The static contact patch of some friction measuring devices

David Woodward, Phillip Millar, Chris Tierney and Campbell Waddell

University of Ulster, Highway Engineering Research Group, Newtownabbey, BT37 0QB, Northern Ireland

ABSTRACT

The tyre/asphalt interface influences a wide range of pavement properties. Compared to other areas of highway research there has been relatively little work done into better understanding this interface given its importance. One of the main problems has been with acquiring data relating to what is happening at this interface. This paper looks at the static contact patch or interface of some measuring devices typically used to measure highway and airfield wet friction. The investigation used a high resolution XSensor pressure pad to measure pressure distribution within the contact patch.

KEY WORDS: Contact patch, interface, pressure mapping.

1. INTRODUCTION

The tyre / asphalt surface contact patch influences properties such as friction, noise generation, fuel efficiency to structural performance. This paper looks at the static contact patch of three devices commonly used around the world to measure highway or airfield friction. The devices are the pendulum friction tester, GripTester and SCRIM. Compared to other areas of asphalt research, their contact patch interface has seen relatively little research. Although simple in principle it is affected by factors such as surface texture at differing scales, tyre properties and vehicle dynamics.

The contact patch is that part of the asphalt surface in contact with a tyre. The simplest method of measuring the contact patch is to apply paint to a tyre and load it onto cardboard placed on a steel plate to obtain a print (ASTM F870-94, 2010). Figure 1 shows an example of this method being used to assess a car tyre. In this example the tyre has been rotated to show where the paint had made contact with the card. Analysis of the print allows parameters such as gross contact area, groove or void area, contact length and contact width to be assessed. Most studies have found that static contact patch has a circular shape at higher tyre inflation pressures and lower load; but becomes elliptical at lower tyre inflation pressure and higher load (Lister and Nunn, 1968), (Liu, 1992), (Siegfried, 1998), (Douglas, 2009).

Figure 1. Using paint to measure the contact patch

The other main area of research associated with the contact patch is contact stress generated by traffic loading. This has three main components i.e. vertical contact stress (z) which acts in the normal direction to the running surface of the contact tire, longitudinal tangential contact stress (x) which acts in the direction of the moving tire, and transversal tangential contact stress (y) which acts from the centre of the tire to both its sides within its given contact area. Douglas (2009) reviewed tyre / asphalt surface contact stress measurement research and identified three main systems based on strain gauge technologies. The first was developed in South Africa and reported in de Beer et al (1997), Weissman (1999), Machemehl et al (2005), Prozzi and Luo (2005) and Wang and Machemehl (2006). A second system was designed and built at the University of Ulster, Northern Ireland and reported in Liu (1992), Siegfried (1998), Woodside et al (1999), Douglas et al (2000) and Douglas et al (2003). A third system, reported by Douglas (2009) was based on the Ulster system and experiences from use of the de Beer apparatus. Figure 2 shows an example of a schematic plan view of compression pin loads for single tyres.

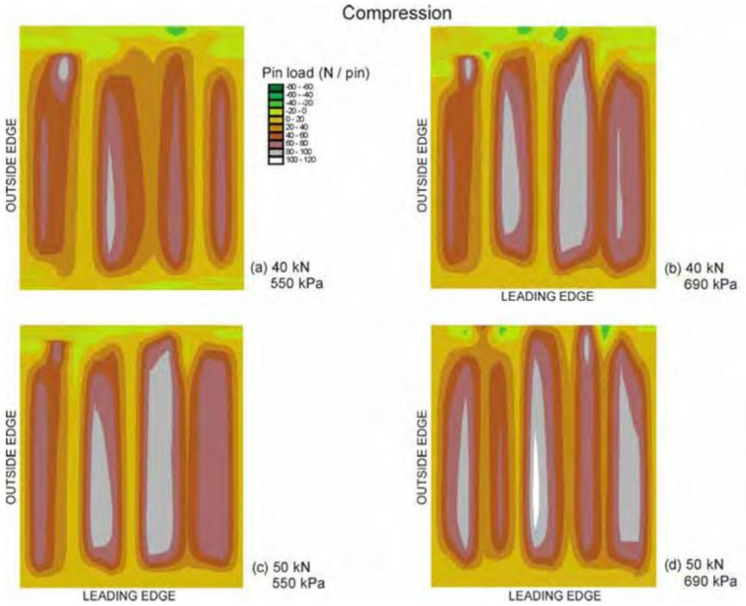


Figure 2. Schematic plan view of compression pin loads for single tyres (Douglas, 2009)

The 3 systems described by Douglas (2009) use strain gauge technologies and in practise are difficult to set-up, calibrate and run. They produce large data files that involve post-processing of the measured stains. In contrast, pressure mapping is much simpler, quick and easy. Two different systems have been used i.e. pressure sensitive film (Backx, 2007; Dunford, 2013) and pressure sensitive sensors (Anderson, 2006; Friel, 2013). Although pressure sensitive film can give highly detailed information they can only be once and require post-processing of the image. The pressure sensitive sensor system used in this paper can capture and process large amounts of data in real-time.

2. EXPERIMENTAL INVESTIGATION

The experimental investigation involved high resolution static pressure mapping of three friction devices i.e. pendulum friction tester, GripTester and SCRIM. This used a XSensor IX500.256.256.22 pressure mapping system (XSENSOR, 2003). This has a 1.15 mm spatial resolution and 65,536 sensing elements mounted on a rigid plexi-glass backing. It has a pressure range of 10 – 200 psi with a data acquisition rate of 6.2 frames per second. XSENSOR X3 PRO Version 6.0 software records and displays data from the sensor pad. Data can be displayed in 2D or 3D. When data recording is complete it can be replayed and viewed as a continuous model or as individual frames. The XSENSOR X3 PRO Version 6.0 software reports a range of values relating to each individual frame of measurement. This includes dimensions, area, load, average pressure and peak pressure. Data relating to each of the 65,536 sensing elements can be exported into Excel, CAD or spatial GIS modelling software for further analysis. With relation to this paper, only contact patch area, length, width and measured load are considered.

3. PENDULUM FRICTION TESTER

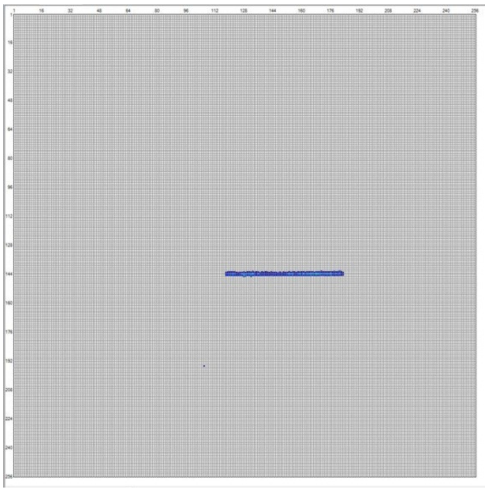
A pendulum friction tester (BS EN 1097-8, 2009; BS EN 13036-4, 2011; BS 7976-1, 2013) was used in the investigation. The test setup is shown in Figure 3. This shows the pendulum friction tester placed over the XSensor pressure mat with the rubber slider in contact with the sensor. The rubber sliders used were new and had been conditioned. Colour is used in the following examples to show variation in pressure. The scale for the 3 rubber sliders was the same i.e. 0 to 16 psi. Three types of rubber slider were assessed:

- The wide slider 57 consisting of a rubber pad 76.2 x 25.4 mm as normally used for surfaces subject to vehicular traffic. This is also known as the TRL slider.
- The wide slider 96 consisting of a rubber pad 76.2 x 25.4 mm as normally used for surfaces subject to shoe or foot usage. This is also known as the 4S slider.
- The narrow slider consisting of a rubber pad 31.75 x 25.4 mm as normally used in the PSV test method.

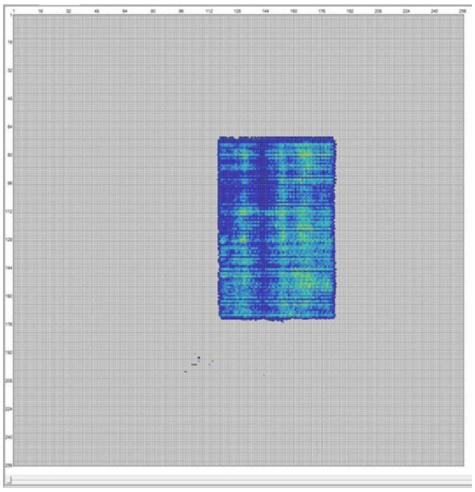
Figure 3. Test setup for measurement of pendulum friction tester contact patch

Figures 4 and 5 show the contact patch for a wide slider 57 i.e. the TRL slider normally used for surfaces subject to vehicular traffic. Figure 4 (a) is a single frame showing the edge of slider making contact with the sensor surface. The sensor grid spacing is 1.15 x 1.15 mm. Figure 5 is an enlargement of this contact patch. This shows that for the slider used in this experiment there was not uniform within its contact patch. This is better shown in Figure 4 (b) which is a composite of 300 individual frames recorded along the

126 mm slide length showing how the rubber slider made contact with the smooth surface of the sensor pad.



(a)



(b)

Figure 4. Wide slider 57 contact patch (a) and merged frames (b) showing how the wide slider 57 contacts the smooth sensor surface (grid spacing is 1.15 x 1.15 mm)

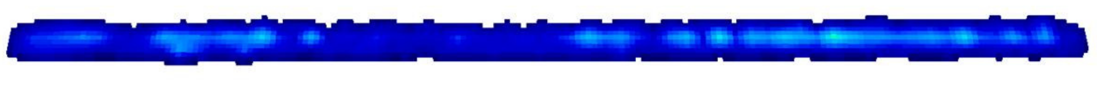
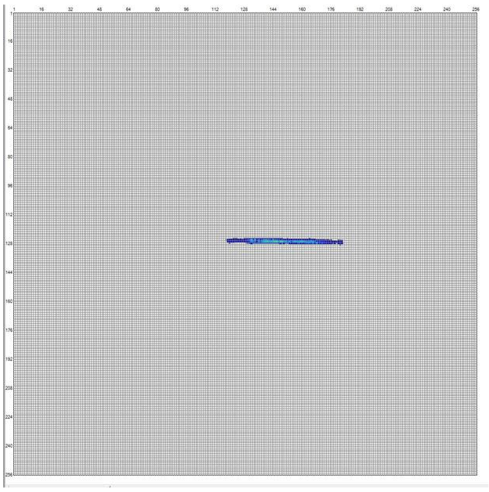
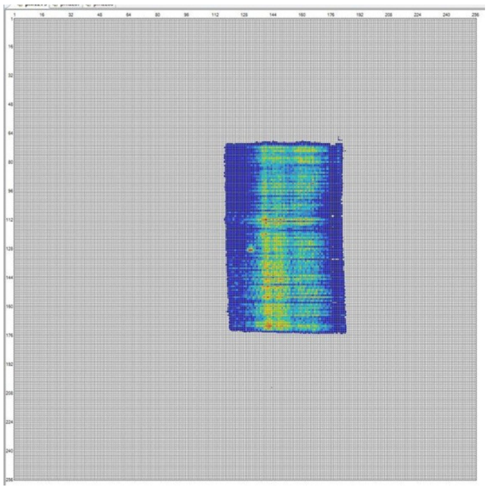


Figure 5. Enlargement of wide slider 57 contact patch

Figures 6 and 7 show the contact patch for a wide slider 96 i.e. the harder 4S slider normally used for surfaces subject to shoe or foot usage. Figure 6 (a) is a single frame showing the edge of slider making contact with the sensor surface. The sensor grid spacing is 1.15 x 1.15 mm. Figure 7 is an enlargement of this contact patch. This shows that for the slider used in this experiment there was not uniform contact within the patch. This is better shown in Figure 6 (b) which is a composite of 300 individual frames showing how the rubber slider made contact with the smooth surface of the sensor pad. The composite image shows that the slider has made greater contact in the centre of the composite contact patch compared to both edges.



(a)



(b)

Figure 6. Wide slider 96 contact patch (a) and merged frames (b) showing how the wide slider 96 contacts the smooth sensor surface (grid spacing is 1.15 x 1.15 mm)

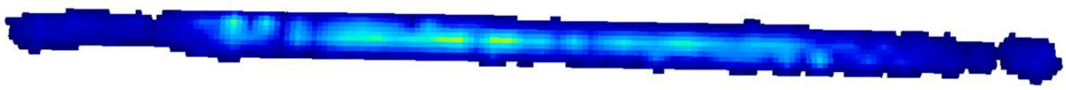
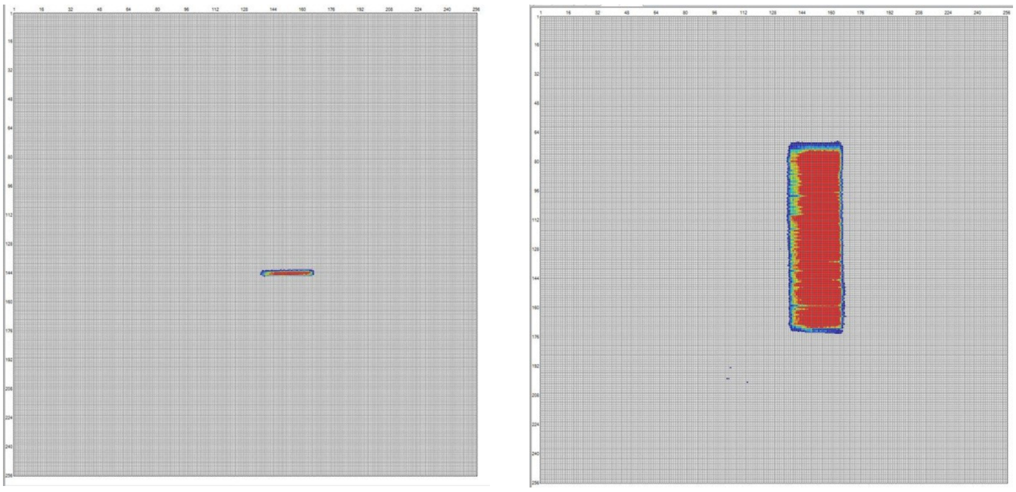


Figure 7. Enlargement of wide slider 96 contact patch

Figures 8 and 9 show the contact patch for a narrow slider used in the PSV test method Figure 8 (a) is a single frame showing the edge of slider making contact with the sensor surface. The sensor grid spacing is 1.15 x 1.15 mm. Figure 9 is an enlargement of this contact patch. This shows that for the slider used in this experiment there was not uniform contact within the patch. The contact pressure is higher as shown by the red in the images. Figure 8 (b) is a composite of 300 individual frames showing how the rubber slider made contact with the smooth surface of the sensor pad. In this image the contact length was maintained at 126 mm similar to the wide sliders. The composite image shows that the slider has made contact with a greater pressure compared to the two wide sliders. This would be expected given their difference in size.



(a) (b)

Figure 8. Narrow slider contact patch (a) and merged frames (b) showing how the narrow PSV slider contacts the smooth sensor surface (grid spacing is 1.15 x 1.15 mm)

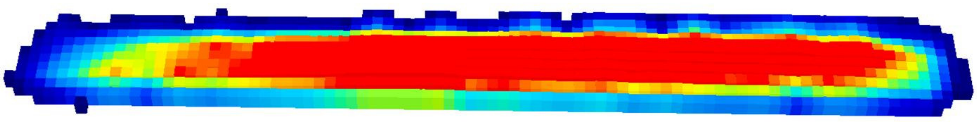


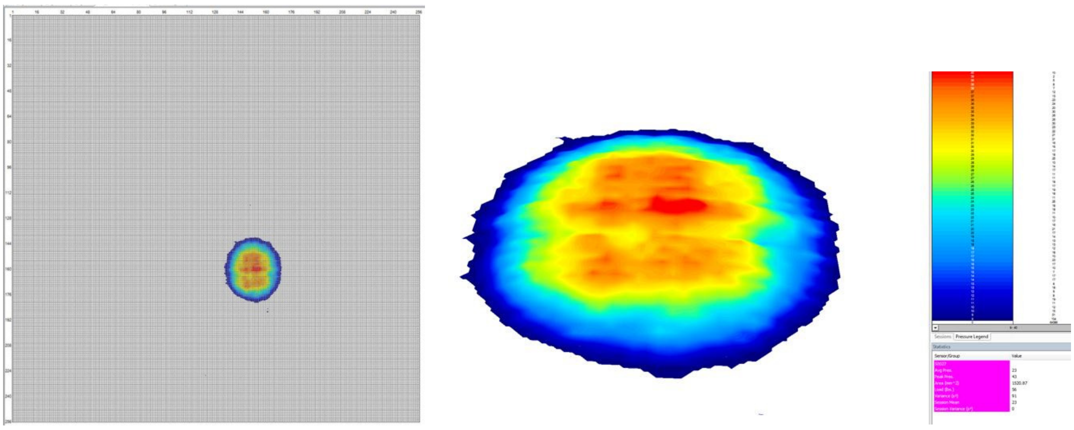
Figure 9. Enlargement of narrow PSV slider contact patch

4. GRIPTESTER TYRE

A Mark II GripTester (BS EN 7941-2, 2000) was used for this laboratory investigation. Figure 1 shows the laboratory set-up with the GripTester tyre sitting on the XSensor pressure pad. Prior to this, the inflation pressure of the standard 10 inch diameter smooth tread GripTester tire had been measured and the GripTester pushed unto the pressure mapping system. A total of 200 individual frames or measurements were recorded in this static test condition. The standard inflation pressure for GripTester is 20 psi or 137.9 kPa.

Figure 11 (a) shows the contact patch at the standard inflation pressure of 20 psi. Figure 11 (b) shows a 3D enlargement of this contact patch showing variation in contact pressure. The scale shown in Figure 11 ranges from 10 to 40 psi. Additional testing was carried out at a range of inflation pressures to determine relationships with contact length, width and area.

Figure 10. GripTester resting on the XSENSOR pressure pad



(a) (b)

Figure 11. GripTester tyre contact patch at 20 psi inflation pressure (a) and enlarged 3D model showing variation in contact pressure (b) (grid spacing is 1.15 x 1.15 mm)

Figure 12 plots the relationship between contact patch length and width for the GripTester tyre at a range of tyre inflation pressures. The expected relationships were found i.e. length and width decreased with increasing tyre inflation pressure. Length has a parabolic relationship with inflation pressure whereas width has a linear relationship.

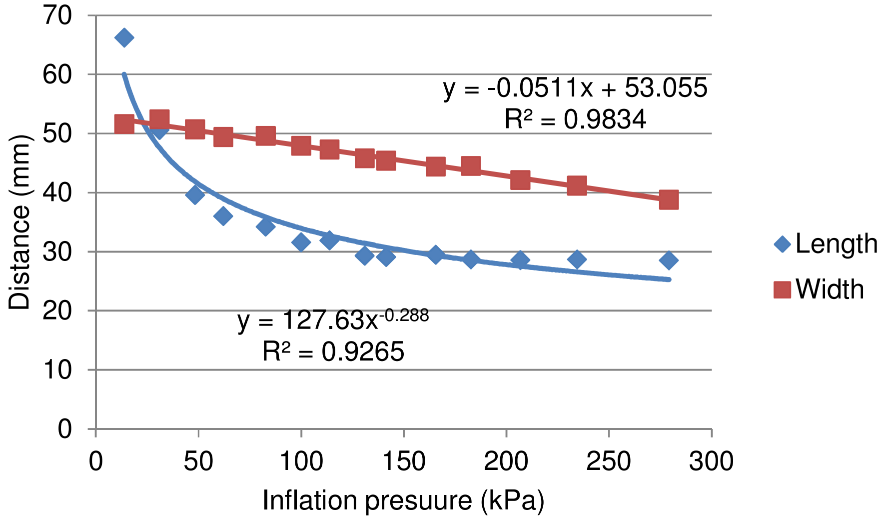


Figure 12. Contact length and width v. tyre inflation pressure

Figure 13 plots contact area against tyre inflation pressure for the GripTester tyre. This shows a power relationship with good correlation (R^2 values of 0.97) and illustrates how contact area increases with decreasing inflation pressure. Figure 14 plots the same data within a range of ±10psi of 20psi standard inflation. Within this narrower range the relationship is linear with only a small decrease in contact area with increasing tyre inflation pressure.

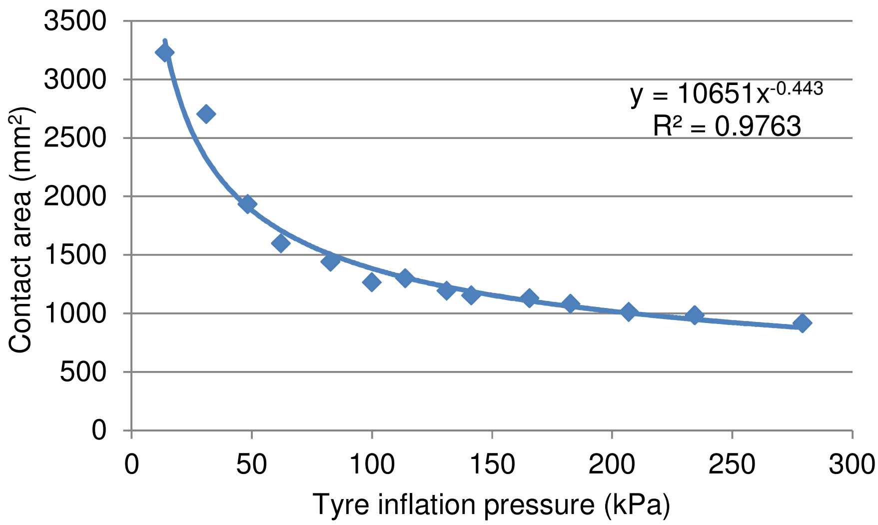


Figure 13. Contact area v. tyre inflation pressure

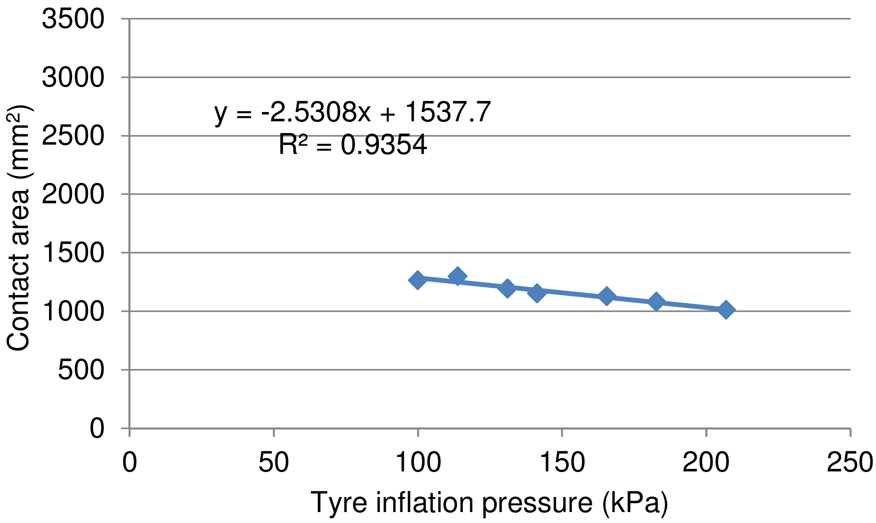
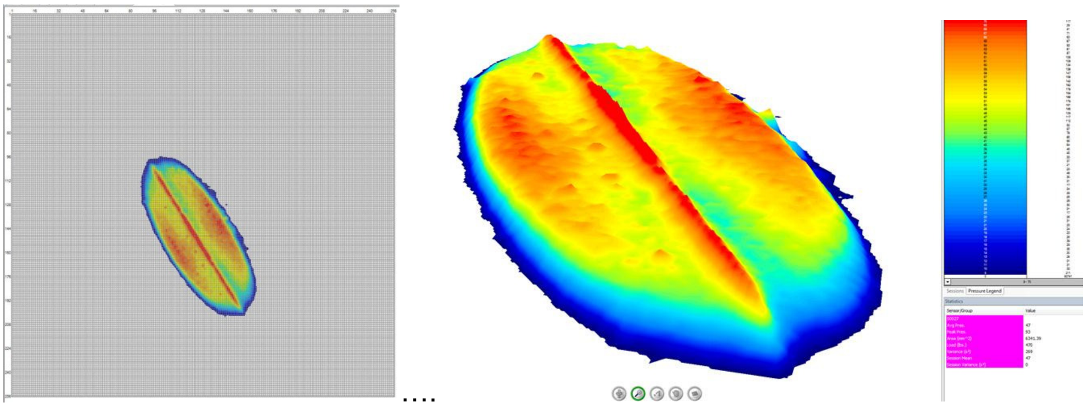


Figure 14. Contact area v. tyre inflation pressure – excluding lower and higher inflation data

5. SCRIM TYRE

This investigation used a partially worn SCRIM tyre (BS EN 7941-1, 2006) inflated to its recommended inflation pressure of 50.7 psi or 350 kPa. This was loaded in the laboratory compression machine to give a static load of 2 kN replicating the test wheel assembly of the SCRIM (BS 7941: 2006). Figure 15 (a) shows the contact patch Figure 11 (b) shows a 3D enlargement of this contact patch. The scale shown in Figure 15 ranges from 0 to 70 psi. A central rib of higher contact pressure is shown for the tyre measured. This feature is common to other types of pneumatic tyre.



(a) (b)

Figure 15. SCRIM tyre contact patch (a) and enlarged 3D model showing variation in contact pressure (b) (grid spacing is 1.15 x 1.15 mm)

6. DISCUSSION

This paper has looked at the static contact patch for three devices commonly used to measure friction. Compared to many other aspects of asphalt research, the tyre / surface interface is probably the least understood. It is also the most important as it relates to safety of the driving or flying public and to other issues relating to a tyre moving over a surfacing material. The three devices used have a smooth measuring surface which interacted with the smooth surface of the XSensor pressure pad. With a spatial resolution of 1.15 x 1.15 mm this produced highly detailed data relating to their contact interface.

Differences between the three rubber sliders used were found. The contact pressure for the narrow PSV slider was greater than for the 2 wide sliders. It was found that there was non-uniform pressure distribution along the width of any of the three sliders used in the investigation.

The contact patch investigations of the GripTester tyre found that pressure mapping produced relationships found by previous researchers using other types of tyre. The main difference between this and previous research was the simplicity and speed of high quality data acquisition. The found relationships show contact area and length to behave in a parabolic manner whereas contact width behaves in a linear manner with tire inflation pressure.

The SCRIM tyre investigation found much higher contact pressures compared to the GripTester tyre reflecting the greater static loading and inflation pressure used in the SCRIM device. A central rib of higher contact pressure was found for the SCRIM tyre assessed. How this influences the measurement of friction as the tyre rolls down a road is still to be determined.

This paper shows how pressure mapping can improve understanding of what happens when a friction measuring device is used. With advances in technology the measurement of what happens in the contact patch is now relatively easy to assess using pressure mapping. The XSENSOR system used in this paper is simple to use giving detailed data with a 1.15mm spatial resolution and contact pressures in the range of 10 to 200 psi. It does in hours what would take weeks using the paint / card board technique.

With regard to better understanding and so improvement in any modelling scenario the simple examples given in this paper show how pressure distribution varies within the contact patch. They show that measurement or prediction of friction is not simply related to contact area. This is an area that needs further research.

REFERENCES

Anderson, J. (2006). Asphalt pavement pressure distributions using Teckscan measurement system. University of Kentucky Masters Theses. Paper 215.

ASTM F870-94 (2010) Standard practise for tread footprints of passenger car tires groove area fraction and dimensional measurements.

Backx, P.W. (2007). Tyre/road contact measurement using pressure sensitive films. Bachelor Final Project, Technische Universiteit Eindhoven.

BS EN 1097-8 (2009). Tests for mechanical and physical properties of aggregates. Determination of the polished stone value.

BS EN 13036-4:2011. Road and airfield surface characteristics. Test methods. Method for measurement of slip/skid resistance of a surface: The pendulum test.

BS EN 7941-1 (2006). Methods of measuring the skid resistance of pavement surfaces. Sideway-force coefficient routine investigation machine.

BS EN 7941-2 (2000). Methods of measuring the skid resistance of pavement surfaces. Test method for measurement of surface skid resistance using the GripTester braked wheel fixed slip device.

BS 7976-1:2002 + A1 (2013). Pendulum testers – Part 1: Specification.

De Beer, M. and Fisher C. (1997). Contact stresses of pneumatic tires measured with the Vehicle-Road Surface Pressure Transducer Array (VRSPTA) system for the University of California at Berkeley (UCB) and the Nevada Automotive Test Center (NATC) Volume 1. Contract Research CR-97/053, TRANSPORTEK, CSIR, June.

Douglas, R.A., Woodward, W.D.H. and Woodside, A.R. (2000). Road contact stresses and forces under tires with low inflation pressure. Canadian Journal of Civil Engineering, 27:1248–1258.

Douglas, R.A., Woodward, W.D.H. and Rogers, R.J. (2003). Contact pressures and energies beneath soft tires: modelling effects of central tire inflation-equipped heavy-truck traffic on road surfaces. Transportation Research Record 1819, Washington, DC: Transportation Research Board, 221–227.

Douglas, R.A. (2009). Tyre/road contact stresses measured and modelled in three coordinate directions. NZ Transport Agency research report 384, Golder Associates Ltd, Mississauga, Ontario, Canada.

Dunford, A. (2013). Friction and the texture of aggregate particles used in the road surface course. PhD Thesis, University of Nottingham.

Friel, S. (2013) Variation of the friction characteristics of road surfacing materials with time. PhD Thesis, University of Ulster.

Lister, N.W., Nunn, D.E. (1968). Contact areas of commercial vehicle tyres. Ministry of Transport and Road Research Laboratory, RRL Report LR 172, Crowthorne, Berkshire.

Liu, G.X. (1992). The area and stresses of contact between tyres and road surface and their effects on road surface, D Phil Thesis, Department of Civil Engineering and Transport, University of Ulster.

Machemehl, RB, F Wang and JA Prozzi (2005) Analytical study of effects of truck tire pressure on pavement with measured tire-pavement contact stress data. Transportation Research Record 1919. Washington DC: Transportation Research Board. Pp 111–120.

Prozzi, JA and R Luo (2005) Quantification of the joint effect of wheel load and tire inflation pressure on pavement response. Transportation Research Record 1919. Washington DC: Transportation Research Board. Pp134–141.

Siegfried. (1998). The study of contact characteristics between tyre and road surface, DPhil. Thesis, Faculty of Engineering, University of Ulster.

Wang, F and RB Machemehl (2006) Mechanistic-empirical study of effects of truck tire pressure on pavement: measured tire-pavement contact stress data. Transportation Research Record 1947. Washington DC: Transportation Research Board. Pp136–145.

Weissman, SL (1999) Influence of tire-pavement contact stress distribution on development of distress mechanisms in pavements. Transportation Research Record 1655. Washington DC: Transportation Research Board. Pp161–167.

Woodside, A.R., Woodward, W.D.H., and Siegfried, 1999. The determination of dynamic contact stress. Paper no. CS5-2, Proceedings of the International Conference on Accelerated Pavement Testing, Reno, Nevada, 18–20.

XSENSOR Technology Corp., 2003. XSENSOR Technology: A Pressure Imaging Overview', Sensor Review Magazine, Vol. 27, Issue 1, p.4.

Author Biography

Dr David Woodward BSc (Hons), MIQ, MPhil, DPhil, MCIHT, MIAT, MIEI

Reader in Highway Engineering at the University of Ulster and responsible for the Highway Engineering Research Group. Graduated from the Ulster Polytechnic in 1982 with a Combined Sciences degree in geology and geography, a Masters of Philosophy in 1988 looking at High Friction Surfacing and a Doctor of Philosophy in 1995 looking at the predicting of surfacing aggregate performance. He is a member of the CIHT, IAT, IOQ and IEI and represents the IAT on British standards committee B/510/5 Surfacing Characteristics for road and other trafficked areas. Research interests include aggregate performance, the tyre / surface interface, surfacing characteristics and sustainable highway technologies.