Road surface properties and high speed friction

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ABSTRACT
High speed friction generation is an important factor that should be considered by road owners to maintain road user safety. The management of high speed friction on the English motorway and all-purpose trunk road network is based on the specification of surface texture depth. This approach was borne out of work showing that the generation of high speed friction is heavily reliant on the road surface texture depth. It is assumed that the correlation between texture and high speed friction is related to the ability of water to drain away from vehicle tyres through the surface texture. For the majority of surfacing types, there is a good correlation between texture depth and high speed friction. There are, however, some exceptions and some porous asphalt surfacings and small aggregate thin surface course systems do not follow the same texture/friction relationship as the majority of surfacing types. The work undertaken explored the relationship between high speed friction and a range of road surface properties with a view to identifying parameters that allow all surfacing types to be represented by the same relationship.

1 Introduction and background

This paper summarises work that is fully described in TRL report PPR727 (Sanders, et al., 2014).

It is currently understood that high speed friction generation between a tyre and road surface is related to the amount of water present, preventing tyre/road contact. The road surface property that has the most influence on the amount of water present at the tyre / road interface is texture depth. High-speed friction can therefore be managed through the specification of texture depth in new surfacing materials and the routine measurement of texture depth in service.

The methodology for the management of high speed friction, by measurement of texture depth, is based on research carried out in the late 1990s, reported in TRL report TRL 367 (Roe, et al., 1998). This work showed that, for the majority of surfaces, should a road have low texture depth, then it is also likely to have low high speed friction.

However, there are some exceptions to this relationship. The research described in TRL 367, and further research reported in TRL report PPR 564 (Roe & Dunford, 2012), showed that for some thin surface course systems with 6 mm maximum coarse aggregate size, and porous asphalts, the relationship developed in the 1990s does not apply. In particular, the work described in PPR 564 showed that some 6 mm thin surfacings can have relatively low texture levels, but provide levels of high speed friction greater than would be estimated using the relationships developed in TRL 367 (Figure 1-1).

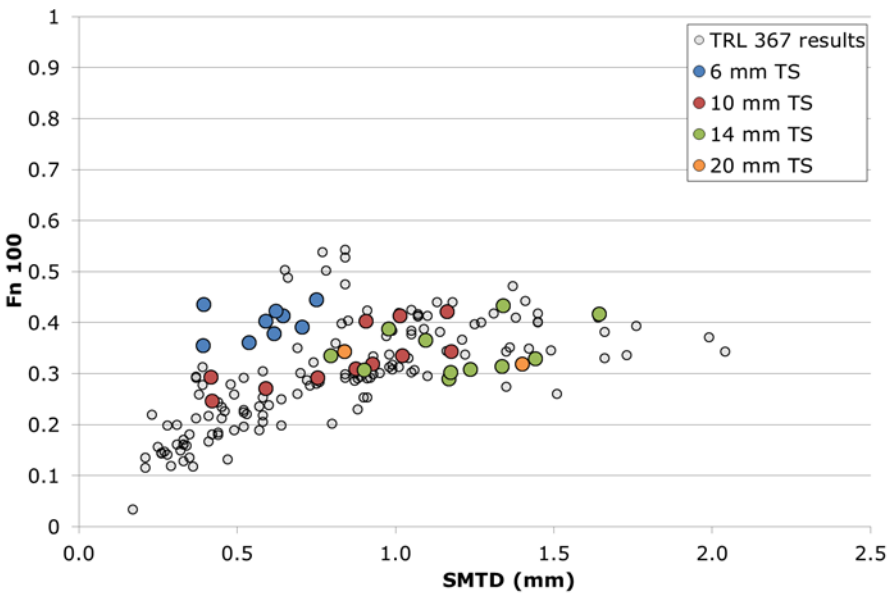

Figure 1-1 SMTD vs high speed locked-wheel friction at 100 km/h for thin surface course systems

It is the aim of this work to understand the properties of the materials which do not conform to the relationships developed in TRL 367. In addition it is the aim to identify a suitable technique for characterising the performance of such materials in a way which correlates to high speed friction.

2 Collection of laboratory specimens

A major component of this work was a series of laboratory measurements designed to investigate the properties of a number of surface characteristics. It was therefore necessary to collect a number of road surface specimens. The specimens were 225 mm diameter cores containing only the surface material (Figure 2-1).

Figure 2-1 Example of a laboratory specimen

Specimens were already available from the work reported in TRL report PPR 564 (Roe & Dunford, 2012) and these covered a wide range of proprietary thin surfacing materials. 65 specimens were extracted from ten different in-service carriageways; the surfacings were supplied and installed by different contractors and used a variety of different aggregates. For the work presented in this paper, the most important distinction between the surface constructions is the different maximum coarse aggregate sizes (6 mm, 10 mm, 14 mm and 20 mm).

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3 Conventional assessment of surface properties

This chapter describes the conventional measurements of skid resistance, high speed friction and texture that have been made on the specimens. The vehicle-based techniques, for measuring high speed friction, sideway-force coefficient and SMTD, could not be used to make measurements on the specimens directly. In these cases the value used is the value for the surface from which the specimen was taken (the parent surface).

3.1 High speed friction

Given that the aim of study was to assess the relationships between different surface properties and high speed friction it was important to make high speed friction measurements on each parent surface. These were made using the Pavement Friction Tester (PFT) shown in Figure 3-1. Testing was carried out under the guidance of ASTM standards E274/E274M (ASTM, 2011) and E524 (ASTM, 2008). To replicate the worst case scenario for motorists a smooth test tyre and a water film thickness of 1 mm were used.

Figure 3-1 Pavement Friction Tester

3.2 Sideway-force coefficient

Sideway-force Coefficient Route Investigation Machines are used for the routine monitoring of the skid resistance condition of the UK strategic road network. Figure 3-2 shows Highways England’s Skid Resistance Development Platform (SkReDeP), which incorporates sideway-force measurement equipment. Measurements from this device provide information that can be used to compare the performance of surfacings with the requirements for skid resistance laid out in the DMRB (Department for Transport, 2004).

Figure 3-2 SkReDeP

Measurements are usually made at a standard test speed of 50 km/h in the nearside wheel path.

3.3 Texture

3.3.1 Sensor Measured Texture Depth

Surface texture is calculated, on a routine basis in the UK, using surface profile measurements made at traffic speed with laser based systems fitted to TRACS, SCANNER and some sideway-force coefficient measurement vehicles. Texture measured in this way is normally reported as Sensor Measured Texture Depth (SMTD). The procedure by which SMTD is calculated is detailed in volume 5 of the SCANNER specification (DfT, 2009). For the purposes of this project, SMTD was measured on the parent surface at the same time as sideway-force coefficient.

3.3.2 Mean Texture Depth

Often called the sand patch test or volumetric technique, the procedure for calculating Mean Texture Depth (MTD) is detailed in British Standard 13036-1:2004 (British Standards, 2010). This technique is the longest established method of calculating texture depth, and is used to check that new pavements conform to specifications. For this study three determinations of MTD were made on each specimen; the average value being used for analysis.

3.3.3 Mean profile depth and root mean squared texture depth

The Circular Texture Meter (CTM) (Figure 3-3) is a portable device designed for measuring the texture depth of road surfaces and road surface specimens. The CTM operates on a similar principal to the texture measurement systems used on traffic speed devices. A triangulation laser is used to measure the distance between the laser source and the specimen surface. The laser is mounted on a rotating arm that moves in a 180 mm diameter circular path.

Figure 3-3 The circular texture meter (CTM)

During one revolution, 1024 distance measurements are made and the CTM software converts these raw distance measurements into values of Mean Profile Depth (MPD) following the principles set out in British Standard 13473-1:2004 (British Standards, 2004), and Root Mean Square (RMS).

4 Alternative assessment of surface properties

In order to identify any features of the surface that might account for the behaviour of the 6 mm surfacings, some alternative measurement and characterisation techniques were used to assess surface characteristics for each specimen.

4.1 Measurement techniques

4.1.1 3D Surface profile

Three dimensional computer models of each specimen were created from measurements made using the Breuckmann SmartSCAN HE system. The system is a stereo-imaging device comprising a structured light projector and two high resolution digital cameras mounted either side of the light source (Figure 4-1). The system produces a representation of the field of view that can be converted to a 3D model.

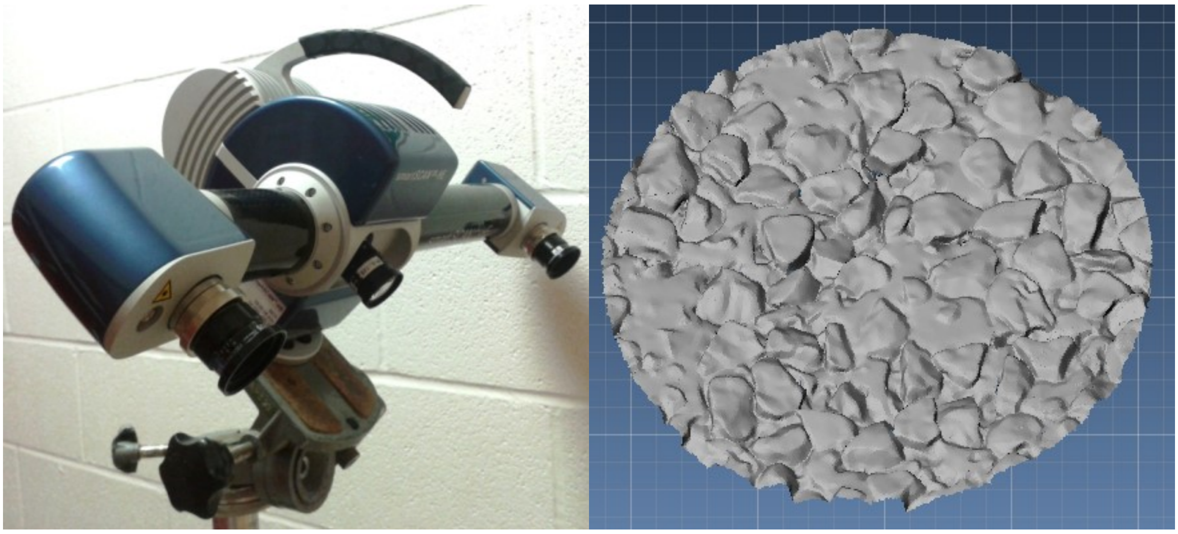

Figure 4-1 Breuckmann SmartSCAN HE System and 3D model of a specimen

4.1.2 Tyre / surface pressure

The pressure distribution and contact area between surface specimens and a standard ASTM tyre under a static vertical load were measured. This was achieved by installing a standard ASTM test tyre on an Instron tensile / compression test machine and a specimen placed directly below it. Fujifilm Prescale pressure measurement film, was placed between the tyre and specimen to create a pressure distribution “map” of the interaction between tyre and surface (Figure 4-2).

Figure 4-2 Pressure distribution test set-up and example of a pressure distribution "map"

4.1.3 Glass spheres texture depth

The measurement of glass spheres texture depth is an important parameter because it acts as a reference to which the other texture measurement techniques can be compared. The method for determining MTD was adapted to allow the measurement of the glass spheres texture depth of the surface specimens. This involved filling the surface voids with glass spheres of a known density and measuring the change in mass between the filled and un-filled specimen.

The spheres used for the measurement of void volume ranged between 0.025 mm and 0.105 mm in diameter, those used in the determination of MTD are between 0.18 mm and 0.25 mm in diameter. The smaller diameter spheres were chosen for the measurement of glass spheres texture depth so that very fine features in the specimen surface, which may not be captured by the MTD spheres, could be filled.

4.2 New surface characterisation techniques

Using the results from the alternative measurement techniques six new surface characterisations were developed.

4.2.1 Percentage pressed area

The percentage pressed areas is the area of the specimen contacted by the tyres expressed as a percentage of the total possible contact area. Calculation of percentage pressed area used the pressure distribution "maps" gained from the pressure testing.

In order to find the percentage of the tyre area that came into contact with the surface a Region of Interest (RoI) was defined to show the physical limits of contact area. The percentage pressed area is then the area of all pressure points indicated by the film divided by the area of the RoI.

4.2.2 3D Surface void volume

Surface analysis software MountainsMap Universal was used to calculate the texture of each specimen, based on the 3D surface profiles generated from the Breuckmann system. The 3D surface void volume was defined simply as the total volume of the voids below the highest peak in the profile, divided by the surface area of the specimen (as if it were completely flat). This provides an average texture depth for the specimen expressed in mm^3/mm^2.

4.2.3 Tyre penetration depth, volume below tyre and volume occupied by tyre

The “slices” tool in MountainsMap allows a 3D surface to be viewed on a two dimensional plane as though it has been sliced at a specific depth. Figure 4-3 shows an example where the blue areas represent voids present below the selected slice depth, and the yellow areas represent the surface material that has been sliced.

A slice depth was selected so that the “projected area” of material matched the percentage pressed area calculated from the pressure tests. If the area pressed by the tyre in the pressure distribution tests is the same as the area of material at a certain depth, then that slice depth may be considered to be representative of the tyre penetration depth. The tyre penetration depth, volume below tyre and volume occupied by tyre were output as part of the standard slices report, Figure 4-3.

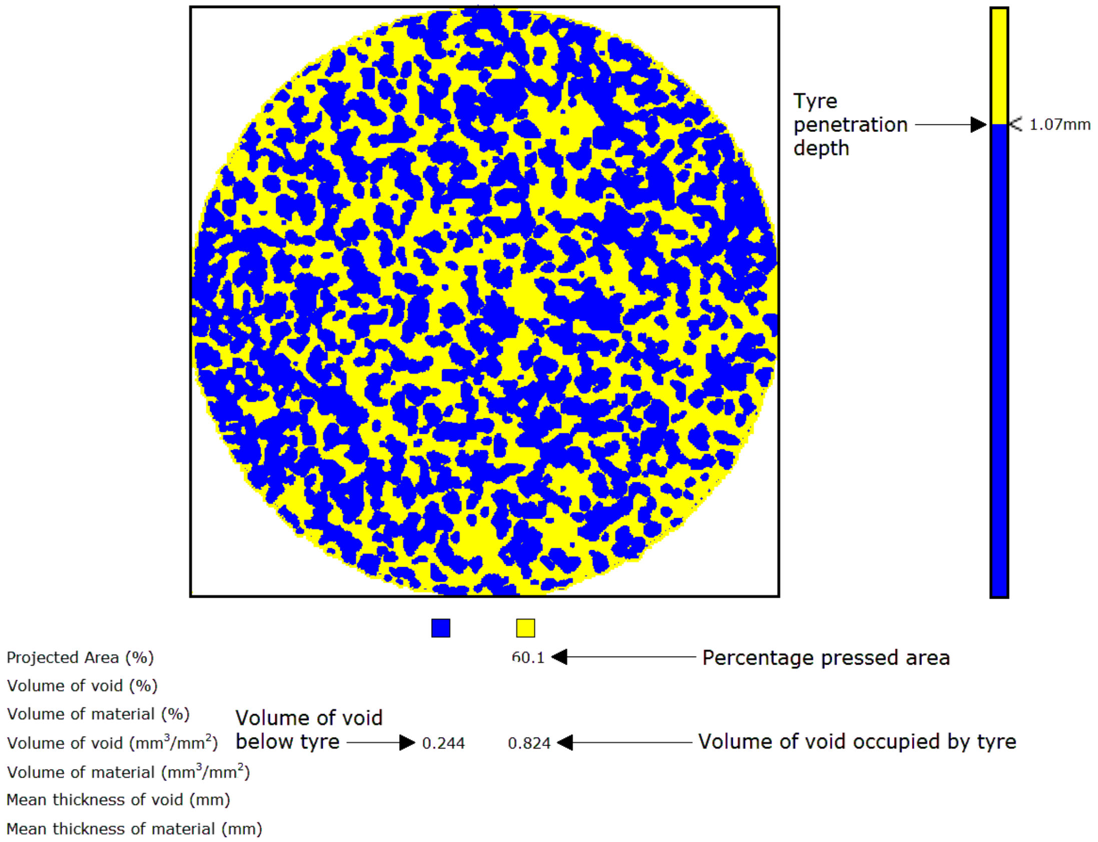

Figure 4-3 Example of slices tool

5 Analysis

5.1 Comparison of texture parameters

Each parameter characterising specimen surface texture (MTD, MPD, RMS and 3D void volume) has been compared with the total surface void volume; the glass spheres texture depth (Figure 5-1 to Figure 5-4).

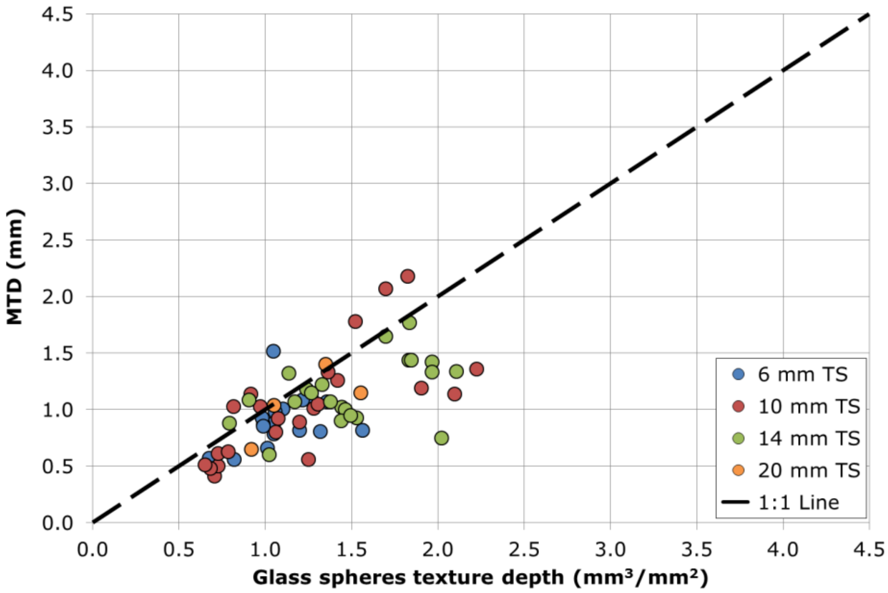

Figure 5-1 Comparison of MTD and glass spheres texture depth

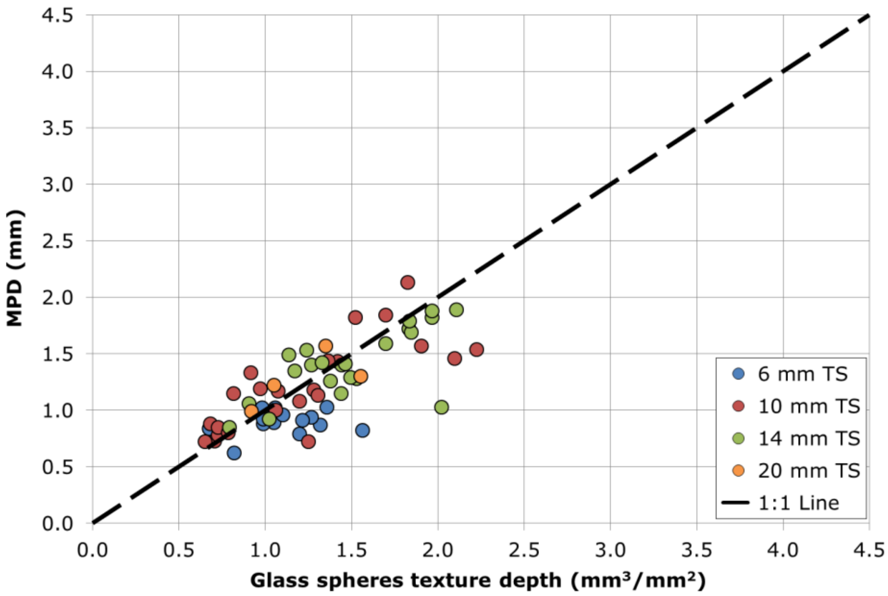

Figure 5-2 Comparison of MPD and glass spheres texture depth

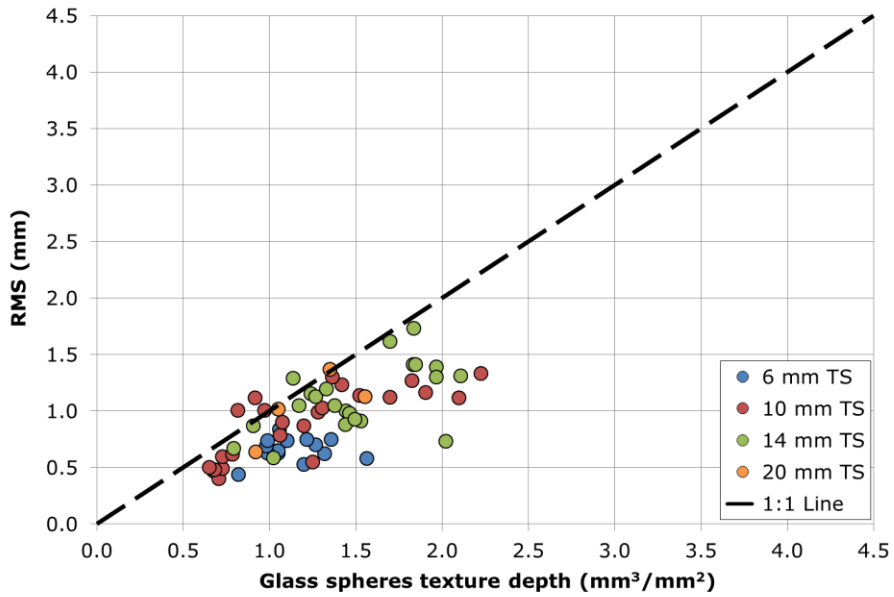

Figure 5-3 Comparison of RMS and glass spheres texture depth

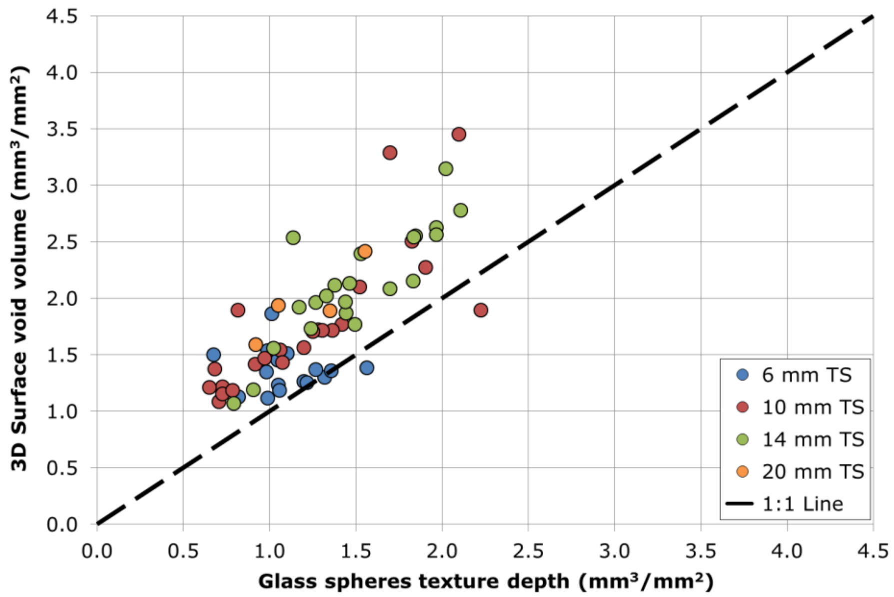

Figure 5-4 Comparison of 3D surface void volume and glass spheres texture depth

For all four variables, the 6 mm specimens are generally found in a cluster in a horizontal line. This is a key observation, and is particularly evident in MPD and RMS results where there is little variation in the y-axis, compared to larger differences in values recorded for the glass spheres texture depth. The 10 mm and 14 mm thin surfacing specimens are more widely spread than the 6 mm specimens and there is generally some correlation for these, and the other surfacing types, between the texture parameter and glass spheres texture depth.

Values of 3D void volume generally sit above the 1:1 line. This shows that the 3D method measures a larger volume than the glass spheres method. This is primarily because the 3D values are referenced from the top of the aggregate chippings whereas the glass spheres method is unable to capture information at the very top of the aggregate chippings.

5.2 Comparison of alternative parameters with high speed friction

5.2.1 *Percentage pressed area*

There is a school of thought that attributes the high speed friction performance of 6 mm thin surfacings to an improvement in tyre contact area as a result of the smaller aggregate size. This stands to reason; a smaller aggregate size would allow for a denser surface, improving the tyre contact area and therefore high speed friction. The measurement of percentage pressed area (tyre contact area) showed that values from the 6 mm thin surfacings were similar to those from other surfacing types. Furthermore there was no correlation between percentage pressed area and high speed friction.

5.2.2 *Tyre penetration depth, volume below tyre and volume occupied by tyre*

The analysis of these parameters showed a slight improvement in the position of the outlying 6 mm surfaces compared with the traditional measurement methods. However the improvements were slight and, based on the limited number of observations, none of the parameters provide a substantial improvement over the current relationship.

5.2.3 *3D surface void volume and glass spheres texture depth*

Figure 5-5 shows the relationship between high speed friction and glass spheres texture depth and Figure 5-6 shows the relationship between high speed friction and 3D surface void volume.

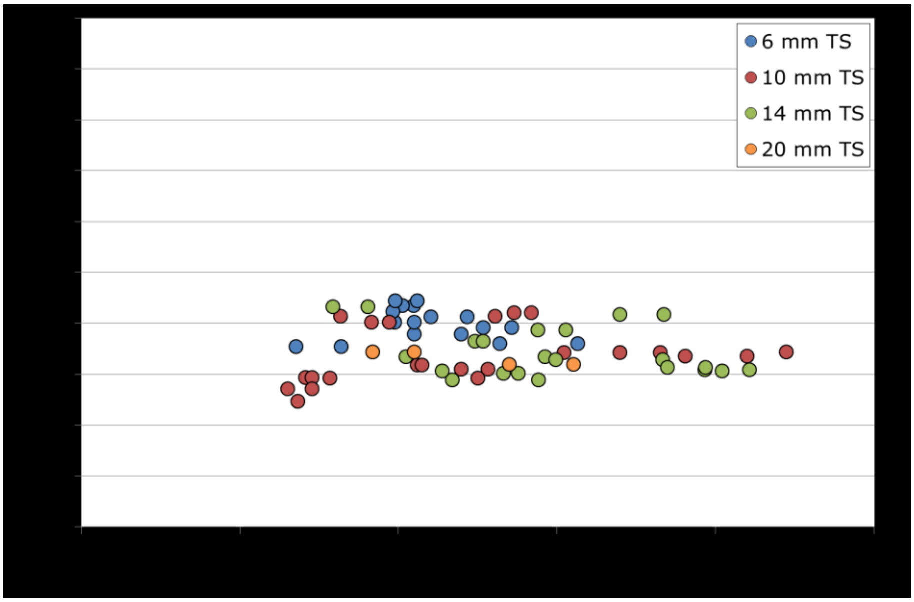

Figure 5-5 Comparison between glass spheres texture depth and Fn 100

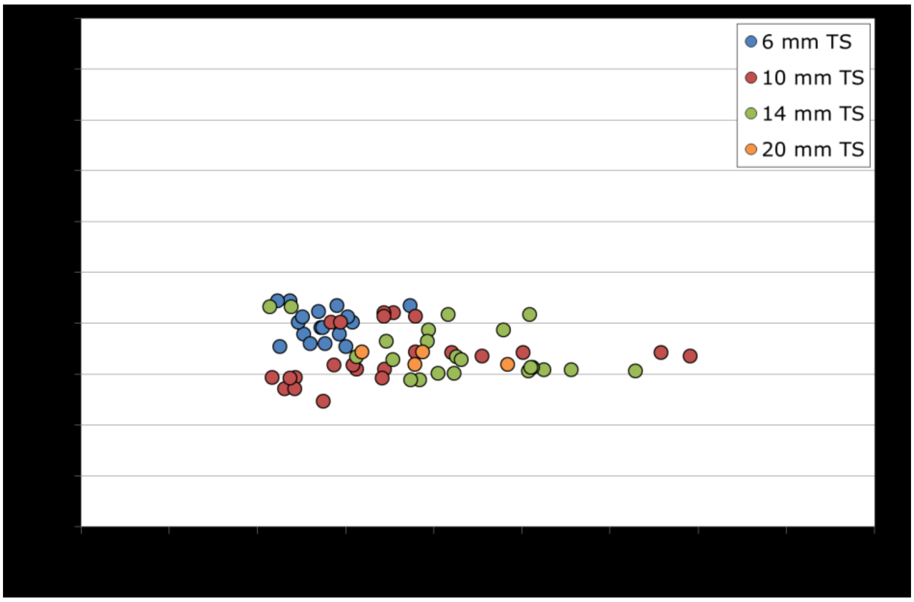

Figure 5-6 Comparison 3D surface void volume and Fn 100

Figure 5-5 shows that the glass spheres measure produces the results with the fewest outliers and the 6 mm specimens share a similar pattern of behaviour to the other surfaces. This indicates that the glass spheres texture depth is showing a clearer correlation for texture and high speed friction than the non-contact measurement methods.

Figure 5-6 shows that the form of the relationship between the 3D surface void volume and high speed friction is similar to that of the SMTD measurements (Figure 1-1), including a cluster of 6 mm surfaces that are outlying from the bulk of results. However, the cluster in Figure 5-6 is less well defined than that in Figure 1-1; more 6 mm specimens appear in the bulk of the measurements.

5.3 Analysis summary

When 2D optical methods are used to characterise texture, the 6 mm thin surfacings lie outside of the bulk of the measurements. The analysis has shown that 3D texture measurement systems are capable of capturing a greater amount of textural information than 2D methods and the parameters based on 3D measurement systems improve the relationship with high speed friction, albeit slightly. The glass spheres method is capable of capturing the very small scale texture, deep within the surface of the specimens and provides the best relationship with high speed friction, for all surfaces, of all the measurement techniques.

Based on these observations a hypothesis was created that the key property of a surface required to generate high speed locked wheel friction is the ability to remove water from the tyre/surface interface. This may be achieved through the surface texture depth or through the inter-connected void network and the effect of the two properties can be considered additive. To test this hypothesis, the horizontal permeability of the specimens was measured to characterise the prevalence of inter-connected voids in the surface.

6 Hydraulic permeability

6.1 Experimental procedure

For this experiment the technique defined in BS EN 12697-19:2012 (British Standards, 2012) was used, Figure 6-1 represents the experimental setup. A steel tube was bonded to a specimen surface, and the specimen sealed with silicon sealant so that water was only allowed to flow from the sides of the specimen.

Water with a constant hydrostatic head was fed into the steel tube and allowed to flow through the specimen surface to saturate the voids in the specimen. Once saturated, the water flowing out of the specimen was collected over a known time and the flow rate was calculated using the mass of the collected water.

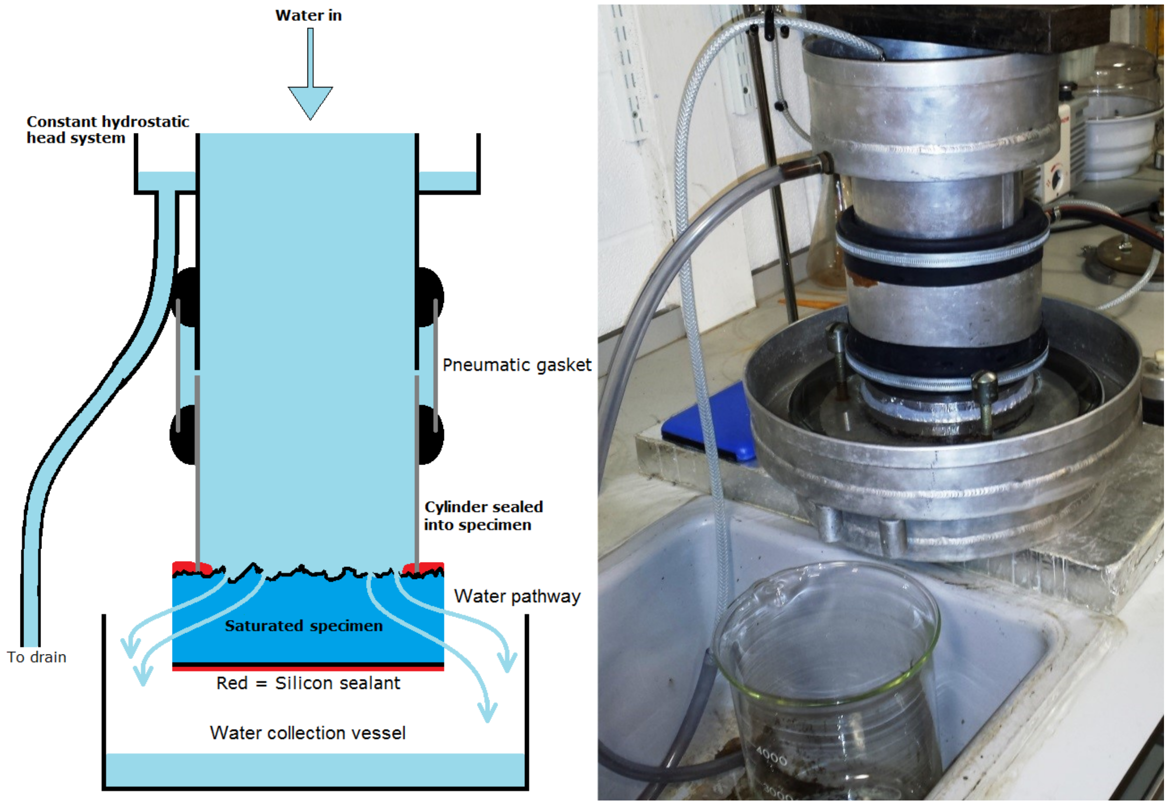

Figure 6-1 Representation of hydraulic permeability setup and the system used

6.2 Results

The results from the permeability, high speed friction and texture depth measurements are presented graphically in Figure 6-2; included with these results are the measurements made as part of TRL 367 to add context to the data. The colour of the series markers represents the coarse aggregate size and the shape, the permeability of the specimen.

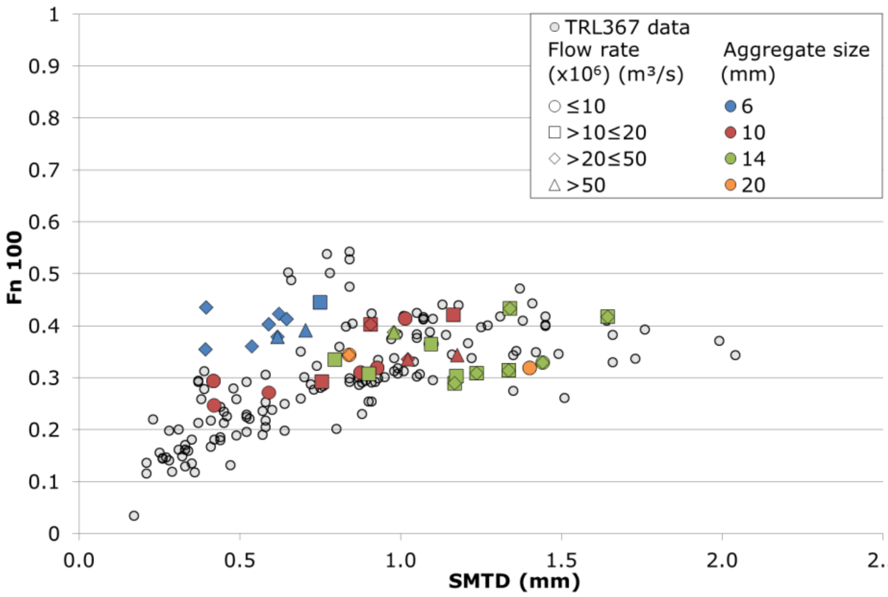

Figure 6-2 Relationship between texture, high speed friction and permeability

If the hypothesis that the amount of water removed by texture and permeability is proportional to friction performance is true then it should be expected for the positions of the series markers to move closer to the bulk of the TRL367 measurements when the effects of texture depth and permeability are combined. This assessment was carried out by augmenting the texture depth, sideway-force coefficient and friction relationship reported in TRL367 so that the effect of texture depth and permeability are considered additive, this is expressed in Equation 6-1.

$$Predicted\ L - Fn100 = 0.00337SR + 0.411\left(1 - e^{(SMTD+(x \times Flow))}\right) - 0.151$$

Where:

- SR represents the sideway-force coefficient measured using SCRIM
- SMTD is the texture depth of the (mm)
- x represents the magnitude of the effect of the permeability
- Flow is the flow rate derived from the permeability assessments (mm^3/s).

Equation 6-1 Prediction of L-Fn100 from sideway-force coefficient, texture depth and permeability

The magnitude of the effect of the permeability (x) was derived using the conversion of fixed point iteration process which compared the measured friction values with the friction values predicted from Equation 6-1 whilst varying the “x” constant. The best relationship between the measured and predicted values was identified with an x constant value of 10201 units.

Figure 6-3 shows the friction and texture relationship but the primary x-axis units have been changed to include the derived flow rate term; the TRL367 data are presented on the secondary x-axis which reports texture depth only.

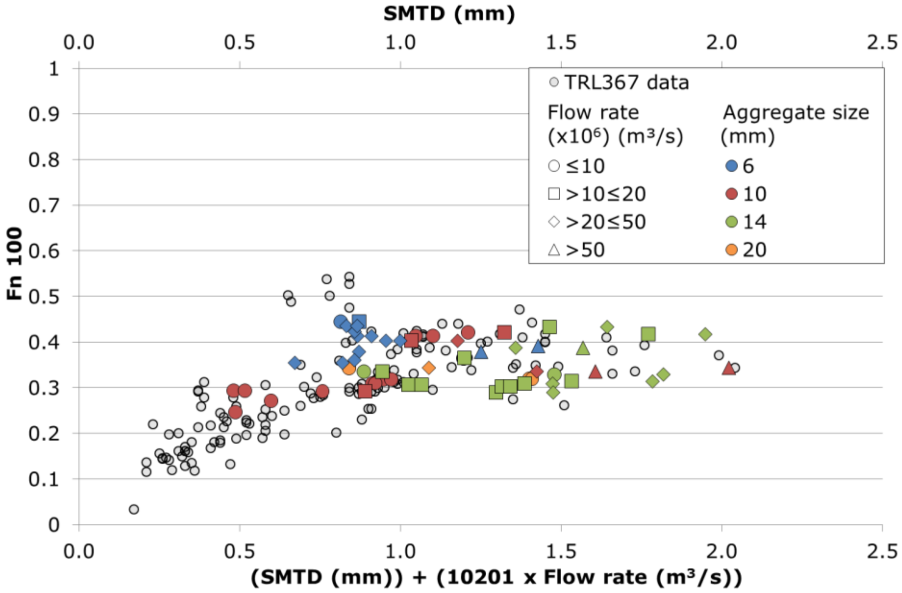

Figure 6-3 Relationship between texture, high speed friction and corrected permeability

The most notable effect observable between Figure 6-2 and Figure 6-3 is that the group of 6 mm surfacings (the blue series) have moved closer to the bulk of the measurements. The positions of other high flow rate materials (the diamond and triangle series) have also moved to the right of the x-axis. Lower flow rate materials however (the round and square series) have moved relatively little.

These observations are in agreement with the original hypothesis and demonstrate a good correlation between the combined effects of texture depth and permeability.

7 Discussion

Measurements of conventional surface texture parameters have shown that, for the majority of surfaces, at textures below approximately 0.8 mm SMTD, friction increases linearly with texture, and for textures above 0.8 mm SMTD friction changes little with increasing texture. There is an exception to this rule, however, and it has been found that some small aggregate thin surfacings are providing higher levels of friction than would be expected, given their texture characteristics. This is a replication of the findings of TRL 367 which did not assess small aggregate thin surfacings but found that porous asphalt surfacings were providing higher friction levels than expected.

The use of alternative texture measurement techniques has shown that characterising texture using 3D imaging techniques more closely represents surface texture than traditional measurement techniques. The 3D texture measures used were able to reduce the number of outlying points in the Fn 100 / texture relationship, although there were still some outliers.

The Fn 100 / texture relationship that showed the fewest outliers was that using the glass spheres method. This, along with the understanding of the influence of water in the generation of high speed friction lead to the hypothesis that the key property of a surface required to generate high speed locked wheel friction is the ability to remove water from the tyre/surface interface. This may be achieved through the surface texture depth or through the inter-connected void network and the effect of the two properties can be considered additive.

Confidence in this hypothesis was improved as a result of the laboratory measurements of horizontal permeability. This has implications for the development of a new texture measurement system for routine use because current technology does not allow the remote measurement of permeability and it may not be possible, to fully characterise the pavement properties that influence friction using purely optical techniques.

Although it is possible to develop an improved texture measurement system based on 3D measurement principles, implementing such a system for routine use requires a number of technical challenges to be overcome. Furthermore, the results of this study show that the improvements gained from such a system are likely to be relevant for measurements made on a small number of surfacings, and even then the improvement is slight.

Further understanding of the relationship between permeability and high speed friction could form the basis for the development of a criterion based on glass spheres texture depth or permeability. This could be used in conjunction with traditional texture measurement systems to allow the universal analysis of friction for all road surfacings.

There are also implications for the development of new road surfacing materials as the permeability of materials could be used to provide greater levels of friction, but permeable materials have been shown to be less durable than dense materials and so an improvement in friction could be achieved at the cost of durability.

8 Conclusions

From the work carried out in this study the following conclusions can be made:

- 3D imaging techniques can more accurately characterise road surface texture than traditional methods
- A 3D imaging based texture measurement system slightly improved the form of the texture / friction relationship but some outliers were still present
- The implementation of a 3D based system for routine use on the road network is unlikely to produce substantially improved results over traditional methods
- The hydraulic permeability of road surfaces may be influencing their frictional performance in a manner similar to that of texture.

References

ASTM, 2008. *E524-08 Standard specification for standard smooth tire for pavement skid-resistance tests,* West Conshohocken: ASTM.

ASTM, 2011. *E274/E274M-11 Standard test method for skid resistance of paved surfaces using a full-scale tire,* West Conshohocken: ASTM.

British Standards, 2004. *BS EN ISO 13473-1-2004 Characterisation of pavement by use of surface profiles - part 1 - determination of MPD,* London: BSI.

British Standards, 2010. *BS EN 13036-1. Road and airfield surface characteristics - test methods. Part 1: Measurement of pavement surface macrotexture depth using a volumetric patch technique,* London: BSI.

British Standards, 2012. *BS EN 12697-19:2012 Bituminous mixtures - test methods for hot mix asphalt part 19: Permeability of specimen,* London: BSI.

Department for Transport, 2004. *HD 28/04 - Skid resistance (DMRB 7.3.1),* London: The Stationery Office.

DfT, 2009. *SCANNER specification 2009, Vol 5 - Technical requirements: SCANNER survey parameters and accreditation,* London: UK Roads Board and TRL.

Roe, P. G. & Dunford, A., 2012. *PPR 564 The skid resistance behaviour of thin surface course systems,* Wokingham: HA / MPA / RBA Collabarative Programme 2008-11: topic 1 prepared for Highways Agency, Minerals Products Association and Refined Bitumen Association.

Roe, P. G., Parry, A. R. & Viner, H. E., 1998. *TRL 367 High and low speed skidding resistance: the influence of texture depth,* Wokingham: Prepared for Pavement Engineering Group, Highways Agency.