance of each test specimen was assessed prior to accelerated polishing using the British Pendulum Tester (PTV0). The test specimens were subjected to the standard 3 hours of accelerated polishing using corn emery abrasive. Following this their skid resistance was determined (PTV3). The test specimens were then subjected to the standard 3 hours of accelerated polishing using emery flour abrasive. Following this their skid resistance was determined again (PTV6). This represents the stage at which a standard PSV value would be reported. The test specimens were subjected to an additional 3 hours of accelerated polishing using emery flour abrasive. During this stage the solid rubber tire of the accelerated polishing machine is offset at an angle of 6 degrees. This imposes a different set of equilibrium conditions and causes most aggregates to loss further skid resistance than would be suggested after the standard 6 hour test method. Following this skid resistance was determined for the fourth time (PTV9).

Table 1. Change in PTV for the selected test specimen used for 3D modelling

Aggregate	PTV0	PTV3	PTV6	PTV9
Carboniferous Limestone A	68	61	40	22
Carboniferous Limestone B	72	65	56	57
Quartz Dolerite	71	68	55	39
Tertiary Basalt	79	70	53	34
Silurian Greywacke	73	71	62	58
Carboniferous Sandstone	85	81	70	44

Table 1 summarises the change in skid resistance for this selected test specimen. The values shown are Pendulum Test Values (PTV) using the small rubber slider. The values have not been corrected. The data shows a general reduction in PTV for the aggregates as a result of accelerated polishing. The further reductions shown by the PTV9 data shows that the standard PSV test that involves 6 hours accelerated polishing does not result in the lowest possible value of skid resistance for an aggregate. Rather, it shows how an aggregate will achieve a state of equilibrium in relation to the accelerated polishing test conditions. This is similar to what would be measured for a highway surface.

Each test specimen was photographed for 3D modelling using Close Range Photogrammetry (CRP). This was done before accelerated polishing (Time 0), after 3 hours coarse emery polishing (Time 3), after 3 hours fine emery polishing (Time 6) and after 3 hours of angled polishing (Time 9). This involved taking stereo image pairs using a Canon EOS 400D digital SLR camera fitted with a calibrated 60mm macro lens. The camera was mounted on a tripod with all images taken normal to the surface of the PSV test specimen. A remote shutter release was used to minimise camera shake. Figure 1 shows the rig designed for holding the PSV test specimen. This shows a calibrated network of control points which act as a reference frame during creation of the 3D model allowing recovery of surface elevation and orientation. Close-up images were taken of individual aggregates to investigate the ability of this photogrammetry method to assess changes in surface texture at the micro-scale.

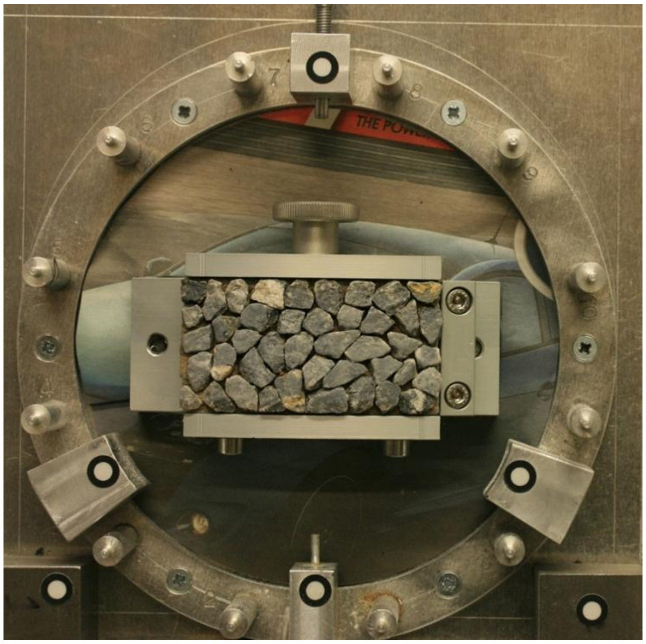

Figure 1. Limestone A test specimen fitted in the control framework rig used for stereo imaging

One of the test specimens for each aggregate was selected for further analysis. Its set of stereo images was used to construct a Triangular Irregular Network (TIN) 3D model using Topcon ImageMaster photogrammetric software [18]. The mesh resolution of the TIN varied depending on the size of the area under investigation. For the PSV test specimen the TIN mesh resolution was 0.1mm with 0.01mm used for individual aggregates. Figure 2 shows an example TIN mesh produced for the sandstone test specimen. No filters were applied to the TIN datasets to avoid possible removal of surface micro-texture.

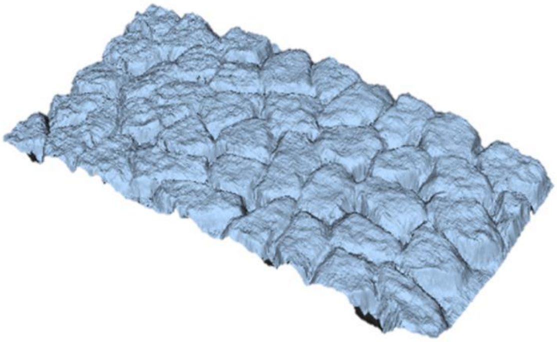

Figure 2. TIN mesh for Sandstone test specimen

The TIN mesh was imported into the Digital Surf MountainsMap 6 software package for analysis [19]. The levelling and symmetry tools were used to ensure that the TIN mesh was orientated to correspond with the actual PSV test specimen. Figure 3 shows an example 3D model created by MountainsMap6. This shows the curved PSV test specimen colour banded to highlight its z-direction height / thickness variation. The curved form was then removed from each TIN to simplify analysis using the flattened model. This now shows the variation in surface texture for just each aggregate particle. Figure 4 shows an example of a single greywacke aggregate particle modelled at Time 0 and Time 6. This shows individual sand grains protruding from the surface or having been plucked from it leaving a hole. The colour banding shows how the surface has worn in contact with the solid rubber tire of the accelerated polishing machine.

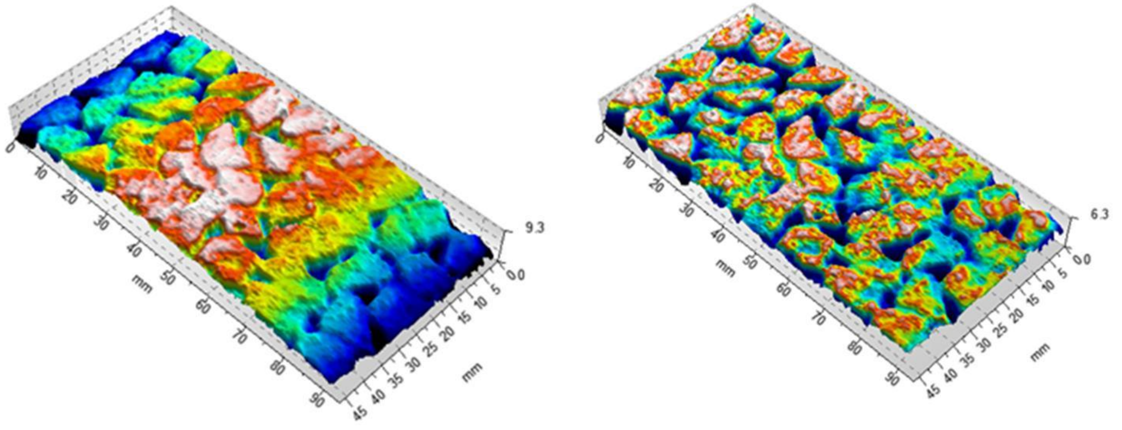

Figure 3. Colour banded 3D model of quartz dolerite curved (left image) and flattened (right image) test specimen

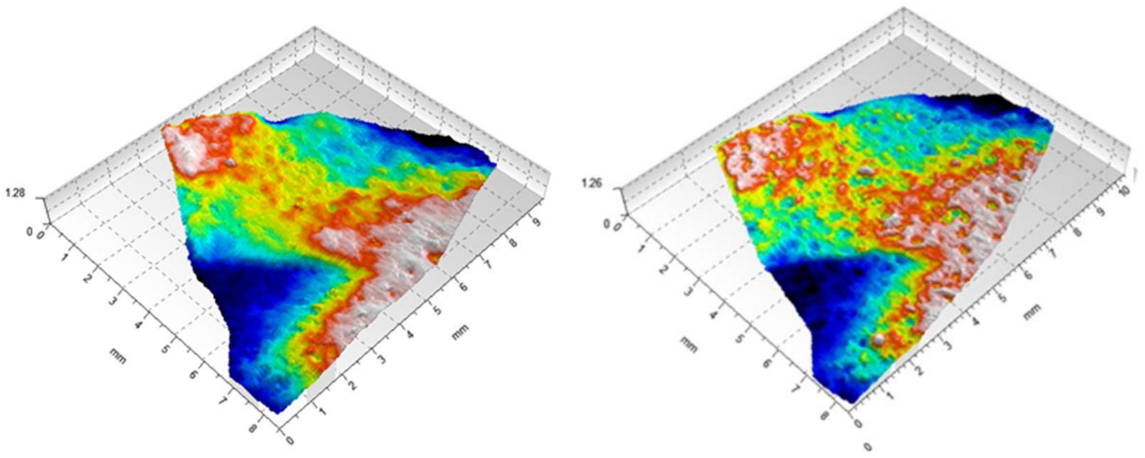

Figure 4. Single greywacke aggregate particle at Time 0 (left image) and at Time 6 (right image)

The Abbott-Firestone curve technique was used to analyse the flattened TIN for each of the selected test specimens. Figure 5 shows an example Abbott-Firestone curve. This is for the Quartz Dolerite test specimen shown in Figures 3 and 4 at Time 0 i.e. before the onset of accelerated polishing. The Abbott-Firestone curve is based on volume ratios and allows comparison between surface volume parameters. The Abbott-Firestone curve divides the surface texture into four volume parameters i.e. volume of peak material (Vmp), volume of core material (Vmc), volume of core voids (Vvc) and volume of valley voids (Vvv). These parameters are detailed in BS EN ISO 25178-2 [20]. The MountainsMap 6 software default settings for lower and upper percentage bearing ratio limits are 10% and 80%. These default limits can be adjusted to investigate issues such as how the peak volume develops down into the surface texture of the 3D model.

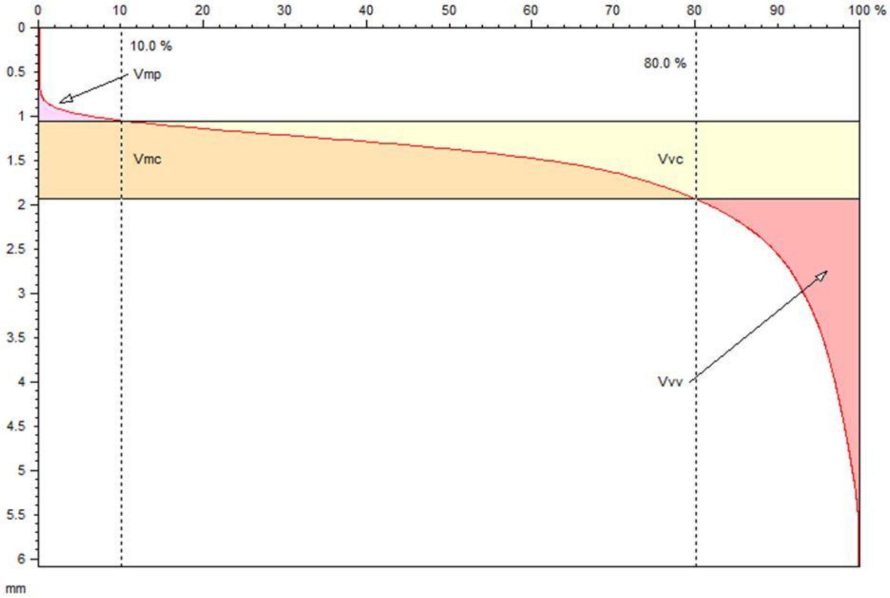

Figure 4. Abbott-Firestone curve at Time 0 for Quartz Dolerite test specimen

By adjusting the bearing ratio limits of the Abbott-Firestone curve a set of volume parameters were obtained for each test specimen at Time 0, Time 3, Time 6 and Time 9. Only Vmp is considered in this paper as this is the volume of peak material i.e. that part of the aggregate particles in the test specimen that will be in contact with the tire during accelerated polishing and with the rubber slider during skid resistance testing using the British Pendulum Tester. Figures 7 to 12 plot Vmp with Bearing Ratio for each of the test specimens at each time interval. The unit for Vmp in these figures is ml/m^2. This conveniently plots the data within a maximum scale of 0 to 1000 units and allows comparison of the different aggregates.

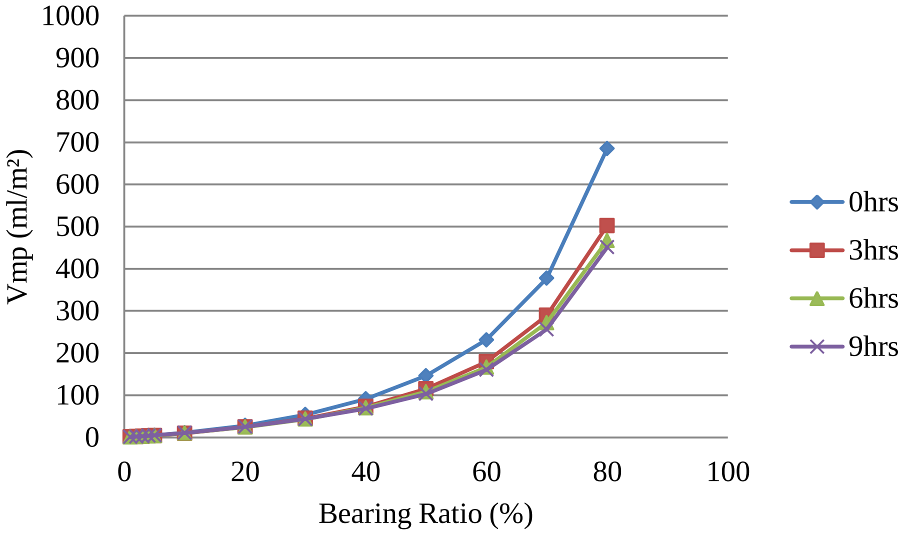

Figure 7. Vmp v. Bearing Ratio for Limestone A at 0hrs, 3hrs, 6hrs and 9hrs polishing

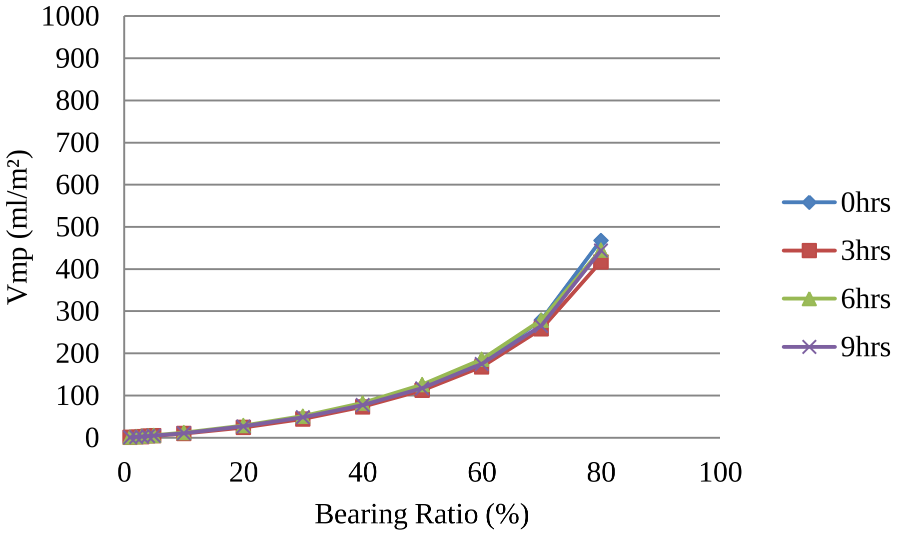

Figure 8. Vmp v. Bearing Ratio for Limestone B at 0hrs, 3hrs, 6hrs and 9hrs polishing

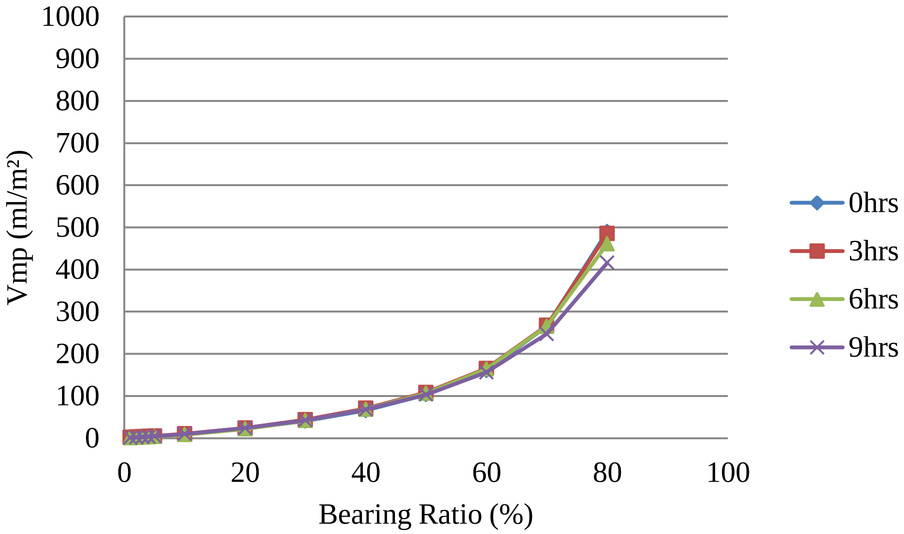

Figure 9. Vmp v. Bearing Ratio for Quartz Dolerite at 0hrs, 3hrs, 6hrs and 9hrs polishing

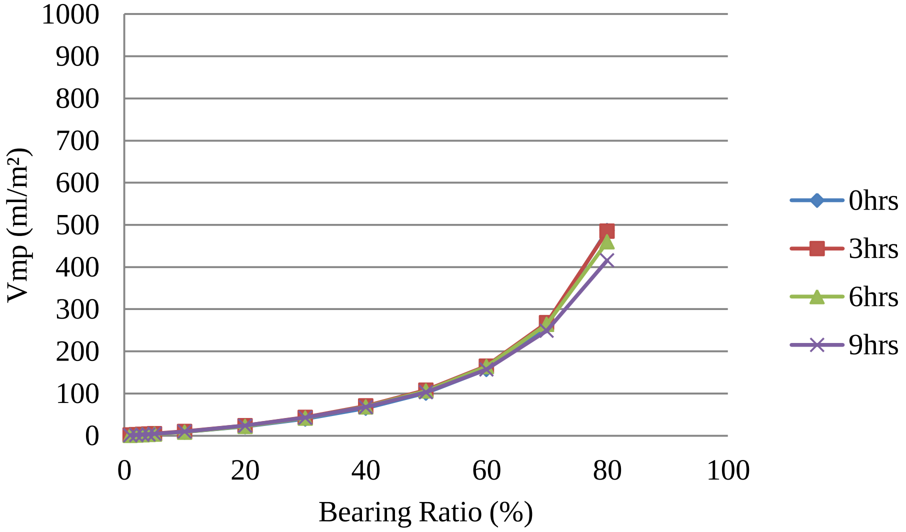

Figure 10. Vmp v. Bearing Ratio for Basalt at 0hrs, 3hrs, 6hrs and 9hrs polishing

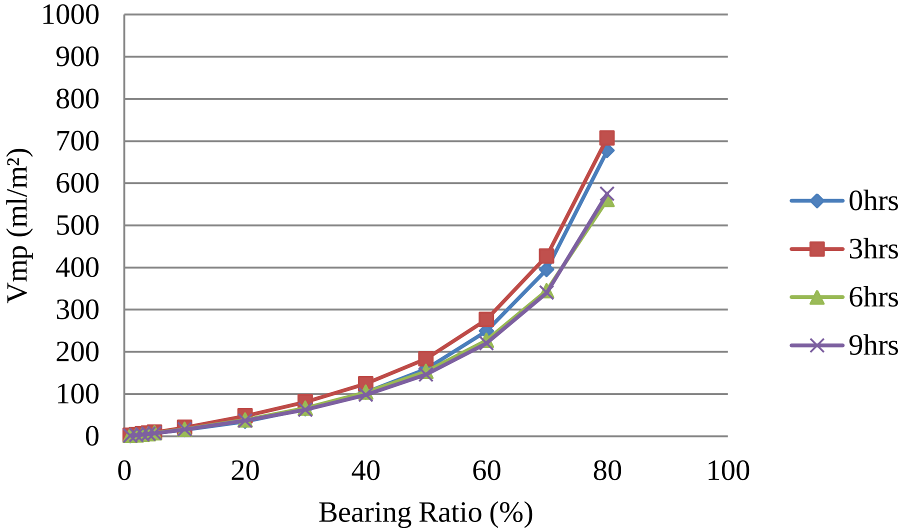

Figure 11. Vmp v. Bearing Ratio for Greywacke aggregate at 0hrs, 3hrs, 6hrs and 9hrs polishing

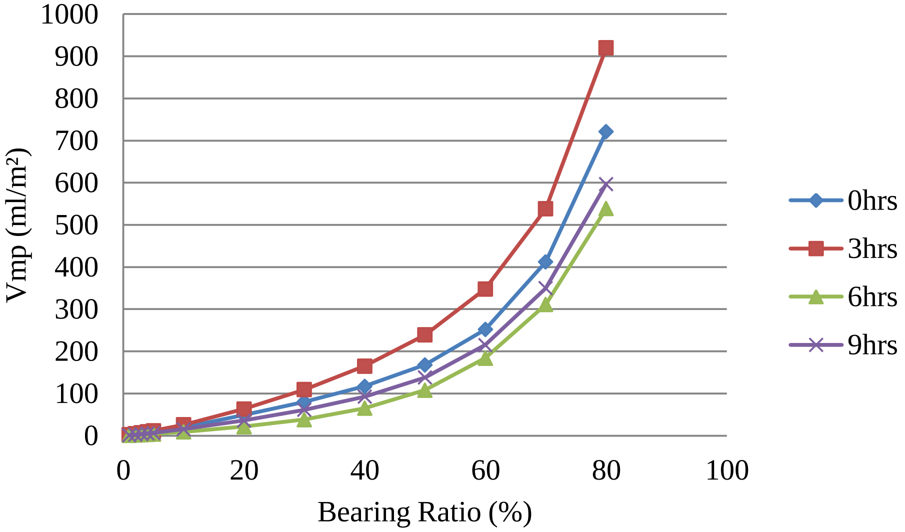

Figure 12. Vmp v. Bearing Ratio for Sandstone aggregate at 0hrs, 3hrs, 6hrs and 9hrs polishing

4. DISCUSSION

Figures 7 to 12 can be used to explain how the surface texture of each test specimen changes during the 4 stages of testing. Initial consideration suggests that each figure shows the four plots of Vmp to diverge with increasing Bearing Ratio. The range of Vmp occupied by the 4 plots is different for each aggregate. For some aggregates there is little difference between the 4 plots. For other aggregates there is a greater range between the 4 plots i.e. there would appear to relationships related to rock type and how they interact with the tire during PSV testing. The following explains in further detail what may be happening to the surface texture of each test specimen during the 4 time periods in relation to the accelerated polishing procedure used.

Time 0 represents the test specimen before accelerated polishing. The surface texture of the aggregate particles represents freshly crushed aggregate that has been subject to screening processes in the quarry and sieving / washing procedures in the laboratory. Time 3 represents the test specimen after 3 hours of accelerated polishing using corn emery. Depending on the aggregate this may reduce surface texture or in some cases increase it. Time 6 represents the test specimen after a further 3 hours of accelerated polishing using emery flour. This typically causes the aggregate particle surface texture to become further polished. Time 9 represents a further 3 hours of higher stress polishing using an offset test tire and flour emery. Previous research found that this additional period cause most aggregate's to loose further skid resistance. However, a small number of aggregates can retain their skid resistance due to plucking of surface grains maintaining micro-texture.

Figure 7 indicates that Limestone A quickly loses its rough initial micro-texture due to corn emery. Thereafter it maintains a smooth surface texture for all of the flour emery polishing cycles. Figure 8 plots the data for Limestone B. This behaves differently with the 4 plots being closely grouped. Figures 9 and 10 are the basalt and the quartz dolerite. The 4 plots in each figure are very similar reflecting the close similarity of both igneous rock types. Figures 11 and 12 plot the greywacke and sandstones. Both figures show the first 3 hours of corn emery to roughen the surface increasing Vmp. The next 3 hours of flour emery cause them both to polish and so loose Vmp. The final three hours of extra stressing using flour emery cause both to increase Vmp again, with the sandstone showing a much greater increase. This would suggest that plucking of surface grains is occurring for both rock types but at different rates.

Figure 13 plots development of PTV v. Vmp at 80% Bearing Ratio during the different stages of accelerated polishing for the 6 rock types. Initially, the trends are confusing. However, these plots confirm the significant importance of rock type during the polishing process as the two limestone aggregates; the two igneous aggregates and the two gritstone aggregates show similar trends. These are shown in Figures 14 to 16. The plots show general trends between PTV and Vmp at 80% Bearing Ratio for these three different rock type groupings. Variation within each grouping appears to result in differences in PTV.

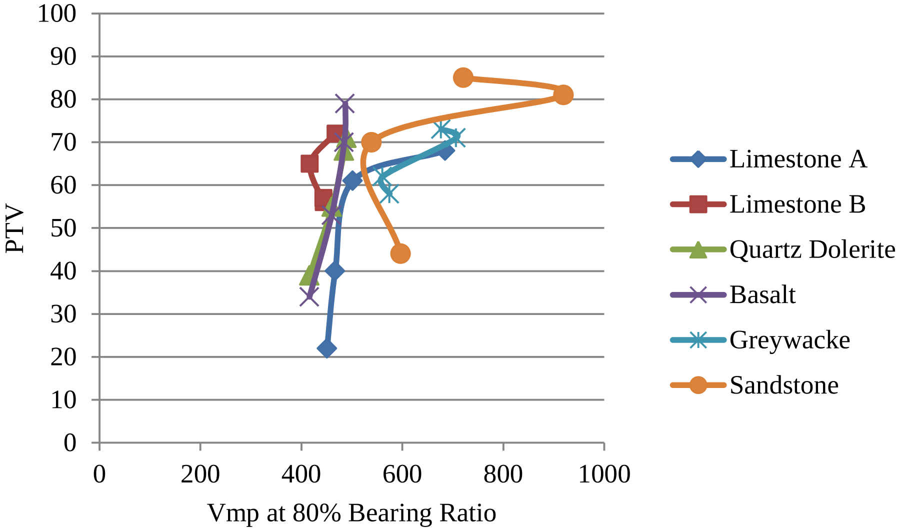

Figure 13. PTV v. Vmp at 80% Bearing Ratio during accelerated polishing – all data

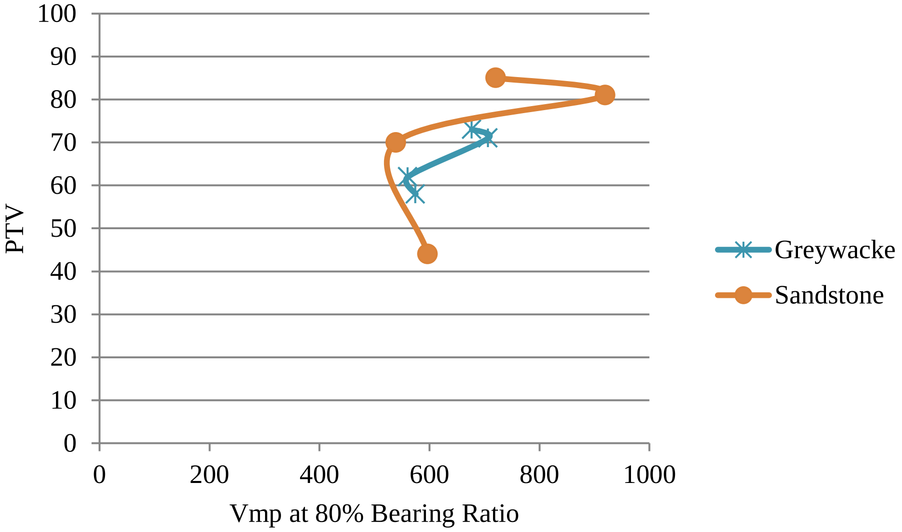

Figure 14. PTV v. Vmp at 80% Bearing Ratio during accelerated polishing – gritstone data

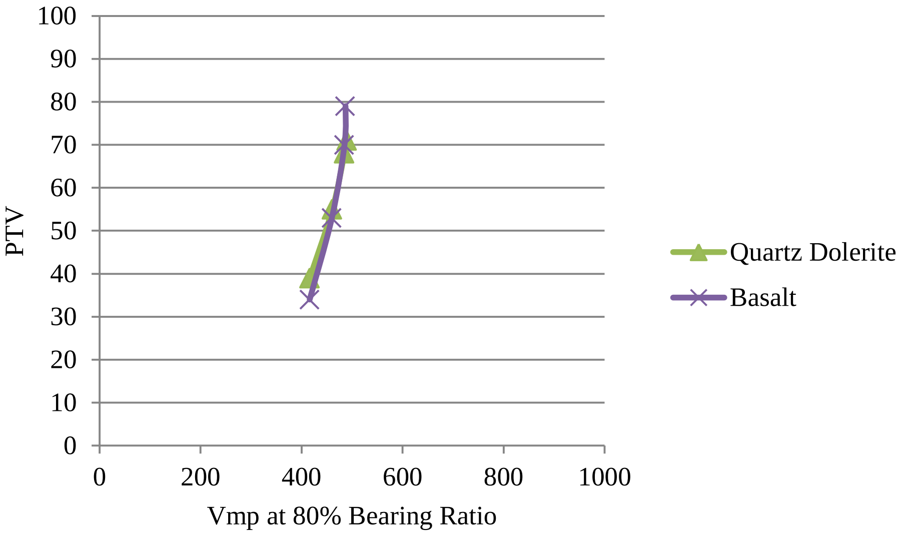

Figure 13. PTV v. Vmp at 80% Bearing Ratio during accelerated polishing – igneous data

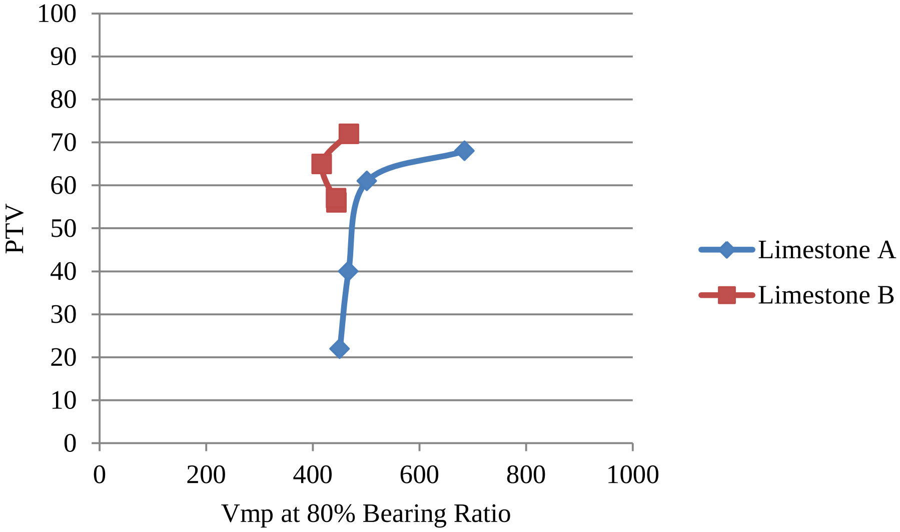

Figure 13. PTV v. Vmp at 80% Bearing Ratio during accelerated polishing – limestone data

During the 4 polishing cycles the interaction between aggregate surface, tyre and polishing medium (corn or flour emery) causes differing equilibrium conditions to occur at two levels i.e. at the rock type level and within a rock-type level. The sandstone and greywacke plots show the effect of plucking. The igneous plots show significant reductions in PTV occur with small reductions in micro texture. The limestone's show one to loose significant levels of PTV whilst the other, with its high silica content, actually roughens up. Whilst the use of Vmp at 80% Bearing Ratio would appear to partially explain what is happening, further work is required to determine the significance of smaller Bearing Ratio Vmp values.

6. CONCLUSION

Six different rock types were subjected to modified polishing using the PSV test equipment. Three dimensional models of the surface texture for the whole PSV sample were constructed from stereo images using close range photogrammetry during testing at 0, 3, 6 and 9 hour intervals. Plots of peak volume (Vmp) at 80% areal material bearing ratio (AMBR) indicate that aggregate types of similar mineralogy show similar wear profile trends. This may help explain the behaviour of aggregate surface micro texture during accelerated polishing. The development of peak volume for each aggregate type is broadly consistent with their physical behaviour as observed through mechanical testing using the PSV test. This is shown in plots of Vmp from 0% to 80% (AMBR) for each time interval. This study proposes that a non-contact, photogrammetric method can possibly recover texture changes within micro-texture wavelengths and offer additional insight into the tyre/surface interface.

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