Use of 3D modelling techniques to better understand road surface textures

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ABSTRACT

This paper considers how the use of close range photogrammetry and hand-held laser scanning can be used to derive 3D models of pavement surfaces. These are two different techniques. Close range photogrammetry is relatively simple using a SLR camera to produce 3D models from stereo images. Hand-held laser scanning uses relatively expensive portable equipment to produce 3D models. Examples are given to show how these methods can be used. Both techniques can be used to measure and quantify parameters that offer new opportunities to investigate issues at scales ranging from the macro to the micro-scale and so allow better understanding of the asphalt / tyre interface. Examples of how these techniques may be used are given.

KEY WORDS: High resolution 3D laser scanning, close range photogrammetry, 3D modelling.

1. INTRODUCTION

Road surface texture influences a wide range of properties including grip, rutting, cracking, ravelling, noise, to how load is transferred from the vehicle tyre down through the pavement structure. Texture is important at differing scales i.e. at a micro-level on the aggregate surface, at a macro-level on the road surface and at a mega level when roads become rutted, cracked or form pot holes. The use of PSV to measure aggregate micro-texture and volumetric sand-patch or 2D laser type measurement for texture depth has been used for many years. However, their data is limited particularly when trying to understand what is happening in the contact patch. This paper considers the use of 3D modelling as a means of getting information. Two techniques are considered i.e. close range photogrammetry (CRP) and 3d laser scanning (3dLS) using a hand held scanner. These produce 3D models that can be analysed using proprietary software to produce parameters in accordance with harmonised European Standards for 3D Areal Surfaces. This paper illustrates the potential of these two techniques.

2. CRP AND 3DLS TECHNIQUES

The two techniques discussed in this paper are quite different but both produce the same type of 3d model for further analysis. Close Range Photogrammetry (CRP) is based on stereo images captured by a camera and analysed using proprietary software to model the subject in 3D. Millar et al. (2009, 2012) found from laboratory and site work that these can be taken under ambient lighting conditions for a wide range of both positive and negative asphalt surface textures. A simple 10 mega-pixel Canon 400D EOS digital SLR camera with a calibrated 60mm macro lens mounted normal to the surface plane on a tripod was used. A remote shutter release and tripod minimised the effects of camera shake during image capture particularly when using slower shutter speeds. During image capture some method of allowing measurement and recovery of surface elevation is required. The simplest method is a steel scale rule included in the image. A better technique is to use a metal framework of control points. Figure 1 shows a control framework designed for roller compacted test specimens.

The x, y and z position of each control point is calculated with a base line referring to the bottom edge of frame. This enables both surface elevation and orientation to be recovered. After capture of a stereo image pair, proprietary Topcon ImageMaster software is used to obtain a Triangulated Irregular Network (TIN). Different mesh intervals are possible depending on the nature of the 3D model required. Filtering data during this process is minimised so as to gain the true nature of the surface. However, if required filters can be applied allowing comparison and evaluation of filtering impact upon the TIN surface.

The Cartesian coordinates produced by the ImageMaster software can be exported in a Comma Separated Value (CSV) file format to spatial information software such as Civil3D, ArcGIS and DigitalSurf MountainsMap software. The Digital Surf MountainsMap software determines parameters of the surface with harmonised European Standard BS EN ISO 25178-2 (2012). The second technique uses a hand-held, high resolution 3D laser scanner. Again this requires a reference network. This is generally a fine plastic mesh with a network of reference points draped over the surface. The model facets can be exported as a text file and analysed using the same spatial software programmes used in the CRP technique.

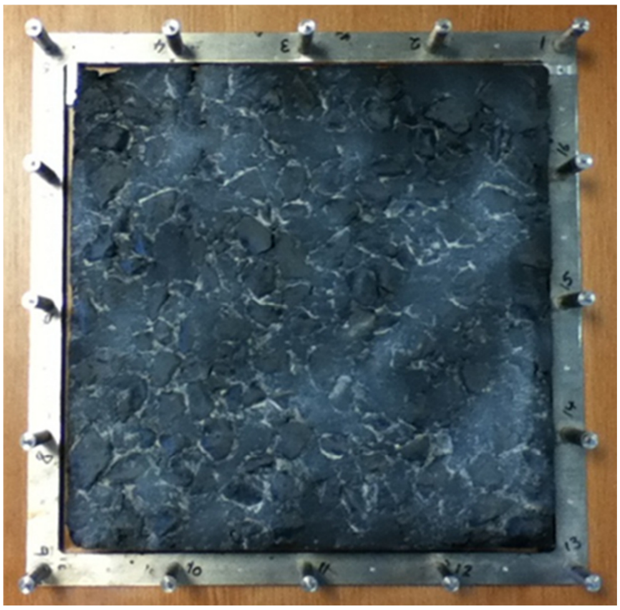

Figure 1. CRP control framework for roller compactor test specimens

3. EXAMPLES USING BOTH 3D MODELLING TECHNIQUES

The purpose of this paper is to illustrate how these two techniques may be used to better understand the role of texture at different scales. The following examples are given:

- Comparison of CRP and volumetric sand patch texture depth data.
- Change in micro-texture during the PSV test.
- Thickness or wear of a white line.
- Monitoring a surface defect.
- Measuring material loss for a ravelling test.
- Particle loss during a ravelling test.

The volumetric sand patch method is the most widely used method to measure texture depth (BS EN 13036-1, 2010). Figure 2 shows how texture depth measured using the volumetric sand patch method correlates with volume data derived from CRP based 3D models (Millar, 2013). This plots three data sets the UK, across Europe and East coast USA. They represent a wide range of surface types including chip seal, asphalt concrete, hot rolled asphalt, stone mastic asphalt and proprietary thin surfacings. At each location two digital images were taken and a volumetric sand patch test done. The camera was a 10 mega-pixel Canon 400D EOS digital SLR camera with a calibrated 60mm macro lens mounted normal to the surface plane on a tripod. No artificial lighting was used other than ambient conditions. The resulting CRP based 3D model was assessed for volume. Figure 2 shows agreement between the two techniques for the three data-sets with a linear relationship with a R^2 of 0.92. This example shows CRP to be a reliable method of surface volume analysis correlating well with the bench-mark sand patch technique used around the world.

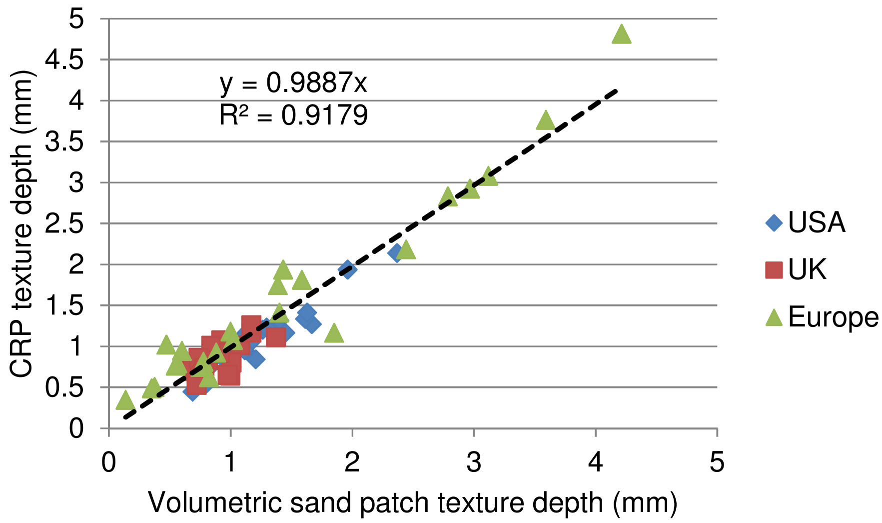

Figure 2. Comparison of texture depth data

The Polished Stone Value (PSV) test was first introduced as a British Standard in 1960 and is now a harmonised European Standard (BS EN 1097-8, 2009). Micro-texture helps cut through the film of water between aggregate particle and tire rubber in wet conditions. The standard PSV test is not a measure of an aggregates ultimate state of polish. It is an equilibrium value that relates to the test conditions. Change the laboratory test conditions and a different value may occur. Some rock types are more prone to different values than others. A similar situation occurs in-service when an aggregate may not perform as expected. Dunford (2013) looked at 3D characterisation at the microtexture scale using an Alicona Infinite Focus microscope. Although it was possible to model small areas of aggregate, recovery of the entire test specimen was impracticable.

McQuaid et al (2013) investigated whether CRP could be used to replicate this study by Dunford. Six aggregates were selected to represent a range of rock types available in the British Isles i.e. Carboniferous sandstone, Silurian greywacke, Tertiary basalt, quartz dolerite and two Carboniferous limestone's. Wet friction was assessed prior to accelerated polishing (Time0). The PSV test specimens were subjected to the standard 3 hours of accelerated polishing using corn emery abrasive and their friction determined (Time3). They were subjected to the standard 3 hours of accelerated polishing using emery flour abrasive and friction determined (Time6). This represents the stage at which a standard PSV value would be reported. The test specimens were subjected to an additional 3 hours of polishing using emery flour abrasive.

During this stage the solid rubber tire of the accelerated polishing machine was offset at an angle of 6 degrees. This imposes a different set of equilibrium conditions and can cause further loss of friction. Friction was determined for the fourth time (Time9). A representative PSV test specimen for each rock type was selected. Table 1 shows the change in friction for the selected test specimen. The data shows the expected change in friction during the standard 6 hour period. The Time9 data shows that the standard PSV test that involves 6 hours accelerated polishing may not result in the lowest possible value.

Table 1. Friction data for selected PSV test specimens

Aggregate	Time0	Time3	Time6	Time9
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

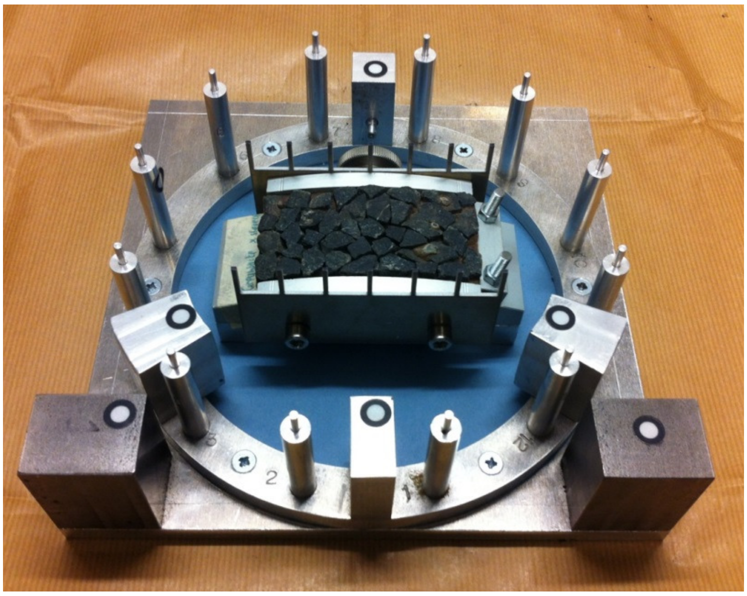

Figure 3. The PSV test specimen control framework

Figure 3 shows the PSV test specimen control framework. Close-up images were taken of individual aggregate particles. Topcon ImageMaster photogrammetric software (Topcon, 2010) was used to create Triangular Irregular Network (TIN) 3D models. The TIN mesh resolution was 0.1 mm for the PSV test specimen and 0.01 mm for individual aggregate particles. No filters were applied to the TIN datasets to avoid possible removal of surface microtexture. The TIN mesh was imported into Digital Surf MountainsMap 6 software DigitalSurf, 2013). Figure 4 shows the curved PSV test specimen colour banded to emphasis its z-direction height. The curved form was removed to simplify analysis using the flattened model.

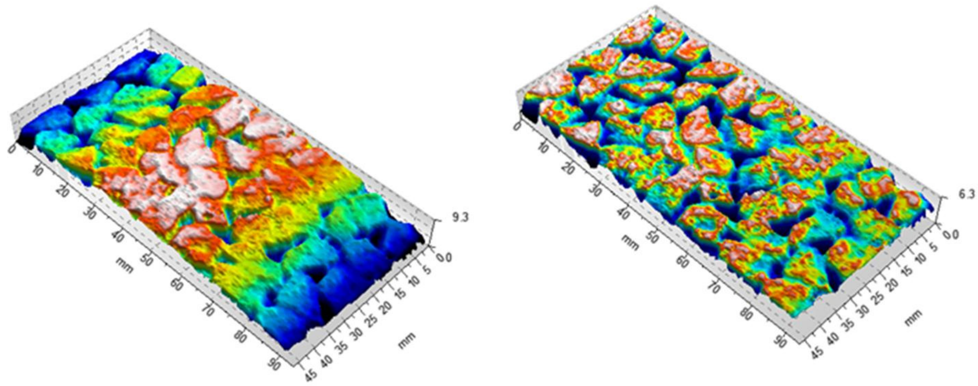

Figure 4. PSV test specimen colour banded 3D model - curved (left image) and flattened (right image)

Figure 5 shows a single greywacke aggregate particle modelled at Time0 and Time6. This shows the surface of the aggregate particle to have worn with 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.

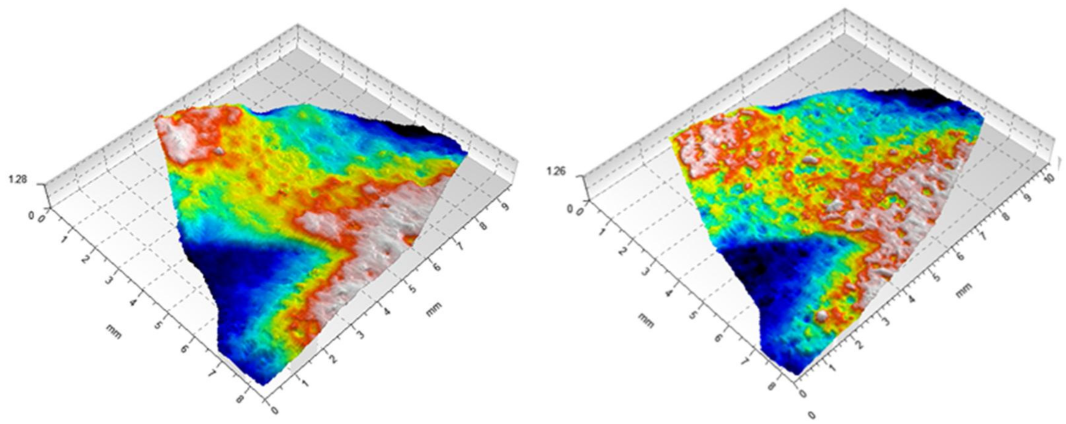

Figure 5. Single greywacke aggregate particle at Time 0 (left image) and at Time 6 (right image)

The Abbott-Firestone curve procedure (BS EN ISO 25178-2, 2012) was used to analyse the flattened TIN for each selected PSV test specimen. This is based on volume ratios and allows comparison between surface volume parameters. It divides 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) (BS EN ISO 25178-2, 2012). 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. By adjusting the bearing ratio limits of the Abbott-Firestone curve a set of volume parameters were obtained for each PSV test specimen at Time0, Time3, Time6 and Time9. Only Vmp is considered in this paper as this is the volume of peak material i.e. that part of the aggregate particle in the PSV test specimen that will be in contact with the tyre during accelerated polishing and with the rubber slider during friction testing. Figure 6 plots Vmp with Bearing Ratio for Limestone A for each friction test time interval.

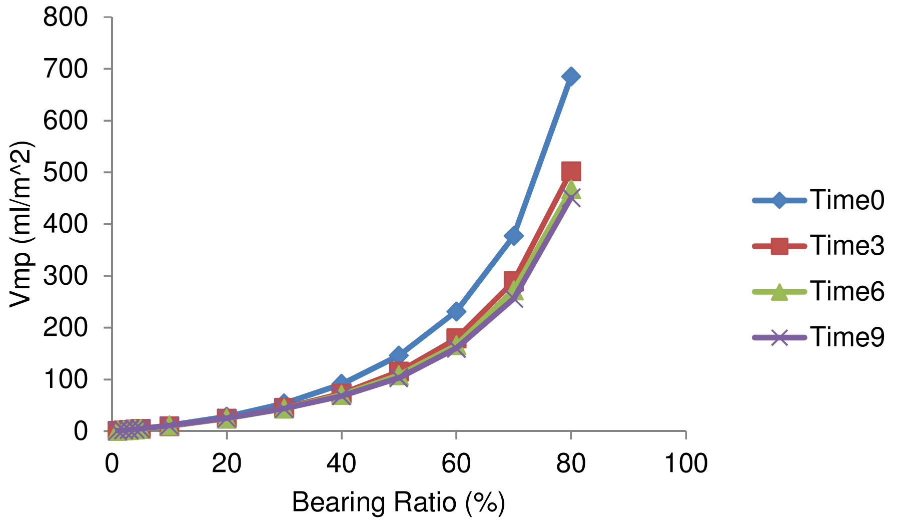

Figure 7. Vmp v. Bearing Ratio for Limestone A

This plot helps explain how surface texture changes during the 4 stages of testing. Limestone A quickly lost its initial microtexture and then continued to polish. Figure 8 plots friction (PTV) v. Vmp at 80% Bearing Ratio during the different stages of accelerated polishing for the 6 rock types. Initially, the trends appear confusing. However, the plots confirm the 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. Variation within each grouping appears to account for the differences in PTV friction.

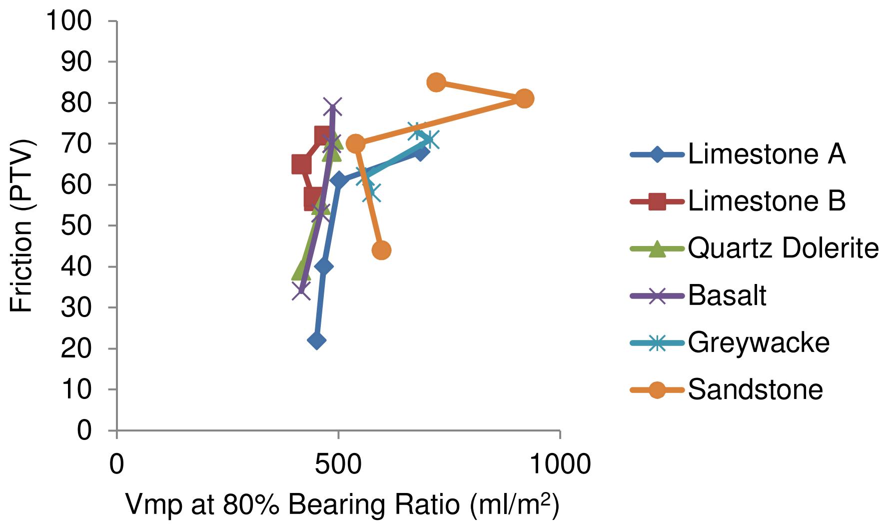

Figure 8. PTV v. Vmp at 80% Bearing Ratio – all data

During the 4 periods of test, 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 specific rock-type. The sandstone and greywacke plots show the effects of plucking. The igneous plots show significant reductions in friction occur with small reductions in microtexture. The limestone's show one aggregate to loose significant levels of friction whilst the other high silica content actually roughens up. This example indicates that a non-contact, 3D method can recover texture changes within microtexture wavelengths and offers additional insight into understanding the tyre / surface interface.

Figure 9 shows how the CRP method can be used to investigate a white line for properties such as thickness. This example is based on two images and two steel rules for reference scale purposes. Colour is used to show variation in thickness of the white line. Figure 10 shows a cross-section across the width of the white line 3D model. This shows the line to be approximately 8 mm thick.

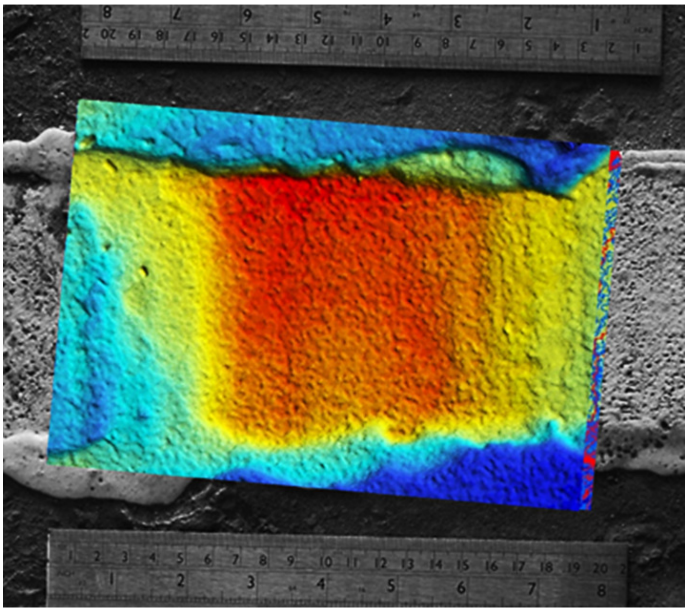

Figure 9. Surface texture recovery of a white road marking (Millar, 2013)

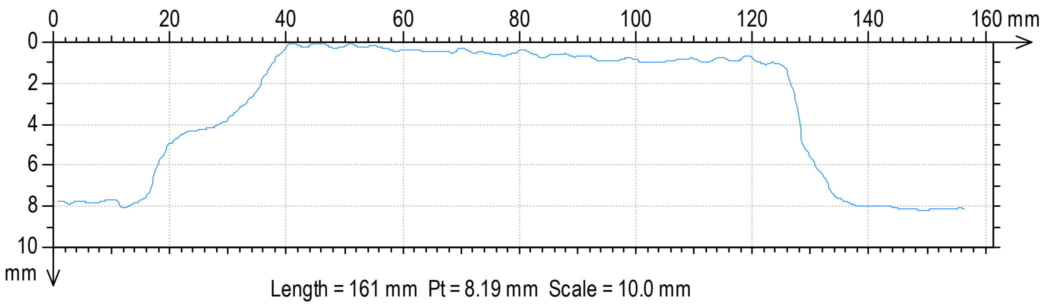

Figure 10. Cross-section taken from white line 3D model

Another common problem faced by those involved in highway maintenance is determining either the size of a structural defect or monitoring its development. Figure 11 shows a failing joint obtained using the CRP technique (Millar, 2013). This is based on 2 images and a single steel scale rule. The depth classification applied to the TIN visually highlights the extent of this surface defect using colour contouring. 2D profiling could show depth of the failure. 3D volume analysis could be used to monitoring volume change as the joint ravels.

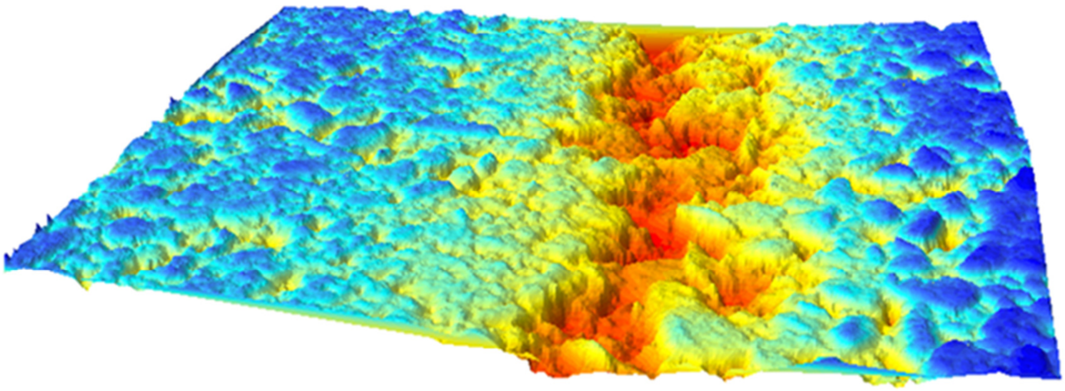

Figure 11. Depth classified 3D model of a failing joint (Millar, 2013)

The examples shown so far in this paper have been based on CRP i.e. 2 digital images post-processed to produce a 3D model. They have been taken both on site and in the laboratory. They could also have been determined using the 3DLS technique. However, the hand held 3D laser requires a power source making it more difficult to use on-site. The final example shows how 3D modelling has been used as a key component in the development of a new Dragged Ravelling Test (DRT) to assess asphalt mixtures (Mitchell, 2014).

This used an immersion wheel track apparatus modified to lock the test wheel in one direction causing it to be dragged across the test specimen surface. The standard solid rubber tyre was replaced with a pneumatic MOJO 10 x 4.5/5 go-cart treaded wet tire to better interact with the test specimen. The test specimens were 305 x 305 x 50 mm roller compacted slabs. The problem was how to determine the amount of ravelling. 3D modelling using a handheld ZScan high resolution 3D laser scanner was used. A scan resolution of 200 µm was used. A range of asphalt concrete, stone mastic asphalt and hot rolled asphalt mixtures were evaluated. Factors including compaction, test temperature, pre-test conditioning, test duration, tyre inflation and load were investigated.

Figure 12 shows a DigitalSurf MountainsMap 6 3D model for a poorly compacted AC14 160/220 pen test specimen. It had been tested in water at 60^0C for just 5 minutes. The depression in the surface of the test specimen caused by the dragged tyre is obvious. The depression depth was measured at 6 locations using the Step Height Measurement procedure. The volume of ravelled material removed from the test specimen was measured using the Volume of Hole / Peak procedure. Figure 13 plots the relationship between compaction (bulk density), average depth and volume of ravelled material for 2 sets of AC14 test specimens. One set of test specimens was less well compacted than the other. Figure 14 plots volume loss against average depth and shows the importance of compaction under these test conditions. This example shows how 3D modelling can be used to readily extract additional detail from a test specimen that would otherwise prove quite difficult to do. It illustrates how new types of test method can be designed around this type of analysis opportunity.

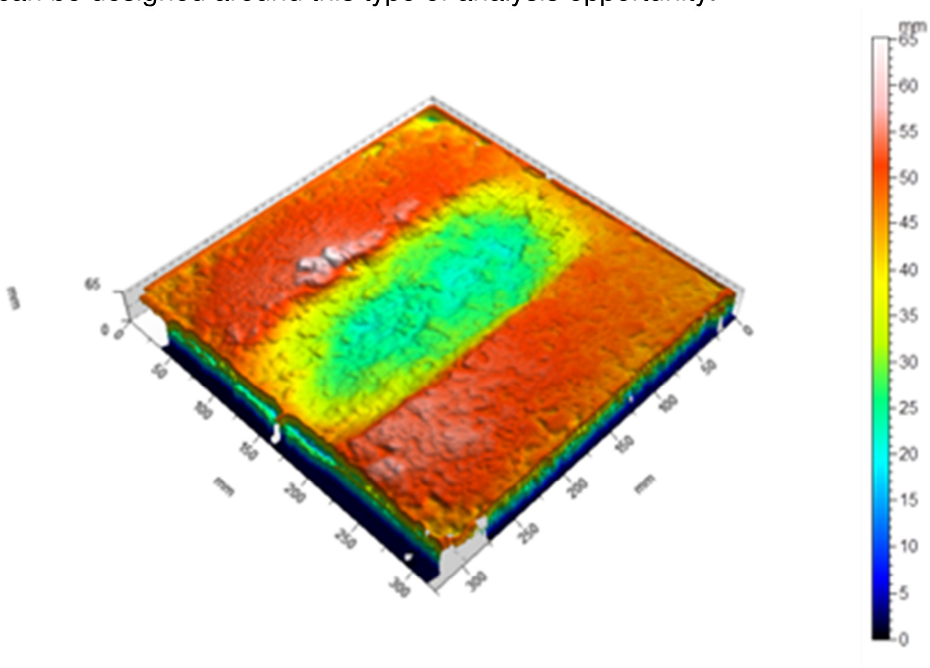

Figure 12. Poorly compacted AC14 slab tested in water at 60^0 C for 5 minutes

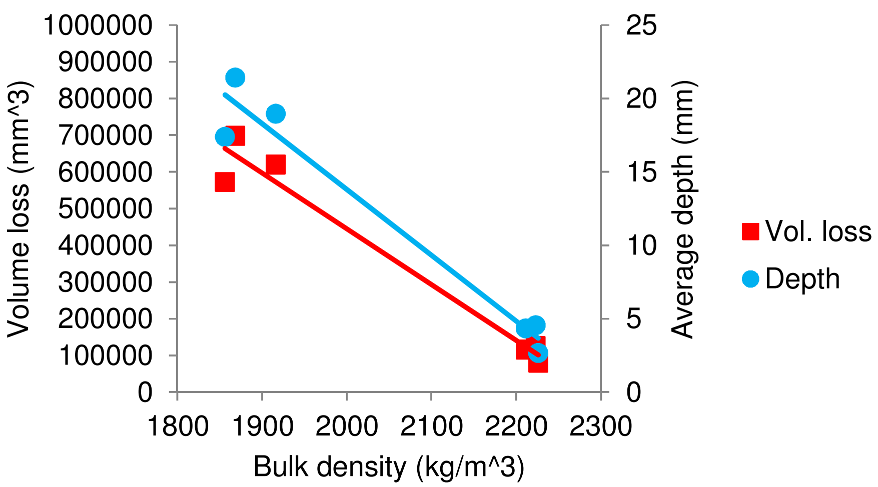

Figure 13. Compaction (bulk density) v. average depth and volume of ravelled material

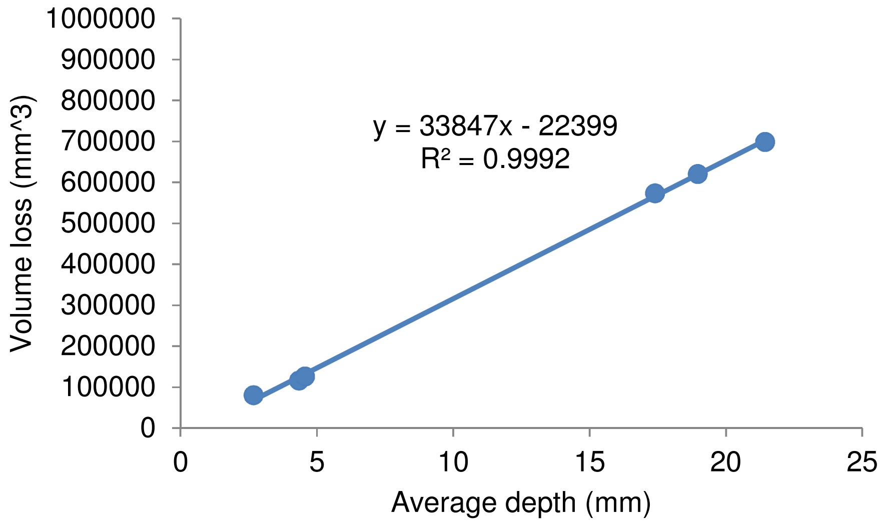

Figure 14. Volume loss v. average depth

4. CONCLUSIONS

This paper has shown how CRP and 3DLS based 3D models can be used to better understand texture related issues for surfacing materials. It has illustrated how the 3D models can be manipulated and analysed using proprietary software to achieve otherwise unattainable surface parameters. This ability to measure and quantify parameters opens new opportunities to investigate issues at scales ranging from the macro to the micro.

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