

MEASURING GRIP AND THE CONTACT PATCH

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ABSTRACT

A vehicle or air-craft tire interacts with a surfacing through its contact patch. Wet grip is one of the most important properties of a highway or airfield surfacing. This paper looks at the contact patch for the GripTester device, widely used around the world to assess both highway and air-field skid resistance. Contact patch properties were measured using a XSENSOR pressure mapping system. The relationships between inflation pressure and properties such as contact area, length and width were assessed for a new and worn GripTester tire. Pressure mapping was found to provide high quality data with the found relationships agreeing with previous research. Contact patch data was related to in-situ measurement of wet grip measured using GripTester fitted with both tires at a range of tire inflation pressures and for a range of asphalt surfacing types. These found robust relationships between inflation pressure, measured wet grip, contact patch area and tire wear. Most relationships were as expected, however it was found that increasing contact area related to a decrease in measured wet grip for the new tire. The distribution of contact pressure within the contact patch is suggested as one of a number of areas that warrant further consideration.

INTRODUCTION

The tire / asphalt interface influences a wide range of pavement properties from skid resistance to structural performance. Although researchers have attempted to measure these interface properties for many years, their investigations have been hampered by problems associated with data measurement as the laboratory and site apparatus have typically involved strain gauge technology. This has been time-consuming, difficult to set-up and relies on complicated post-processing of limited amounts of data. Subsequent attempts to model interface properties such as tire-pavement interaction has only been as good as the data or the assumptions on which

the models are based. In contrast to most previous research the methodology described in this paper is relatively simple.

This paper combines two investigations i.e. the laboratory measurement of static contact patch properties with the dynamic measurement of wet grip on-site; to better understand the role of the tire in the measurement of tyre / asphalt interface properties of wet grip. The laboratory study used a XSENSOR high resolution pressure mapping system and the tire from a GripTester (BS EN 7941-2: 2000). Pressure mapping systems have been used in a range of areas including the tire industry for a number of years. The GripTester is widely used around the world and uses a pneumatic tire to measure skid resistance of highway and runway surface materials.

Two GripTester tires i.e. new and heavily worn, were used in the laboratory pressure mapping investigation and the on-site GripTester measurement. The investigation concentrated on how tyre inflation pressure relates to contact patch properties and whether this subsequently affected the measurement of wet grip. The two tires were then used to measure wet grip using GripTester at a range of tire inflation pressures similar to those used in the laboratory study. The inflation pressures ranged much lower and higher than the standard specified operating values. They were used at these extremes to assess the effect of contact patch properties such as area, length and width.

LITERATURE REVIEW

Most relevant literature to this investigation relates to measurement of contact patch properties or to contact stress. Compared to other aspects of asphalt research this is an area that has received relatively little research given its importance. The contact patch or footprint is that part of the asphalt surface in contact with a tire. Although simple in principle it is affected by factors such as surface texture at differing scales, tyre properties and vehicle dynamics. The simplest method to measure the tire contact patch is to apply paint and load it onto cardboard placed on a steel plate to obtain a print (ASTM F870-94, 2010). This allows parameters such as gross contact area, groove or void area, contact length and contact width to be assessed. Studies have found that the contact patch has a circular shape at higher tyre inflation pressures and low load; but becomes elliptical at low tyre inflation pressure and high load (Lister and Nunn, 1968), (Liu, 1992), (Siegfried, 1998), (Douglas, 2009).

Contact stress is generated by traffic loading at the tire / asphalt interface and affects asphalt properties such as skid resistance, permanent deformation and resistance to fatigue failure. It 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 tire / 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). Their general approach was to use measured contact stresses to first verify numerical models and then predict pavement response and/or performance. 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. The 3 systems used strain gauge technology and in practise were difficult to set-up, calibrate and run. They produced large data files that involved considerable post-processing of the measured stains.

In contrast, pressure mapping is an alternative technology that is relatively simple. Two main systems have been used i.e. pressure sensitive film that is placed under a loaded tire (Backx, 2007) and pressure sensitive sensors (Anderson, 2006). Although the pressure sensitive films can give highly accurate information they have the problem of being used only once with post-processing of the image required to determine meaningful data. The pressure sensitive mapping systems have the benefit of capturing and processing large amounts of data in real-time. Equipment manufactured by XSENSOR was used in this investigation (XSENSOR, 2003).

EXPERIMENTAL INVESTIGATION

The experimental investigation consisted of two stages i.e. high resolution static pressure mapping of the GripTester tire contact patch followed by in-situ dynamic measurement of wet skid resistance. Both investigations were carried out at a range of tire inflation pressures using a new and worn tire.

Laboratory contact patch pressure mapping

Figure 1 shows the laboratory set-up i.e. the GripTester resting on the high resolution XSensor IX500.256.256.22 pressure mapping system. This has a 1.15mm spatial resolution and 65,536 sensing elements mounted on a rigid plexi-glass backing. It has a pressure range of 10-200psi 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 data may also be exported into Excel, CAD or spatial GIS modelling software for further analysis.

The inflation pressure of the standard 10 inch diameter smooth tread GripTester tire was first measured and the GripTester pushed onto the pressure mapping system. 200 individual frames or measurements were recorded in this static

test condition for each tire inflation pressure. Although the British Standard for GripTester testing specifies a tire inflation pressure of 20psi (137.9kPa), the inflation pressures assessed ranged from 2 to 41psi (13.8 to 282.7kPa). The reason for this was to determine how pressure varied within the contact patch in relation to tire inflation pressure and whether this subsequently affected the measurement of wet in-situ grip.



Figure 1. GripTester resting on the XSENSOR pressure pad

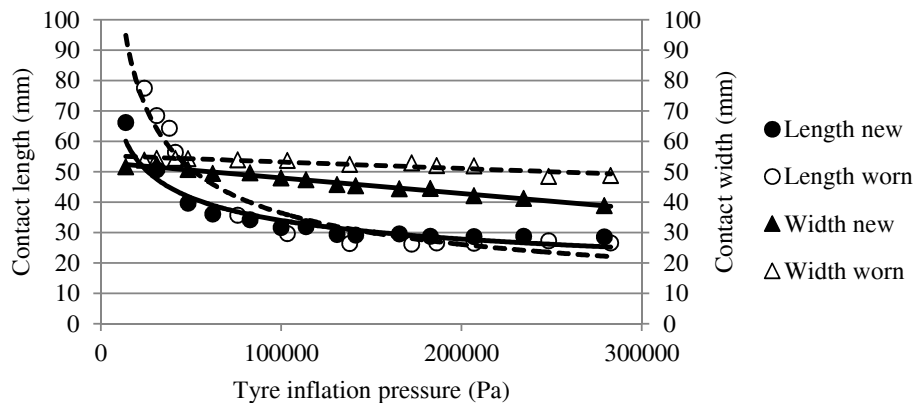


Figure 2. Contact length and width v. tyre inflation pressure - both tires

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. With relation to this paper, only contact patch area, length, width and measured load are considered. Figure 2 plots the relationship between contact patch length and width for the two tires at a range of tire 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. The length of the

contact patch for the new tyre at a given inflation pressure was slightly greater at the higher inflation pressures. However, at lower inflation pressures it was less than the worn tyre. The width of the contact patch was greater for the worn tyre at all inflation pressures reflecting the worn profile of the smooth measurement tread.

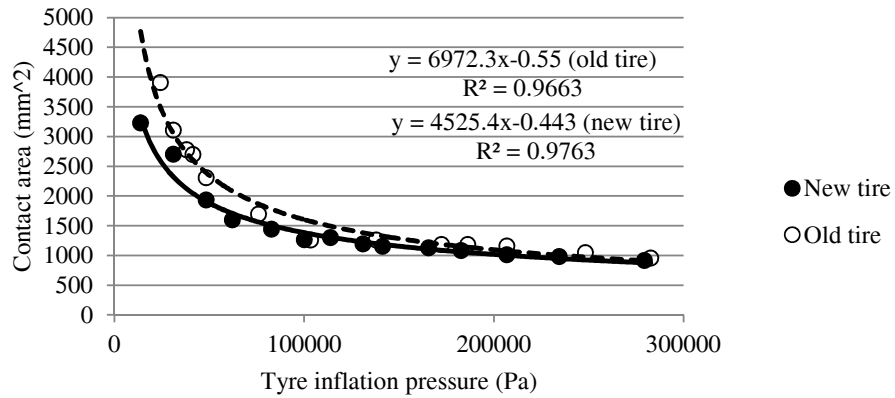


Figure 3. Contact area v. tyre inflation pressure – all data

Figure 3 plots contact area against tyre inflation pressure for the 2 GripTester tires. This shows a power relationship for both sets of data with good correlation (R^2 values of 0.97). At high tyre inflation pressures both plots are similar; however they start to diverge with decreasing inflation pressure. The new tire has increasingly lower contact area probably reflecting the stiffening effect of the unworn tire. Figure 3 shows how contact area varies with lower tyre inflation pressures. This may be used as a surrogate for increasing tyre loads if tyre inflation pressure remains constant. However in this investigation all test variables remain constant except tyre inflation pressure. In practise the GripTester tyre is operated with a tyre inflation pressure of 20psi.

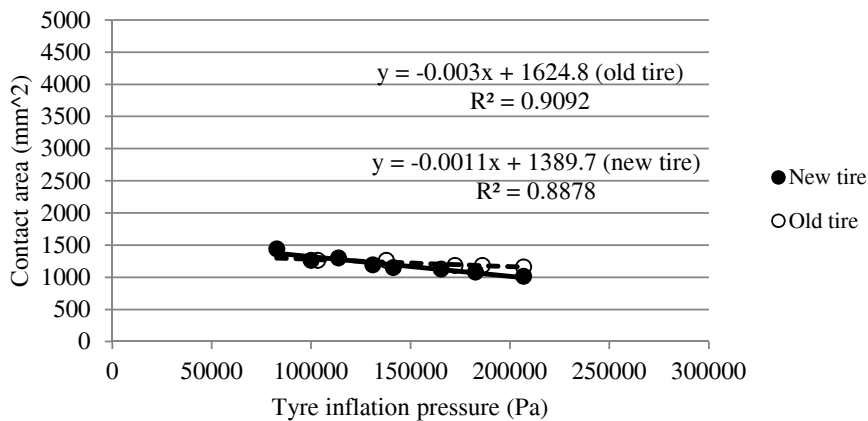


Figure 4. Contact area v. tyre inflation pressure – excluding lower and higher inflation data

Figure 4 plots the same data minus the lower and high inflation pressures i.e. showing the range of 20+/-10psi. Within this narrower range both plots are virtually linear with only a small decrease in contact area with increasing tyre inflation pressure.

Figure 5 plots measured load from the pressure pad against tire inflation pressure for the two tires. Both plots are similar showing greatest measured load at lowest inflation pressure. In theory the measure load should remain constant as the test condition was static. The highest values of measured load from the pressure pad relate to the lower inflation pressures. This suggests that the distribution of pressure within the contact patch may be having an influence i.e. concentrated under the sidewalls of the tire at the lower inflation pressures. The lower values for the new tire possibly reflect the stiffening effect of the unworn tyre. Figure 6 redraws this data excluding the lower and higher tire inflation pressures i.e. values for 20 +/-psi. Both plots are linear showing a small increase in measured load with increasing tire inflation pressure.

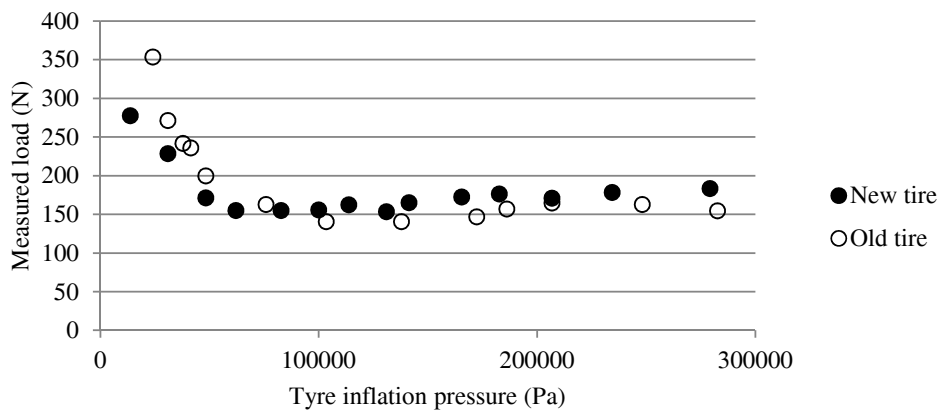


Figure 5. Measured load v. tyre inflation pressure – all data

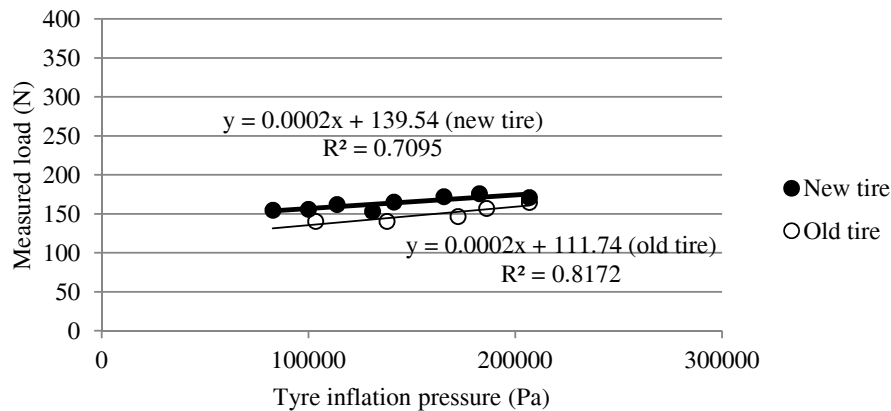


Figure 6. Measured load v. tyre inflation pressure – excluding lowest and high inflation data

Figure 7 plots measured load against contact area from the pressure pad. Again the data plots different to what would be expected reflecting the distribution of pressure within the contact patch. Figure 8 redraws the data excluding the highest and lowest inflation data. Within the tyre inflation pressure range of 20 +/- 10psi the plots show measured load to be relatively unaffected by tyre inflation pressure. The previous plots suggest that variation in pressure distribution measured within the contact patch may be affecting the data. With respect to any attempt to model tyre / asphalt surface interaction, this aspect of pressure distribution within the contact patch is critical.

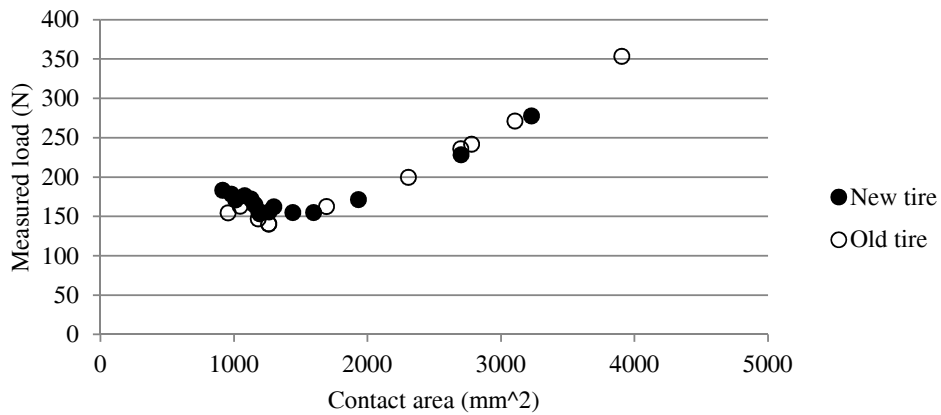


Figure 7. Measured load v. contact area – all data

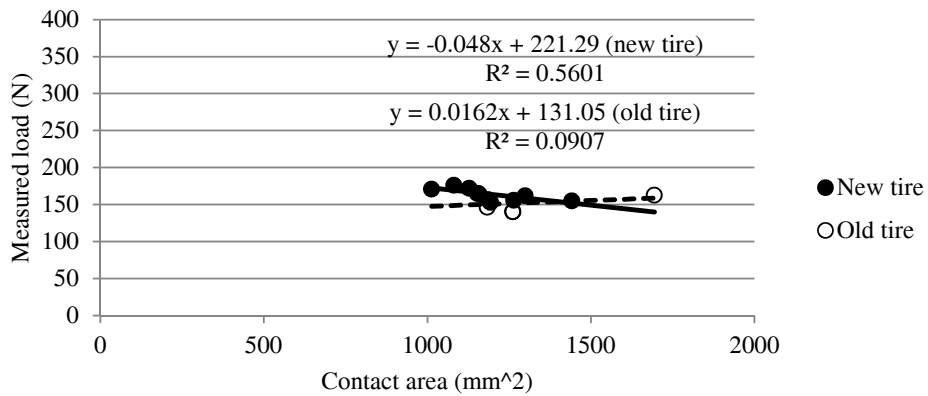


Figure 8. Measured load v. contact area – excluding lowest and high inflation data

MEASUREMENT OF WET GRIP DIFFERING INFLATION PRESSURES

The second part of the investigation aimed to determine whether tyre inflation pressure could be used as a surrogate for contact area i.e. lower inflation pressure equals greater contact area; and whether this affected the measurement of wet grip. The two tyres used in the pressure mapping experiment were used. Test speed and water application rate was kept constant for all test measurement runs i.e. 50km/h

and 10.5 l/min respectively. This is the standard test conditions for GripTesting. All testing was done within a 3 hour time period so the highway test surface and air temperature was constant. The same route was taken for all test measurement runs. The road surfacing assessed was Hot Rolled Asphalt (HRA) with 20mm chippings. A short section of 3mm high friction surfacing (HFS) separated the two sections of HRA used in the subsequent analysis. This corresponded to 66m of HFS, 150m and 330m of HRA respectively.

Figures 9 and 10 plot the GripTester data for the two tires measured at the differing tire inflation pressures. The high wet grip of the HFS surfacing is clearly shown in both figures. The plots show a limited but significant effect for tire inflation pressure i.e. the surrogate being used for contact area.

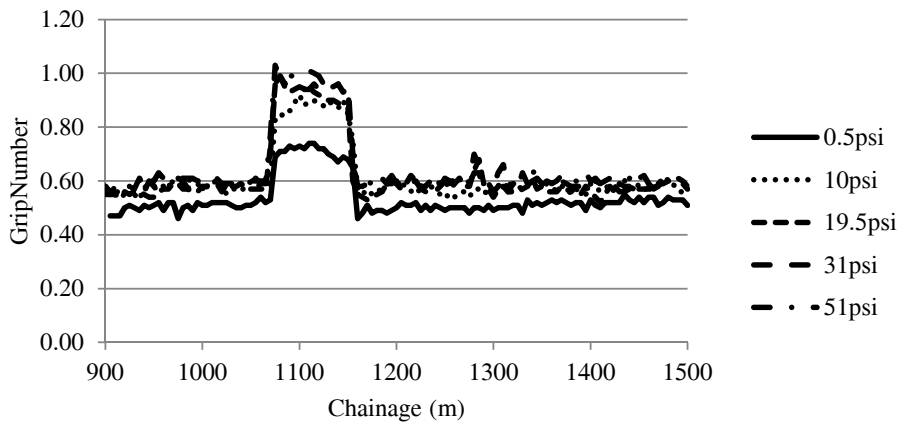


Figure 9. GripTester data for the new tire

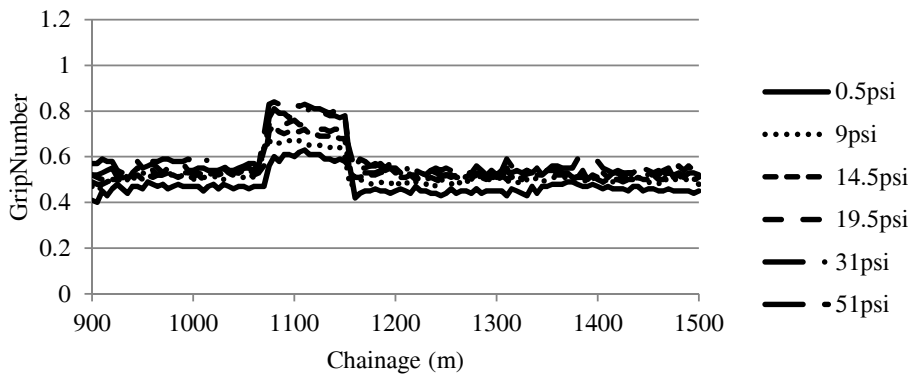


Figure 10. GripTester data for the worn tire

Figures 11 and 12 plot average GripNumber for the HRA and HFS surfaces at different inflation pressures. This shows a general trend of wet grip increasing with increasing tire inflation pressure. There is no difference between the two HRA surfaces. Inflation pressure for the new tyre has less effect on wet grip compared to

the worn tire. There was a greater difference between the two surfaces for the new tire at all inflation pressures. The found wet grip values are less for the worn tire. These findings probably reflect the influence of the stiff base of the new tire in contact with the asphalt surfaces. This area needs further consideration.

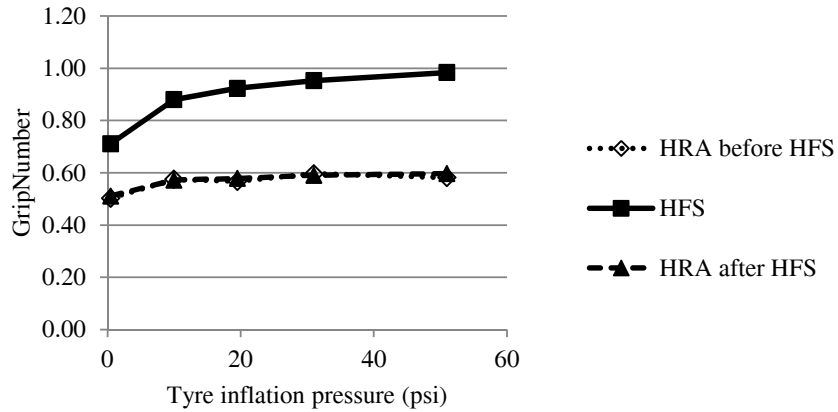


Figure 11. GripTester data for new tyre

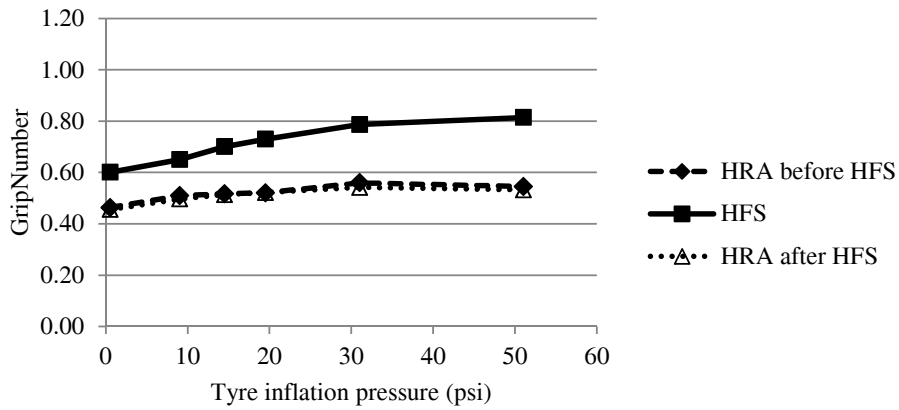


Figure 12. GripTester data for worn tyre

Figure 13 shows how wet grip and contact area vary in relation to inflation pressure for the new tyre. As inflation pressure increases Figure 13 shows contact area to decrease whilst grip increases. Figure 14 plots contact area against GripNumber. This shows decreasing contact area relates to increasing measured wet grip for both tires and surfacing types.

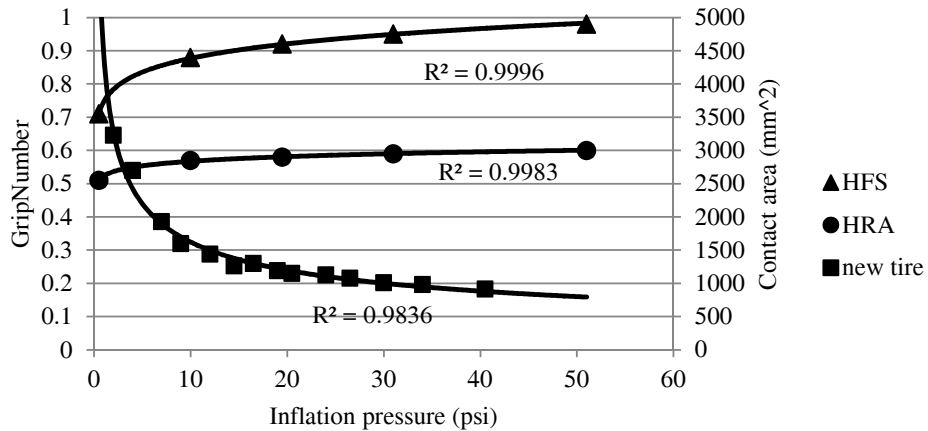


Figure 13. Plot of inflation pressure v. GripNumber and contact area (new tire)

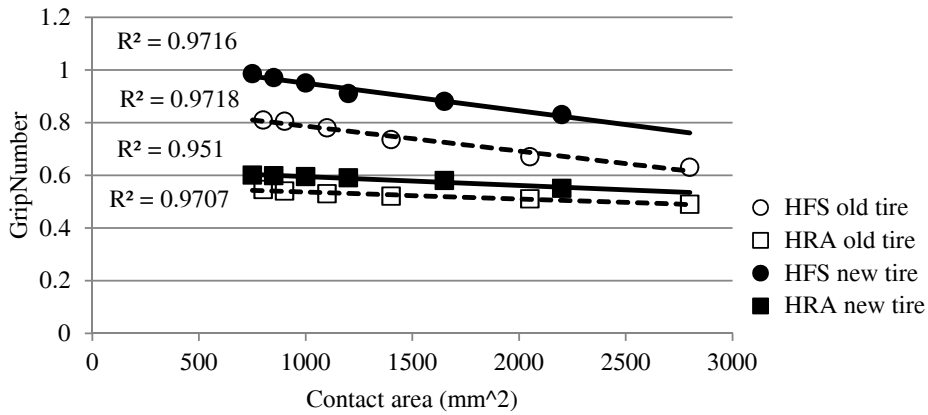


Figure 14. Contact area v. GripNumber

DISCUSSION

Compared to most other aspects of research, the subject of tire / surface interaction is probably the least understood but most important as it relates to safety of the driving or flying public and all other issues relating to a tire moving over a surfacing material. This paper is a first attempt to combine two relatively simple experiments that involve the measurement of skid resistance, one of the most important properties of a surfacing, whether in an airfield or highway situation. With advances in technology the measurement of what happens in the tyre foot-print 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 10-200psi.

The first part of this paper used this technology to verify what is essentially known regarding the relationships between tire inflation pressure, contact length and

width. The GripTester tires used had a smooth surface so avoiding complications caused by tread block patterns. However, the two tires were different in regards to the amount of wear experienced by the measurement rubber. One was new whereas the other had been used to such an extent that all of the measurement rubber had been worn off. This was done to assess the effect of extreme tire wear or to determine the extremes of contact patch properties.

Rather than working with paint and card-board and the tedious work involved with post-processing paint impressions, the XSENSOR equipment quickly produced very detailed data in real-time in a form that was easily analysed using its own proprietary software or Excel. It did in hours what would take weeks. Similar to other researchers, this found contact area to increase in a parabolic nature with decreasing tire inflation pressure. Contact patch length decreased in a similar parabolic trend whilst contact patch width decreased in a linear manner. The resulting correlations had good R^2 values showing the relationships to be robust and the data predictable. Given the significant difference in the condition of the two tires regarding how much wear they had received, there was only a relatively small difference in the found relationships between the two tires. Both followed similar trends however the differences were most pronounced at tire inflation pressures either lower or greater than the normal 20psi operating value.

The second part of the paper involved standard measurement of wet grip using the two tires fitted to a GripTester at a range of inflation pressures. Everything else was kept constant. Two typical UK surfaces were assessed i.e. hot rolled asphalt and high friction surfacing. These were chosen for their different wet grip values. They also have different types of surface texture. The HRA is a bitumen / sand / filler mastic unto which 20mm chippings are rolled during construction to provide texture depth and wet skid resistance. The HFS is a 3mm aggregate held rigidly to the underlying surface using a resin based binder. With regard to tire / surfacing interaction these two surfaces have very different textures. This was reflected in the found data regarding how the tire interacts with a surfacing. This area needs further consideration.

Similar trends between measured wet grip and inflation pressure were found for the two surfaces and the two tires. However, there were small but significant differences relating to how interaction occurred. The effect of inflation pressure is greater for the 3mm HFS surfacing, whereas the lower grip HRA appeared to be less affected by inflation pressure. Most effect occurred at the lower inflation pressures used in the investigation. However, it must be remembered that these are much lower i.e. almost flat, compared to the specified operating inflation pressure.

The plots show measured wet grip to increase with increasing inflation pressure for both tires and surfaces. For the new tire the amount of increase was greatest for the lowest inflation pressures thereafter remaining almost constant. The worn tire took longer to reach this condition. Figure 13 combines the static contact area data with the dynamic wet grip data for different new tire inflation pressures.

This shows how contact area and wet grip varies for the two surfaces. Figure 14 further simplifies this by plotting tire contact area and GripNumber for both tires and surfaces. The linear trends have good correlation but appear opposite to what would initially be expected i.e. as more tire comes in contact with the surface it would be expected that more interaction is occurring resulting in more grip.

This simplistic assumption needs further consideration. For example, the two surfaces have very different textures i.e. 20mm aggregates v. sharp angular 3mm particles. This must have an effect on tire interaction. The degree that the measurement rubber has worn must affect both overall tire stiffness and stiffness of the measuring rubber and hence its interaction with the surface texture.

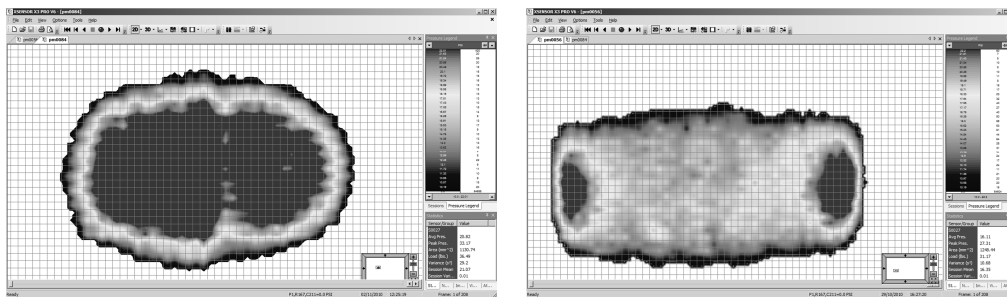


Figure 15. Pressure distribution under the new (left) and worn (right) tire at 20psi

There also remains the issue of pressure distribution within the contact patch. This is a factor not covered in this paper. However, Figure 15 shows two XSENSOR images comparing the pressure distribution for the two tires at the standard operating condition of 20psi. In these high resolution XSENSOR images the underlying grid is at 1.15mm spacings. The examples show the two tires to have very different pressure distributions related to their degree of wear. Although both contact areas are similar, the new tire has a more circular contact patch shape with increasing pressure towards its centre. In contrast, the pressure distribution for the worn tire is concentrated at the edge of the contact patch.

These two images reflect the effect of tire wear and loading under the side-walls of the tire. Any attempt to model tyre / asphalt surface interaction, even for this simple smooth tire needs to consider this aspect of pressure distribution within the contact patch. The measurement of wet grip is simply not related to contact area but also to the distribution of contact pressure within the patch and helps to explain the relationships presented in this paper.

CONCLUSIONS

This paper reports an investigation relating the contact patch properties of what may be regarded as a simple smooth treaded tire and how it is used to measure wet grip. It combines static laboratory measurement with dynamic on-site measurement. The two main factors assessed are degree of tire wear and inflation

pressure. Inflation pressure was varied as a surrogate to contact area in the wet grip measurements. The laboratory based investigation used high resolution pressure mapping using a XSENSOR system. This produced highly detailed data relating to tire contact patch properties. It showed how pressure distributions can vary significantly with inflation pressure and degree of tire wear. However, this aspect is not covered in this paper.

The contact patch investigations found that pressure mapping produced the expected relationships found by previous researchers. The main difference between this and previous research is 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 same trends were found for both tires however greatest variation occurred at the extreme inflation pressures used, particularly the lower values. However, at the normal operating inflation pressure of the tire the differences were quite small.

The onsite wet grip measurements found the new tire to be relatively unaffected by inflation pressure, however the type of surface has an effect that needs further consideration. Predictable relationships were found between tire inflation pressure, measured wet grip and contact area. However, for the inflation pressures assessed, an increase in contact area resulted in a small but significant decrease in wet grip. This was initially unexpected but would appear to be related to a factors including distribution of pressure within the contact patch. This needs further consideration.

In conclusion, this paper combines two simple experiments that show the basic methodology to have potential in better understanding tire / surfacing interaction and properties such as the measurement of wet grip. Further work is required especially to determine the effect of pressure distribution within the contact patch.

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