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Road surface properties and high speed friction

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Executive Summary

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 strategic 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 difference in characteristics between surfacings has led to an inconsistency in the specification of surface types for use on the English strategic road network. For the majority of surfaces, texture depth is specified, but for small aggregate thin surface course systems there is a further requirement that high speed friction, measured directly, should also be verified. This extra requirement leads to additional complexity in monitoring the in-service performance, where texture depth is routinely used as a proxy for high speed friction. A better understanding of the relationships between texture, friction, and speed could enable the development of a robust and universal specification for all surface types.

The work described in this report sought to improve the current knowledge by making detailed surface geometry measurements and correlating them with high speed friction. A library of specimens was built up in the form of surface cores representing 8 different surface types. Conventional texture depth measurements were made to assess current accepted techniques. To gain more detailed information, the following laboratory measurements were also made:

- 3D surface profile
- Tyre / surface pressure distribution
- Surface void volume

The analysis sought to identify whether new surface characterisation techniques could be developed which improve the correlation between small aggregate thin surfacings and high speed friction. A key finding was that surface void volume measurements gave the best correlation with friction on all surfacing types. Measurements from 3D surface profiles gave a better correlation with friction than traditional texture measurement methods, but the improvement was slight.

The findings suggest that surface void volume offers a universal measure of texture that correlates well with friction for all surfaces. However, the method used is not practical for use on the network as it requires contact with the surface.

It was observed that, for some specimens, the void volume, measured using small diameter glass spheres, was considerably greater than measured with the conventional patch method. This suggests the presence of fine voids within a complex surface structure. This complexity may not be visible using optical measurements, which rely on establishing line-of-sight.

It is plausible that sub-surface structure could influence high speed friction generation. Just as surface texture provides a pathway for water to drain away from the surface, it is
also likely that small voids within a complex surface structure could also provide conduits, allowing water to be removed from the tyre contact area and improving high speed friction.

To test this theory, hydraulic permeability tests were carried out on a sub-set of specimens. The results from this testing showed that small aggregate thin surfacings generally have a greater hydraulic permeability than the other surfacings tested. A key observation of this work was that when the texture and permeability results were combined, the performance of the small aggregate thin surfacings were better aligned with the other surfacing types. It should be noted that the conclusions borne out by the hydraulic permeability testing are based on a small number of laboratory tests and could be validated by a more robust study.

The results from this work show that by categorising surfaces in terms of the surface void volume, a correlation can be gained with high speed friction for all the surface types assessed. However this approach is not practicable for routine measurement. A wider implication of the work is that the hydraulic conductivity of surfaces may also aid in the generation of high speed friction. The porosity of road surfacings may therefore prompt some further investigation.
1 Introduction

The aim of this work is to further develop the understanding of road surface properties that contribute to high speed friction. The ultimate goal is to develop a relationship that is applicable to all surface types that could be used to update current requirements with a universal methodology for the assessment of road surface friction.

1.1 Background

Providing adequate levels of low speed skid resistance and high speed friction is an important task for road owners, as a key component for motorist safety. The Highways Agency’s skid resistance policy requires direct annual measurement of low speed skid resistance across the whole strategic road network. Direct routine measurement of high speed friction is technically challenging, and so texture is measured as a surrogate for high speed friction according to the following principles.

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 amount of friction generated between a tyre and road surface reduces with increasing speed, and that the rate of reduction is also dependent on the amount of water present at the tyre/road interface.

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 as characterised by sensor measured texture depth (SMTD) (the normal measure for texture on in-service carriageways), then it is also likely to have low high speed friction (Figure 1-1).

![Figure 1-1 SMTD vs locked-wheel friction at 100 km/h](Roe, et al., 1998)
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 1-2).

![Figure 1-2 SMTD vs high speed friction at 100 km/h for thin surface course systems](image)

Current guidelines permit the use of 6 mm thin surfacings and the specification for initial texture depth was relaxed in Interim Advice Note 154/12 (Department for Transport, 2012). The specification for retained texture depth was also relaxed but a further requirement was added that high speed friction, measured directly, should be verified. This departure from the current policy of measuring texture as a surrogate for high speed friction highlights a gap in the understanding of tyre/road interaction. In order to facilitate the use of 6 mm thin surfacings, and other potentially more durable materials, a better understanding of the relationship between texture, speed and friction is required. This in turn will help the development of a robust methodology for specification and measurement.

### 1.2 Report outline

Chapter 2 discusses the location and collection of specimens inspected using conventional techniques and more novel laboratory tests. In Chapter 3 the conventional measurement techniques used to gather the following information are discussed:

- High speed friction
- Low speed skid resistance
- Texture depth
The use of a number of alternative laboratory techniques is discussed in Chapter 4. These techniques were used to gather information about:

- 3D surface profile
- Tyre contact pressure
- The total surface void volume, referred to as the glass spheres texture depth

Using this information, new methods for characterising texture depth were devised. The relationships between these new parameters and high speed friction were assessed to find out if the new measures were better able to estimate high speed friction than conventional texture depth measurements.

In addition, some further laboratory testing was carried out to assess the sub-surface properties of the specimens. Hydraulic permeability testing, described in Chapter 6, was carried out to quantify the interconnectivity of the voids in the structure of the surface.

The outcomes from all of the measurements made, and their implications, are discussed in Chapter 7.
2 Surface specimens

A major component of this work was a series of laboratory measurements designed to investigate the properties of a number of surface types. It was therefore necessary to collect a number of road surface specimens. The specimens used were 225 mm diameter cores cut to a thickness of approximately 50 mm (Figure 2-1).

![Figure 2-1 Example of a core specimen](image)

A number of specimens were already available from the work reported in TRL report PPR 564 (Roe & Dunford, 2012). These specimens cover a wide range of proprietary thin surfacing materials, full details of the specimens are available in TRL report in PPR 564 (Roe & Dunford, 2012). 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 present work, the most important distinction between the surface constructions is the different maximum coarse aggregate sizes (6 mm, 10 mm, 14 mm and 20 mm).

To supplement these specimens, and to include a wider range of surface types typically found on the UK road network, specimens were also taken from the TRL test track. The following surfaces were included:

- Thin surfacing with nominal maximum coarse aggregate size 6 mm (TS)
- Calcined flint surface dressing (SD)
- Hot rolled asphalt (HRA)
- Sawn concrete (SC)
- Brushed concrete (BC)

Three cores for each of the test track surfaces were taken. After extraction it was only possible to use one specimen of the sawn concrete surface for laboratory testing because two specimens were broken when the cores were being sawn to the correct depth.
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, low speed skid resistance and SMTD, are designed to be used on in-service carriageways and so 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.

The PFT is a locked wheel road surface friction testing device owned by the Highways Agency and operated on its behalf by TRL. The PFT comprises a tow vehicle and trailer. The trailer holds the test wheel, which is mounted on an instrumented axle and can be independently braked. The forces acting upon it are measured to determine the friction between the test tyre and road surface.

![Figure 3-1 Pavement Friction Tester](image)

During testing, the tyre contact patch slides over the surface at the same speed as the towing vehicle. This device can therefore measure skidding resistance at any practical speed up to about 120 km/h. Whilst testing, the load and drag forces on the tyre are measured every 0.01 seconds throughout the braking cycle. From these measurements, the peak\(^1\) and locked\(^2\) friction are determined. With repeat testing, the PFT allows speed / friction curves to be determined.

---

\(^1\) Peak friction is the maximum friction value reached as the test wheel begins to slip.

\(^2\) Locked friction is the friction value experienced when the test wheel is locked.
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 are used.

3.2 Low speed skid resistance

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 the Highways Agency Skid Resistance Development Platform (SkReDeP), which incorporates sideways 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](image)

The machines use a smooth test tyre angled at 20 degrees to the direction of travel, which is mounted on an instrumented axle to record a skid resistance value for every 10 m length of road. The skid resistance value is the average ratio between the measured sideways force and the 200 kg vertical load, multiplied by 100. Readings are speed-corrected if necessary, and converted into values of SCRIM Coefficient (SC) by using a multiple of 0.78.

Measurements are usually made at a standard test speed of 50 km/h in the nearside wheel path. At this speed, since the test wheel is at 20 degrees to the direction of travel, the effective speed at which the tyre contact patch moves over the surface (the slip speed) is 17 km/h. For this reason, the measurements are considered to represent low speed skid resistance.
3.3 Texture

This section describes the three main techniques used to characterise texture on road surfaces.

3.3.1 Sensor Measured Texture Depth

Surface texture is calculated, on a routine basis, using surface profile measurements made at traffic speed with laser based systems fitted to TRACS, SCANNER and some sideways-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 low speed skid resistance.

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). The test involves spreading a known volume of glass spheres over a pavement surface in a circular pattern until the spheres are level with the top of the surface. The diameter of the patch created by the glass spheres is then measured and the MTD calculated using the following equation:

\[ MTD = \frac{4V}{\pi D^2} \]

Where:
\[ V = \text{the volume of spheres used} \]
\[ D = \text{is the diameter of the circle created} \]

**Equation 3-1**

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 is reported for each specimen.

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 systems. 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, in the case of the device used for this work, moves in a 180 mm diameter circular path.
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) using the following equation:

\[
RMS = \sqrt{\frac{(x_1^2 + x_2^2 + x_3^2 + \cdots + x_n^2)}{n}}
\]

Where:

\(x_i\) = individual texture depth measurements

\(n\) = total number of individual measurements

**Equation 3-2**
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

Three measurement techniques were used:

- 3D surface profile
- Tyre / surface pressure
- Glass spheres texture depth

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 (2448 x 2048 pixels) 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 in the proprietary software package OPTOCAT 2011 (Breuckmann, Meersberg).

During image capture the light projector displays a series of eleven linear dark and light patterns onto the specimen and the cameras capture the deformation of these patterns across the surface. A deformation is considered as any pattern that, when analysed, differs from the expected pattern of the projection on a flat plane. Given that the geometry of the system is fixed and known, the surface profile of the specimen can be calculated and modelled.
The 3D capture system was mounted on a tripod with a viewing angle of 53 degrees to the horizontal. During capture ambient light sources were turned off so that the contrast between dark and light areas from the projector would be as great as possible. The specimen was placed on a turntable that allowed it to be rotated between captures whilst remaining in the same place.

Four captures of each specimen were taken with the specimen being rotated by 90 degrees between captures. The images from each capture were then stitched together and combined using the OPTOCAT software to a single model of the specimen surface. Once the four digitized captures were combined, the model was cropped so that only the surface of the specimen remained, as in Figure 4-2. This allowed the specimen surface to be analysed using surface analysis software, MountainsMap Universal (Digital Surf, Besançon).

Three dimensional models were created for each of the surface specimens. The purpose of the 3D modelling was to compare texture values calculated from the 3D models with values obtained from standard texture measurement methods. It was also intended to use the 3D models in conjunction with other measurements, such as pressure distributions, to create new variables based on the tyre’s interaction with the surface.

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. These measurements help to investigate the interaction between the tyre and road surface and will be used as inputs during calculation of new surface parameters.

A standard ASTM test tyre used for high speed friction testing was installed on the Instron tensile / compression test machine and a specimen placed directly below it. Fujifilm Prescale pressure measurement film, which produces a pressure distribution “map” under loading, was placed between the tyre and specimen. The measurement set-up is shown in Figure 4-3.
The pressure measurement film is composed of two polyester sheets; one coated with a layer of micro-encapsulated colour forming material, “A-Film”, and the other with a layer of colour developing material, “C-Film”, (Figure 4-4).

When pressure is applied to the sheets the microcapsules are broken in the A-Film and produce a pressure distribution map similar to that shown in Figure 4-5.
During a test, the machine was set to deliver a force of 5 kN which is representative of the load placed on a PFT tyre during testing. This load was applied for a period of five seconds so that the pressure film could fully develop. The pressure distribution maps were digitized using the software package supplied as part of the pressure measurement system. The software package converts the pixel intensity values in the digitized image to pressure values and outputs a matrix of pressure intensity values that can be used to calculate a number of variables including the percentage pressed area between tyre and surface (the tyre contact patch).

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.
The procedure for determining the glass spheres texture depth of the specimens is described below and in Equation 4-1:

- The bottom and sides of the specimens were sealed using a silicon compound, to prevent the loss of any spheres through the texture of the specimen
- The specimens were weighed before applying the glass spheres, \( m_{ec} \)
- The glass spheres were evenly applied to the surface of the specimens and vibrated to ensure all the voids were filled
- The glass spheres were levelled to the surface of the specimens using a flat wooden disk (a “sand patch spreader”)
- The specimens, now full of spheres, were weighed, \( m_{fc} \)
- The mass of glass spheres used was calculated and the volume inferred by dividing the mass of spheres used by the pre-determined density of the spheres
- The area of each specimen was measured and the void volume of spheres used was divided by the surface area

\[
\text{Mass of glass spheres used (} m_s \text{)} = m_{fc} - m_{ec} \\
\text{Volume of glass spheres (} V \text{)} = \frac{m_s}{d_{gs}} \\
\text{Glass spheres texture depth} = \frac{V}{A}
\]

Where:

- \( d_{gs} \) = the density of the glass spheres
- \( A \) = the surface area of the specimen

Equation 4-1

### 4.2 New surface characterisation techniques

Using the results from the alternative measurement techniques five new surface characterisations were developed:

- Percentage pressed area
- 3D surface void volume
- Tyre penetration depth
- Volume of void below tyre
- Volume of void occupied by tyre

#### 4.2.1 Percentage pressed area

The calculation of percentage pressed area used the pressure distribution matrices gained from the pressure testing described in section 4.1.2. Some noise could be seen in the pressure distribution matrices; pressure points were registered where it appears from the overall pattern that no contact is occurring. It is speculated that the additional points appear where cells in the sheet burst due to the pressure between the tyre and the sheet itself rather than because of the pressure between the tyre and specimen.
A 2D median filter, often referred to as a “salt & pepper” filter, was applied to the pressure matrices to remove this noise and give a more accurate representation of the pressed area. Figure 4-6 shows a filtered and unfiltered image of the same area where red areas represent high pressure. The filter acts on a matrix by replacing an individual value with the median value of its neighbours. The filter was designed to act over a narrow field so that only isolated spots would be affected and measurements made on areas coming into contact with the tyre were relatively unchanged.

![Figure 4-6 Unfiltered image (left) and filtered image](image)

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. Quantifying a specific RoI for each specimen would have provided the most accurate results but would have been prohibitively time consuming. An alternative method was used to estimate the RoI for each specimen based on measurements made on a flat steel plate.

The RoI calculated using a flat surface results in a slightly larger RoI than would be expected on a specimen surface. This is due to the voids in the specimen surfaces resulting in higher pressure at the points of contact and therefore a smaller area required to support the load. To account for this, the size and shape of the RoI from the flat surface was used to calculate outer and inner mask areas that, when used together, would estimate the RoI for the specimens.

The outer mask area was defined as the RoI of the steel plate. Because this mask is likely to be larger than the RoI on the specimen surfaces, it was used to calculate the lower limit of the Percentage Pressed Area (PPA_L). The inner mask area was defined as the RoI of the steel plate, excluding the effects of tyre deformation, and is likely to be smaller than the RoI on the specimen surfaces. This mask was used to calculate the upper limit of the percentage pressed area (PPA_U).

The image on the left of Figure 4-7 shows measurements of pressure from a film placed between the test tyre and a flat plate, overlaid with the upper mask area (black outline showing the full extent of potential tyre contact) and the lower mask area (white outline showing a minimum potential contact area). The image on the right of Figure 4-7 shows
how these mask areas are applied to a specimen with a maximum aggregate size of 14 mm.

![Figure 4-7 Example of outer and inner mask areas calculated from a flat plate (left) and as used on a specimen](image)

The mean Percentage Pressed Area \(\frac{PPA_L + PPA_U}{2}\) within each of the two mask areas was used to represent the Percentage Pressed Area (PPA) of the specimen.

### 4.2.2 3D Surface void volume

Surface analysis software MountainsMap Universal (Digitalsurf, Besançon) 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 \(\text{mm}^3/\text{mm}^2\). One drawback to this approach is that the texture value can be overestimated by the presence of a particularly large peak in the profile. When inspecting the 3D profiles of the specimens the peaks were found to be homogeneous enough for this approach to be appropriate.

### 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 4-8 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 displayed in MountainsMap, matched the percentage pressed area calculated from the pressure distribution tests, for each specimen. 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.

Because the slice depth represents the tyre penetration depth then the volume of voids below that depth represents the volume into which the tyre does not intrude; the volume
of voids below tyre. Conversely, any voids above that depth could be filled with tyre, assuming an easily deformed tyre rubber; the volume occupied by the tyre. These two volumes, divided by the area of the surface, are represented by the values indicated in Figure 4-8.

![Figure 4-8 Example of slices tool](image_url)
5 Analysis

This chapter discusses the analysis carried out on the results collected. In order to improve confidence in the results the friction / skid resistance / texture relationship developed in TRL 367 had been repeated. The results collected from the conventional and alternative measurement techniques are then compared and discussed.

5.1 Repetition of TRL 367 relationship

A model for predicting high speed friction was developed and reported in TRL 367 (Equation 5-1).

\[ Fn_{100} = (0.00367 \times SR) + (0.411 \times (1 - e^{-SMTD})) - 0.151 \]

Where:

\( SR = \) The surface SCRIM Reading (the unprocessed output from SCRIM)
\( SMTD = \) The surface texture as measured using SMTD

Equation 5-1

Equation 5-1 was used to estimate high speed friction, \( Fn_{100} \), for the surfaces analysed during the present study, using measurements of skid resistance and texture made on the sites. The estimated high speed friction was then compared with high speed friction actually measured on the sites. This comparison is shown graphically in Figure 5-1; previous measurements made during the TRL 367 study are included for reference.

Figure 5-1 Comparison between estimated \( Fn_{100} \) using Equation 5-1 and measured values

Figure 5-1 shows that there is an agreement with the results from the TRL 367 study. Whilst the 10 mm and 14 mm specimens are scattered around the 1:1 line, the majority
of the 6 mm specimens are clustered below the 1:1 line. The outlying points reported in TRL 367, below the 1:1 line, mainly represent porous asphalt surfaces.

It is possible that the outlying surfaces, porous asphalt and 6 mm thin surfacings, share a common mechanism causing actual high speed friction to be greater than predicted.

5.2 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 5-2 to Figure 5-5). There is no relationship shown with SMTD because the SMTD and RMS measures are very similar and the RMS measure was calculated for each specimen whereas SMTD measurements were made on the specimens’ parent surfaces. A broken diagonal line shows the line of unity on each graph.

Figure 5-2 Comparison of MTD and glass spheres texture depth
Figure 5-3 Comparison of MPD and glass spheres texture depth

Figure 5-4 Comparison of RMS 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. Figure 5-6 is an image of a surface specimen after it had been filled with glass spheres; note the dark protruding aggregate particles.
5.3 Comparison of alternative parameters with high speed friction

Some of these parameters may be useful in finding a relationship between the outlying 6 mm thin surfacings and high speed friction. To test the new parameters, each one was compared with Fn 100. Graphs showing these relationships can be found in Appendix A.

5.3.1 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.

5.3.2 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.

5.3.3 3D surface void volume and glass spheres texture depth

Figure 5-7 shows the relationship between high speed friction and glass spheres texture depth and Figure 5-8 shows the relationship between high speed friction and 3D surface void volume.
Figure 5-7 Comparison between glass spheres texture depth and Fn 100

Figure 5-8 Comparison 3D surface void volume and Fn 100

Figure 5-7 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 5-8 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 1-2), including a cluster of 6 mm surfaces that are outlying from the bulk of results. However, the cluster in Figure 5-8 is less well defined than that in Figure 1-2; more 6 mm specimens appear in the bulk of the measurements.
5.4 Analysis summary

There are many methods for measuring road surface texture and, because of the efficiency associated with making measurements at traffic speed, most use contactless techniques. Contactless measurement systems can be vehicle mounted and collect information in conjunction with other parameters, such as skid resistance or road geometry. All currently used contactless methods characterise texture using a two dimensional texture profile.

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.

For the majority of materials, the texture that can be seen from above the surface is representative of the volume available for water to escape the tyre/road interface. But, for some surfaces, such as the 6 mm thin surfacings assessed, there may be an amount of texture that cannot be seen from the surface in the form of interconnected voids or texture that is too deep, or small, for optical systems to characterise.

It is plausible, therefore, that the glass spheres texture depth produces the best relationship with high speed friction because this measurement method is capable of characterising some of the texture that cannot be seen from the surface, including interconnected voids. These voids could provide a pathway for water to be removed from the surface, and could improve the friction characteristics of some surfacings.
6 Hydraulic permeability

In Chapter 1 the influence of water on friction generation was discussed, and in Chapter 5 it was suggested that the interconnected voids within a surface may provide a pathway for water to escape the tyre road interface and therefore aid friction generation. This chapter discusses the experiments carried out to assess the hydraulic permeability of the specimens. This will characterise the specimens’ ability to transport water through the interconnected voids within the surface structure.

6.1 Experimental procedure

For this experiment a variation on 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 outside edge of the top of the specimen was sealed using silicone sealant to remove the effects of surface texture because they are likely to mask the effects of permeability. The bottom of the specimen was also sealed to reduce any effect of drainage relating to variations in the amount of base course still attached to the surface course. Water with a constant hydrostatic head of 2.94 N/m² 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.
To investigate the depth of any inter-connected voids, the experiment was repeated several times for each specimen, with the sides of the specimen sealed to different extents. Firstly, the sides of the specimen were completely sealed with aluminium tape to restrict the water flow. For further repetitions, 5 mm of tape was removed from the bottom of the specimen to reveal progressively more of the specimen’s sides, until all of the tape was removed.

A sub-set were chosen for testing based on aggregate size and their position in the friction / texture relationship shown in Figure 6-2; the circular points with solid colours represent the specimens selected for permeability testing and the shaded circular points represent the remainder of the available specimens. TRL 367 results have been included for reference and are represented by the shaded diamond points. The specimens selected were chosen because they represent the range of behaviours observed.

![Figure 6-2 Specimens selected for permeability testing](image)

**Figure 6-2 Specimens selected for permeability testing**

### 6.2 Results

The testing yielded a permeability profile for each specimen like the one shown in Figure 6-3. The permeability profile shows the flow rate measured at different sealed depths. In Figure 6-2 the flow rate at 35 mm is the rate when all but the bottom 5 mm of the specimen was sealed with aluminium tape, the flow rate at 0 mm is the rate with the sides of the core completely open. A full account of the permeability measurements is given in Appendix B.

Figure 6-3 shows that, as the tape is removed and more of the specimen is revealed, the flow rate increases; this behaviour was similar for all the specimens. In this case, the flow rate remains fairly consistent for measurements made until only the top 20 mm of the surface was sealed. For other specimens this depth differs, but the example suggests that the permeability of the material, at considerable depths below the surface, may influence the flow of water at the surface.
For further analysis, the permeability of the specimens without any sealing of the sides was considered in relation to their textural and frictional performance. Figure 6-4 shows the behaviour of the specimens; the position of the points on the graph represents the textural and frictional performance, as before, and the shape of each point represents the specimen’s permeability. The TRL 367 results have been included for reference.

Figure 6-4 Specimens chosen for hydraulic permeability tests

Figure 6-4 shows that the specimens with texture below approximately 1 mm SMTD, which also fall within the bulk of the friction measurements, have low flow rates. Conversely, specimens with texture below 1 mm SMTD, which have higher friction than the bulk of the measurements, generally have higher flow rates. Specimens with
Road surface properties and high speed friction

textures greater than approximately 1 mm SMTD have a range of flow rates, although the friction / texture relationship above 1 mm SMTD suggests that an increase in texture does not improve the friction performance, and this may also be true for an increase in flow rate.

A primary function of both texture depth and permeability is to remove water from the tyre/road interface and so their measurements could be considered to be additive. Using this assumption, the sum of values of SMTD and flow rate (multiplied by a constant of 11000, derived using the least squares method) were plotted with the TRL 367 results in Figure 6-5, although since the flow rate for the TRL 367 results is unknown these points have not been adjusted.

![Figure 6-5 The combined effects of texture and permeability](image)

The performance of the outlying specimens is now much closer to the bulk of the measurements. The positions of specimens with high flow rates have been affected greatly whereas the position of specimens with low flow rates have been less affected. Supporting this observation, the group of points surrounded by the broken red line represent porous asphalt surfaces. It is highly likely that these surfaces would have very high flow rates and so if this was taken into account their position on the x-axis would move to >2.5. The overall shape of the point cloud would then be more representative of the bulk of the measurements.

This demonstrates the potential for permeability to be considered as adding texture to the surface, and that when these effects are taken into account the relationship between texture and friction developed in TRL 367 remains valid for the small aggregate thin surfacings that are the focus of this study.

It is worth noting at this point that the results are based on a small number of laboratory measurements. The results cannot therefore be definitive and the behaviour shown above may differ significantly for other surfacing types or if measurements were to be made on in-service carriageways.
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 suggests that the ability of the spheres to access areas deeper in the surface that cannot be seen using optical techniques leads to a texture characterisation more closely related to high speed friction.

The relationship between glass spheres texture depth and friction suggests that there may be some features below the surface that are influencing friction generation. Hydraulic permeability measurements were made to characterise the interconnected voids in the surface of the specimens. Results from these measurements have shown that the hydraulic permeability of the 6 mm TS specimens, outlying from the bulk of the points in the Fn 100 / texture relationship, generally have a higher permeability than specimens with similar texture within the bulk of the relationship. Further analysis of the texture and permeability results showed that, when texture and permeability are thought of as additive properties, their combined effects can bring outlying measurements into the bulk of the TRL 367 relationship.

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 research presented in this report shows 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 the frictional performance of road surfacings in a manner similar to that of texture

It should be noted that the final conclusion is based on laboratory measurements made on a small sample size and that the characteristics noted above may differ for other material types or in-service carriageways. The assessment of texture, permeability and friction on in-service carriageways of various constructions would be useful in determining the role that permeability plays in friction generation.

References

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


Appendix A  Relationship between Fn 100 and new texture parameters

Appendix A-1 Comparison between FN 100 and SMTD

Appendix A-2 Comparison between FN 100 and 3D surface void volume
Appendix A-3 Comparison between FN 100 and glass spheres texture depth

Appendix A-4 Comparison between FN 100 and percentage pressed area
Appendix A-5 Comparison between FN 100 and tyre penetration depth

Appendix A-6 Comparison between FN 100 and volume of the void below the tyre
Appendix A-7 Comparison between FN 100 the volume occupied by the tyre
Appendix B  Results of permeability testing

The graphs below show the results of the permeability testing. Tests were primarily carried out on specimens used as part of the collaborative project. The labelling convention for these specimens is: Road name_Lane_Section_maximum aggregate size. Full details of the surfaces are available in TRL report PPR 564 (Roe & Dunford, 2012)

Appendix B-1 Hydraulic permeability measurements for 6 mm thin surfacings

Appendix B-2 Hydraulic permeability measurements for 10 mm thin surfacings
Appendix B-3 Hydraulic permeability measurements for 14 mm thin surfacings

Appendix B-4 Hydraulic permeability measurements for a 20 mm thin surfacing and a HRA surfacing