

Aggregate particle wear and the tyre / surface interface

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ABSTRACT

This paper considers the relationship between aggregate particle wear and stress at the tyre / surface interface. Changes at this interface during its life influence surfacing properties including skid resistance, noise generation and rolling resistance. This paper combines two areas of study to consider such change. It looks at the wear of aggregate particles due to simulated trafficking and changes in contact stress that result as a consequence. A modified wet micro-deval test was used to investigate aggregate particle wear. The modification involved carrying out a post-test grading analysis of the single-sized test sample. This offers simple insight into how original single sized particles change as a result of a standard amount of wear. It suggests how a given aggregate may perform in different types of use e.g. positive textured chip seal or relatively smooth SMA type surface. Interfacial stress was measured by placing a flexible pressure pad between a friction measuring tyre and idealised road surface textures representing increasing amounts of particle wear. These idealised textures had been drawn in CAD and then printed using a 3D printer. This allowed a range of interfacial stress conditions to be investigated under ideal laboratory conditions.

Keywords: Aggregate wear, tyre / surface interface, pressure mapping.

Introduction

A road surface is designed to have a textured finish. This texture is present at different scales. The two most recognised scales are termed microtexture and macrotexture representing the aggregate particle surface and road surface respectively. These texture scales evolve over the life of a road. The surface of individual aggregate particles can become polished leading to unsafe driving conditions particularly in the wet.

Aggregate polishing has been studied for many years and laboratory methods such as the polished stone value (PSV) and friction after polishing (FAP) developed to predict in-service performance. The values from these test methods are used to specify and select suitable aggregate for a particular use. However, both the PSV and FAP test methods are laboratory test methods done under standardised conditions.

If the test conditions are changed e.g. increase the applied load, offset the test wheel, then the aggregate under test may respond to this change in ways different to that of the standard test and give a different measurement when assessed. With respect to predicting performance, the standard test does not represent an ultimate state of polish nor can the standard test result be used to predict performance for all possible in-service conditions.

The same can be said for how macrotexture can be ensured over the life of a road. How aggregate particles exposed at the surface wear away due to trafficking is essential to understanding the evolution of road surface texture during the life of the road surface. Methods of aggregate assessment have existed for more than 100 years. There are 2 basic types: dry tests such as the Aggregate

Abrasion Value (AAV) and wet tests such as the wet Micro-deval test (MDE). The AAV is a dry abrasion test using silica sand as the abrasive. It dates from Victorian times when stone setts were assessed for resistance to wear associated with horses hooves and metal carriage wheels. The MDE a dynamic method which measures the wearing action of aggregate against aggregate particles and steel ball-bearings as they tumble in the presence of water.

These are major differences in test methodology. Woodward (1995) critically compared the two methods and concluded the MDE closer resembles in-service trafficking conditions where the pneumatic tire rubber deforms around individual particles as it rolls across the road surface. Trafficking does not cause aggregate particles to abrade in the uniform manner assessed in the AAV test. Rather, aggregate particles edges become rounded and weaker particles are differentially abraded just as it happens in the MDE test. A small number of hard wearing aggregate particles can protect a majority of softer particles in the AAV test.

These comments relate to the existing laboratory methods of predicting micro and macrottexture of aggregate particles. This paper develops these basic ideas into considering whether it is possible to improve prediction of in-service performance using laboratory methods. It considers the relationship between aggregate particle wear and stress at the tyre / road surface interface. Changes at this surface interface during the life of a road influence surfacing properties including skid resistance, noise generation and rolling resistance.

This relationship between road surface texture and these properties formed the basis of the recently completed European Union ROSANNE project (2016). This project highlighted the need to better understand the road surface / tire interface as it affects a wide range of issues ranging from road safety to global issues such as CO₂ emissions and addressing the goals of the Paris Agreement.

This paper combines these two different but related areas of laboratory study to determine whether it is possible to get improved insight into road texture and the tyre / surface interface. The two areas are aggregate particle wear and contact pressure mapping. The aim is to determine whether it is possible to improve in-service prediction by showing how the tyre / road surface interface may change as the aggregate particles wear due to trafficking.

Aggregate particle wear

A simple modification to the wet micro-deval test was used to investigate aggregate particle wear. The modification involved carrying out a post-test grading analysis of the single-sized test sample. This offers new insight into how the particle form or 3-dimensional shape of the test specimen aggregates change as a result of a standard amount of wear in the micro-deval apparatus. The following example illustrates how this may give added insight into predicting road surface texture change.

The aggregate used in the example is a 10 mm Tertiary basalt of uniform composition i.e. it did not contain weathered particles. If a greywacke had been used then it may be argued that the resulting findings are influenced by the presence of weaker shale within the test sample. MDE testing was carried out on the poorly graded basalt 10 mm aggregate as received for testing, single size 10 to 6.3 mm with over and under size removed and single size 10 to 6.3 mm with Flakiness Index values (FI) of 0, 30 and 100 %. The test specimens were sieved using a 10, 6.3, 3.35 and 1.6 mm sieves after the standard 2-hour wet test.

A comparison of the pre-test and post-test grading curves is shown in Figure # for this basalt aggregate. The standard MDE is calculated as the percentage passing the 1.6mm sieve after testing. Figure 1 shows the four basalt test specimens with different size / flakiness to have approximately the same value of MDE after testing. Shape did not have a detrimental effect with the standard MDE result changing from 33.0 to just 34.1 for 100% cubical and 100% flaky chippings respectively. The poorly graded 10mm basalt test sample, as supplied, was similar to that obtained for the single size test specimens of FI 0 and 100%.

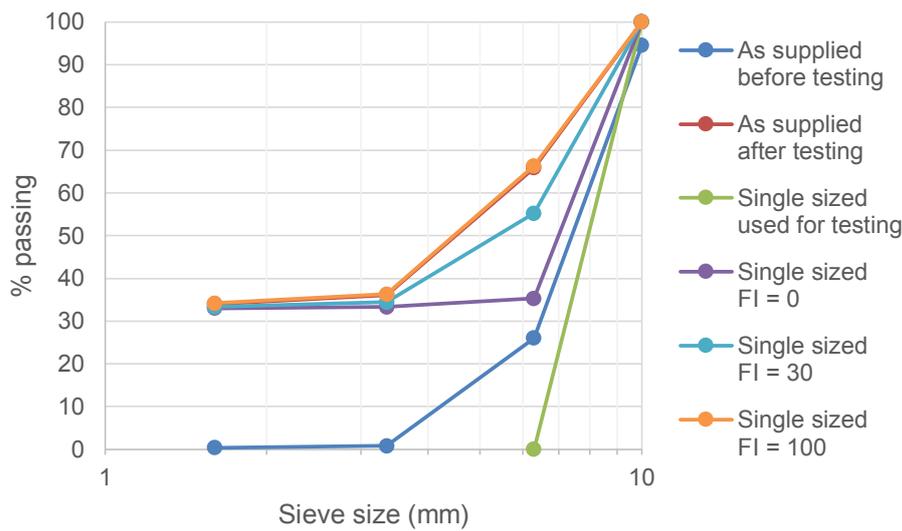


Figure 1. Comparison of post MDE test gradings.

However, the post-test grading curves shows how the form of the original aggregate particles change due to testing. It shows significant variation in the amount of aggregate particles passing the 6.3mm sieve size. The % passing the 3.35 mm and 1.6 mm sieves was similar. With respect to predicting retention of macrotexture during in-service trafficking, the amount of aggregate retaining its original 3 dimensional size and shape is a better indicator of performance.

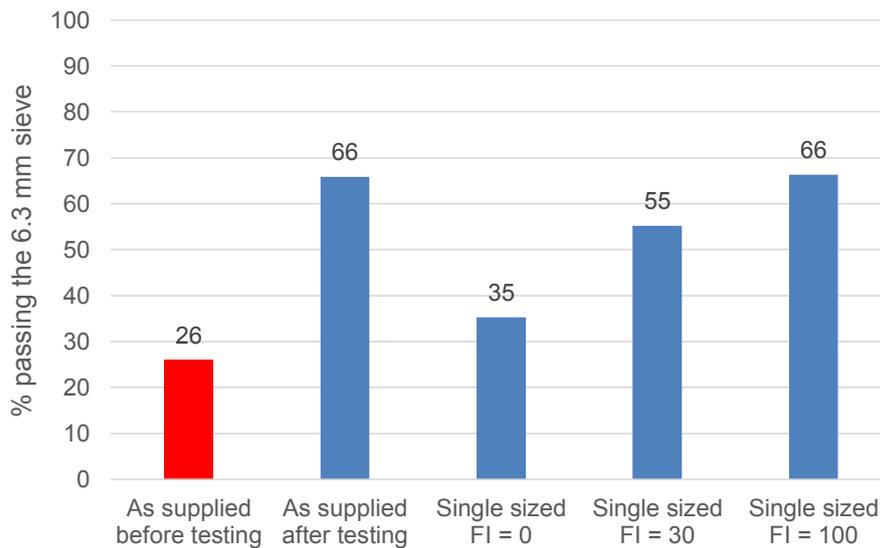


Figure 2. Percentage of aggregate passing the 6.3 mm sieve after MDE testing

This is illustrated in Figure 2 which compares the % of aggregate particles passing the 6.3 mm test sieve for each of the test specimens. Increasing the amount of flaky aggregate particles increased the amount of particles passing the 6.3 mm sieve. The flaky aggregate particles lost more of their original size compared to the cubic chippings. Although the MDE test in this example indicated all aggregate

samples to have similar MDE values, the 6.3 mm data suggests otherwise with respect to maintaining road surface texture.

The initial conclusion from this first stage of the paper is that its possible with small modifications to an existing method to improve the prediction of likely in-service aggregate performance with respect to parameters related to road surface texture.

Change in interfacial stress

The tyre / surface interface influences all road texture related parameters i.e. skid resistance, noise and rolling resistance. It also influences how the dynamic loading of a moving vehicle is transferred from initial contact with the surface of road surface aggregate particles down through the different layers of the pavement structure.

Investigation of the tyre / surface interface can be traced back to researchers such as Bradley and Allen (1930) who investigated the principles of what would subsequently be developed as the sideways-force method of road surface friction measurement. 90 years later, the tyre / road surface interface dependant properties are still not properly understood or implemented.

A methodology was developed at Ulster University to investigate this interface. It had to be a relatively simple, quick method that used available equipment. It had to produce reliable, robust data that could be analysed in different ways. It had to produce visual representations of interface conditions, be used as inputs for computer modelling or be used to verify model predictions.

The method had to be able to assess tyre properties and the different materials used in road surfaces. It had to evaluate how this interaction would change over the life of the surfacing material due to simulated trafficking.

This was achieved by combining four main elements (i) a tyre, (ii) a z-axis pressure mapping system, (iii) a device to allow measurement of static or dynamic interface properties and (iv) a device to simulate accelerated trafficking of test specimens. Although the emphasis in development was on friction, the data can be used to better understand other interface properties such as noise and rolling resistance.

The tyre can be that used for friction measurement e.g. the tyres fitted to fixed slip or sideways-force devices; or it can be the tyres used for noise measurement using the CPX method; or it can be any tyre fitted to a car or truck. The interface conditions between the tyre and test specimen are quantified using z-axis pressure mapping. Two mapping systems are used depending on what aspect of the interface is being assessed.

The first system has 1.15 x 1.15 mm resolution and 65,536 sensing elements mounted on a rigid plexiglass backing. This high resolution rigid system is used for tyre interface measurement only. The second system consists of a flexible mat or pad with 2.54 x 2.54 mm resolution and 16,384 sensing elements. This flexible lower resolution system is used for tyre interface measurement and for tyre / test specimen surface interface measurement where it is placed between the test surface and the tyre.

Proprietary software records and displays real time data recorded in frames. This can be displayed as individual 2D or 3D frames or as a continuous composite model if the test surface and pressure pad is moved underneath the test tyre during data capture. Pressure data may be exported in csv format for further analysis or as modelling inputs. Both pressure mapping systems have a calibrated pressure range of 68.9 to 1378 kPa (10 psi to 200 psi) with a data acquisition rate of up to 16 frames per second during dynamic testing when the test specimen is moved under the test tyre.

Two devices were developed to hold smaller and larger diameter tyres. Load on the tyre is varied using weights attached to the end of a lever arm. The interface conditions of newly compacted asphalt or concrete materials are influenced by coatings on the aggregate particles in contact with a tyre. In real-life, trafficking initially removes these coatings. With continued trafficking the exposed aggregate particles begin to polish, wear and ultimately be susceptible to particle loss.

Therefore, an important element of the methodology was the need to subject test specimens to accelerated trafficking and so be able to better simulate what happens in real-life. This is achieved by subjecting test specimens to simulated trafficking under controlled laboratory conditions using the Road Test Machine (RTM) located at Ulster University. Test specimens can be 305 mm x 305 mm x 50 mm slabs, 150 mm diameter gyratory compacted or cores extracted from a road.

Figure 3 shows the basic setup for a small fixed slip friction measuring tire. This shows the friction tire fitted to a loaded lever arm resting on the flexible pressure pad which has been placed on top of a textured test specimen. Real-time interface data is shown on the computer screen.

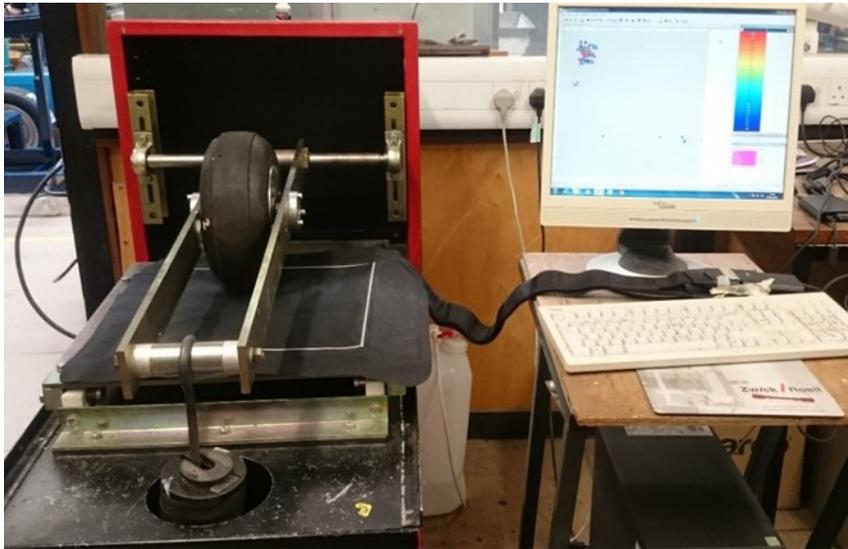


Figure 3. Setup for a small fixed slip friction measuring tire.

This adaptability allows different tire / aggregate / bitumen / compaction / mixture combinations to be quickly assessed without the need for full-scale road trials. Simulated trafficking can be stopped periodically to measure change in parameters such as macrotexture and wet skid resistance. Photographic images can be taken for 3d photogrammetry modelling. This allows change in standard test parameters to be compared with 2d and 3d areal parameters and pressure mapping derived interface data.

With regard to this paper the small size ASTM 1844 friction tire was used along with the flexible pressure pad. Rather than using real asphalt test specimens it was decided to use idealised surfaces where the dimensions of each particle could be controlled. The reason for idealised surfaces is illustrated in Figure 4 which shows pressure pad data for a test slab of 10 mm SMA. This shows z-axis pressure data at the 2.54 x 2.54 mm resolution of the flexible pressure pad. The composite image shows contact area and the distribution of z-axis pressure as the friction tire is moved across the SMA surface.

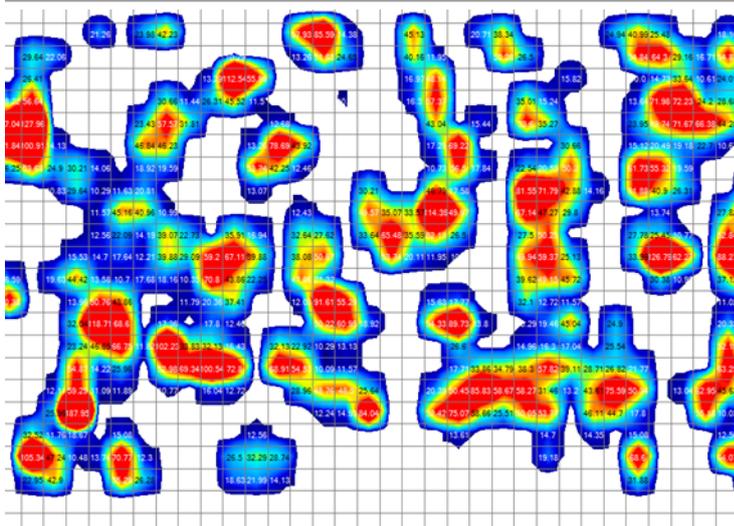


Figure 4. Flexible pressure pad data for an actual 10 mm SMA.

This shows a complex interface surface. The 10mm SMA that was responsible for this figure can be photographed, 3d modelled and quantified using a wide range of areal parameters. Being able to 3d model any type of road surface texture, based on photographs allows any surface anywhere in the world to be evaluated on a computer screen (Woodward, Millar and McQuaid, 2014). However, being able to assess its actual interface with a real tire and pressure pad is not possible using 3d computer screen imagery.



Figure 5. 3d model made from road surface photographs taken in France and printed in 2 types of media.

This led to investigating the use of 3d printers to create an actual hard copy of the 3d model derived from photographing a road surface (Hamilton, 2016). Figure 5 illustrates a 3d model made from road surface photographs taken in France and printed in 2 types of media. The ability to 3d print any type of 3d model opens up all sorts of possibilities with understanding the tyre / road surface interface.

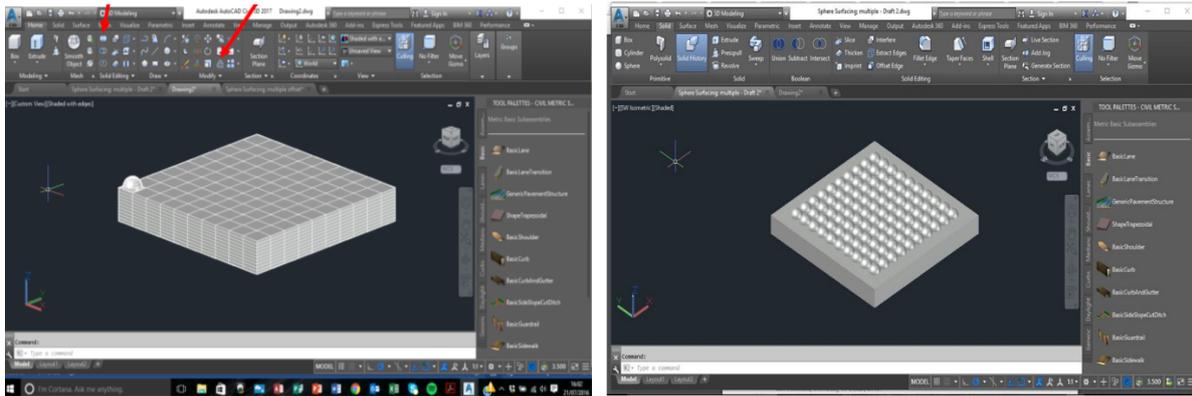


Figure 6. Screenshots showing the creation of an idealised worn 10mm SMA surface.

Autodesk AutoCAD Civil 3D was used create idealised road textures (Hamilton, 2016). Figure 6 show screenshots in the creation of an idealised 10mm SMA surface where each aggregate particle is the same size and has been worn equally to form a hemi-spherical shape. These Civil 3D CAD models were then sent to a FORM 2 3d printer. Figure 7 shows two 3d prints with different orientation of the idealised worn 10 mm hemi-spherical aggregate particles. These are referred to as rectangular packed (left image) and close packed (right packed).

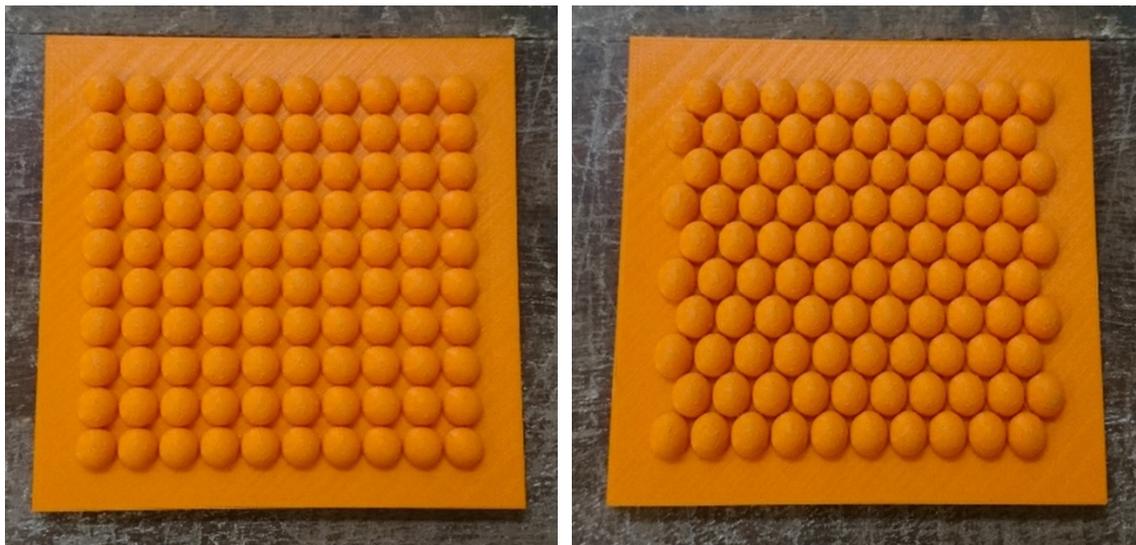


Figure 7. 3d printed idealised worn 10mm SMA surfaces - rectangular and close packed.

The interface of these idealised 3d surfaces was assessed using the flexible pressure pad and small sized friction measuring tyre. Figure 8 shows the composite image for a idealised unworn 10mm SMA with 2 mm spacings between individual particles. The flexible pressure pad has an individual cell size of 2.54 x 2.54 mm. Figure 9 compares single frames for the rectangular packed (left image) and close

packed (right packed) idealised worn 10 SMA. The examples show how the rounding of the aggregate particles has influenced the contact interface.

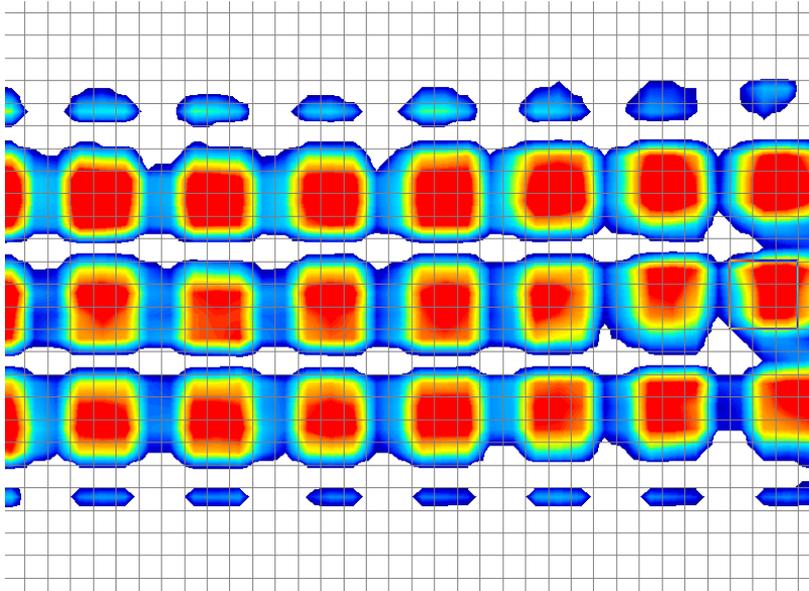


Figure 8. Variation in z-axis contact for idealised unworn 10mm SMA.

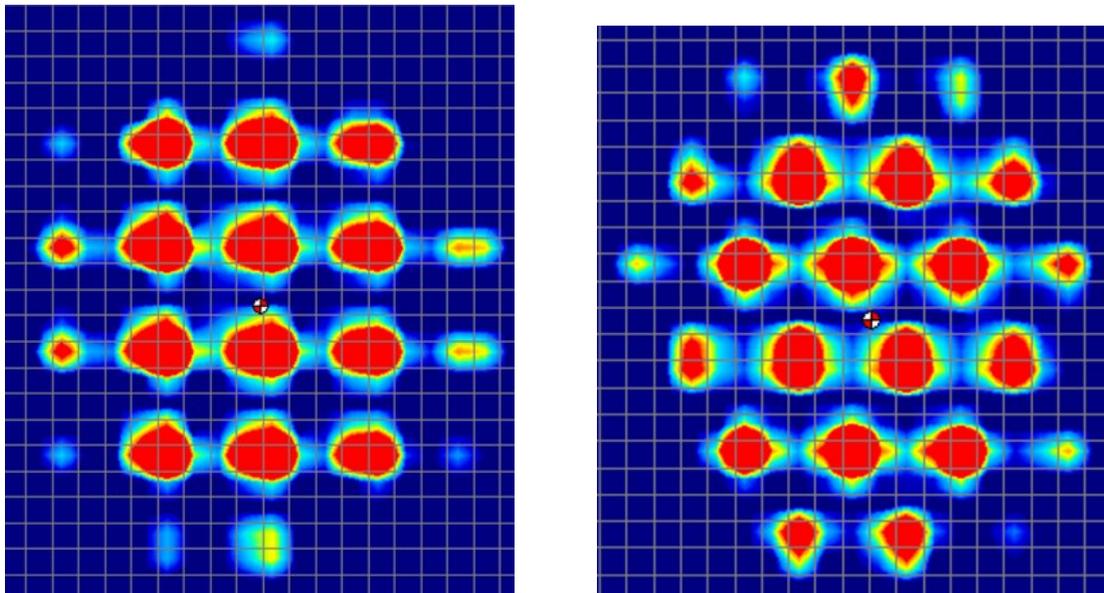


Figure 9. Variation in z-axis contact for idealised worn 10mm SMA (rectangular and close packed single frames).

Analysis of this data can provide different ways of expressing the tyre / surface interface. Figure 10 shows compares peak pressure for the unworn idealised 10mm SMA with the 2 versions of worn idealised 10mm SMA in terms of cumulative frequency. The source of this data are the individual measurements recorded for each 2.54 x 2.54 mm pressure pad measurement cell as the tyre is

moved across the test surface. This shows the unworn 10mm SMA to have a different frequency distribution compared to the two worn idealised 10mm SMA surfaces.

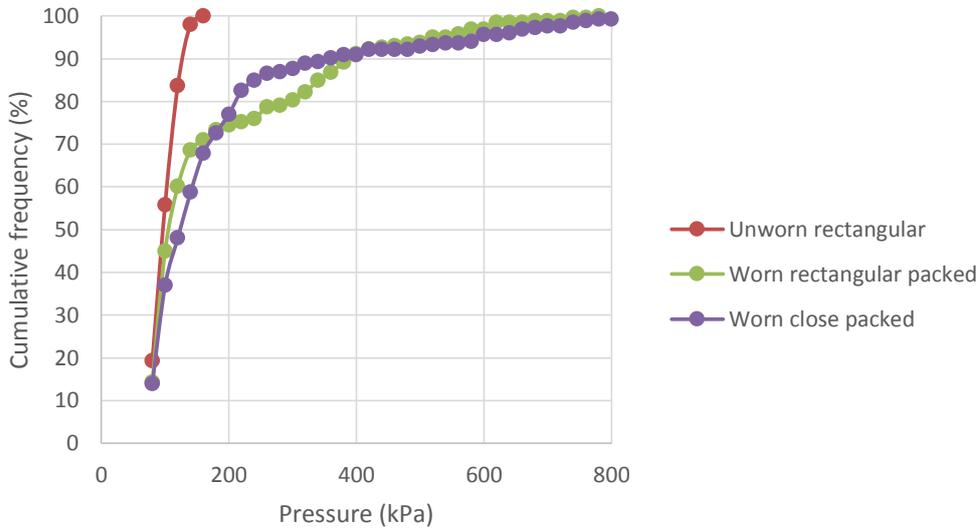


Figure 10. Comparison of unworn and worn peak pressure based on cumulative frequency.

The same data has been plotted in Figure 11 to illustrate the peak pressure data in terms of % frequency. This also shows differences in peak pressure and how a rectangular cubic aggregate is much different to that of a hemi-spherical shape. This shows the unworn surface to have a small positive skew whereas the worn surfaces to have a considerable positive skew with some very high vertical pressures associated with the rounding of the particle tips in contact with the tyre.

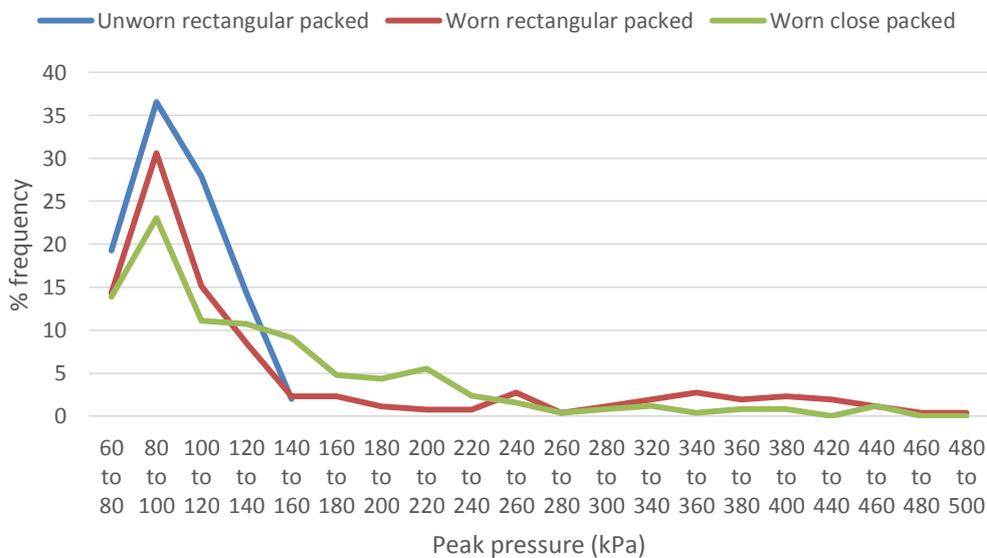


Figure 11. Comparison of unworn and worn peak pressure based on % frequency.

Although these are idealised surfaces the examples show the potential of using pressure mapping and modern tools such as 3d modelling and 3d printing to bring the complexity of real life into the controlled environment of the laboratory and visa-versa.

Conclusion

This paper has considered the tire / road surface interface, a very complex place. The paper has brought together two quite different studies to show how this interface can be better understood. Both methods try to compliment each other and offer a means whereby most people can appreciate what happens over the life of a road. A minor modification to a simple laboratory test starts to address the question of how the size and shape of coarse aggregate particles may change as a result of in-service conditions. This change may then influence parameters such as skid resistance, noise and rolling resistance. The use of 3d printers can create test specimens of any road surface anywhere around the world based on some photographs. Flexible mats can give real-time measurement of tire / test specimen contact phenomena. The simple examples given in this paper illustrate these new developing areas of performance prediction.

References

Bradley, J. and Allen, R. F. (1930). Factors Affecting the Behaviour of Rubber-Tyred Wheels on Road Surfaces, 1930-31 Proc. Institute of Automobile Engineering, vol.25, p. 63.

Hamilton, E. (2016) Analytical evaluation of a friction tyre / surface interface. MSc Dissertation, Ulster University.

ROSANNE (2016) <http://rosanne-project.eu/>

Woodward W. D. H. (1995) Laboratory prediction of surfacing aggregate performance. DPhil, University of Ulster.

Woodward, D., Millar, P. & McQuaid, G. (2014). Use of 3D modelling to better understand road surface textures. Safer Roads 2014 4th International Safer Roads Conference, Cheltenham, United Kingdom, May 18.