Transport Research Laboratory

Surface properties of longitudinally diamond ground concrete - Interim report

by P D Sanders, H E Viner and J W E Chandler

CPR908

CLIENT PROJECT REPORT

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by P D Sanders, H E Viner and J W E Chandler (TRL)

Prepared for: Client: Highways Agency, (Mr. D Lee)

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Contents

Executive summary

The Highways Agency is investigating the potential of a longitudinal diamond grinding process, similar to that commonly used in America, to provide a cost-effective method of restoring the skid resistance characteristics of worn, but structurally sound concrete pavements.

The grinding process involves passing a rotating profiled drum over the pavement surface. The drum is constructed of a number of diamond blades of different diameters, ordered in such a fashion as to create the desired surface profile. During the grinding operation the drum rapidly revolves, pressure is applied by a vertical force and the drum is pulled along the surface in the direction of traffic at a constant speed. This results in the removal of between 3mm and 10mm of the original pavement surface creating a completely new surface. The new surface consists of longitudinal grooves approximately 2-3mm wide, 3-4mm apart and 0.5-1.5mm deep.

In March 2009, a 500m length of the A12 Chelmsford bypass at Boreham was treated with a longitudinal diamond grinding technique and a similar treatment was applied on a 6km (aprox.) section of the A14 during March and April 2010. As part of the assessment of these trial sections, TRL was commissioned to carry out measurements of low-speed skid resistance (with Sideways-force Coefficient Routine Investigation Machine (SCRIM), the device used for normal routine monitoring) and of high-speed friction (using the Highways Agency's Pavement Friction Tester (PFT), a specialist friction measurement device). In addition, regular GripTester measurements have been carried out by the Area 6 Maintaining Agent, and these have been reviewed within this report.

The study has also included a short programme of laboratory work using cores taken from the trial sites. An accelerated polishing technique has been used to simulate the potential effects of traffic, combined with a special methodology using laser profile measurements to assess changes in profile, in an attempt to assess the potential longer-term influence of trafficking on the surface texture.

Initial measurements of skid resistance on the trial sites have demonstrated that:

- On the surfaces treated, diamond grinding produced a marked increase in low speed skid resistance compared with the untreated surface.
- However, as might be expected, after 16 months of traffic the older of the two sites was showing signs that the surface was polishing under the influence of traffic and the skid resistance was reducing.
- On the untreated concrete surfaces, the original brushed texture had been worn away and these sections, as expected from previous studies, showed very low locked-wheel friction at higher speeds. The grinding process had a beneficial influence on high-speed friction, increasing it to a level comparable with the lower end of the range typically observed on older asphalt surfaces.

The improvements in low-speed skid resistance and high-speed locked-wheel friction observed may have been influenced by sharp-edged asperities in the ridges of the concrete and, particularly, in the exposed aggregate particles left after grinding. These appear to have had a strong interaction with the test tyres, scoring them in the case of some of the locked-wheel tests. However, this may be a characteristic of the flint aggregate used in the concrete at the trial sites and its reaction to the grinding action rather than a general feature of the results of the grinding process.

The high-speed friction characteristics of road surfaces are strongly linked to texture depth and previous work has shown that low levels of high-speed friction can be expected on brushed concrete with low texture depth. The improvement in high-speed friction seen so far in these trials probably results from two components: the marked increase in low-speed skid resistance due to improved microtexture and the change in texture form.

Normally, a measurement of texture depth is used as a surrogate for high-speed skid resistance, both in specifying new surfacings and in monitoring them in service. However, this approach may not be applicable for this type of surface finish for a number of reasons, for example:

- The form of texture is unusual and it is unlikely to follow the same relationship with high-speed friction as has been observed on other surfaces.
- The volumetric measurement technique can be very variable as a result of the peaks, flanges and troughs creating the texture and consequently may not characterise the texture adequately.
- Routine laser-based measurements made in the longitudinal direction may not characterise the texture adequately.

Early results from the laboratory study suggest that there may be a reduction in the texture depth of the ground surfaces under traffic.

The initial results from the trials are encouraging and the improvement in low-speed skid resistance is potentially of benefit in terms of reducing accident risk, especially where the initial skid resistance is at or below a CSC investigatory level of 0.40 or 0.35. However, there is already evidence that the surfaces are polishing under the influence of traffic and that skid resistance is decreasing again. Continued monitoring is needed to assess how far and how rapidly the levels will fall.

Although high-speed friction has improved as a result of the modified texture of the surface, it remains at a comparatively low level in its early months in relation to other types of surfacing after many years in service. If the texture also decreases over time, either as a result of direct wear or of fracturing of the ridges in the ground pattern, this might negate any benefit achieved in terms of high-speed friction. As with the low-speed skid resistance, further monitoring is required to assess this.

The present trials are on sites in which the coarse aggregate in the concrete was flint gravel, a material that naturally has low microtexture and is prone to polishing. However, if the process is to be used more widely, other coarse aggregates will be encountered and exposed, typically limestone, which may also have poor resistance to polishing. Further trials on such sites should therefore be considered.

The difficulty of measuring texture depth routinely on surfaces with a longitudinal form, and the influence that this form of texture has on high-speed friction, require further attention before appropriate specifications for the initial treatment and in-service monitoring of such services can be developed.

Abstract

TRL have carried out surface friction measurements on a section of the A12 Chelmsford bypass between the Boreham and Sandon interchanges, and a section of the A14 between Whitehouse and Copdock. Each site had been treated with a longitudinal diamond grinding technique used to restore surface texture and skid resistance. Low speed skid resistance measurements were taken from each of these sites up to 16 months after the grinding treatment was applied. Measurements of locked wheel friction were made over a range of speeds on treated and un-treated surfaces, seven months after grinding. In addition to the skid resistance testing, a programme of laboratory testing was also undertaken in an attempt to analyse any changes in surface properties as a result of accelerated wear testing, and to assess the suitability of texture measurement techniques for use on surfaces of this type. This interim report presents the results of the measurements to date and discusses their implications.

1 Introduction

The two main properties of a road surface that influence its wet friction performance are microtexture and macrotexture (measured as texture depth). On a concrete surface, texture is normally provided by the sand present in the laitance (microtexture) and the transverse brush marks (macrotexture). The action of heavy traffic removes much of the laitance over time and reduces the texture depth within the wheel paths, thus exposing the coarse aggregate which can then become polished. This leads to poor frictional properties and the requirement for a surface treatment to restore them.

The Highways Agency is investigating the potential of a longitudinal diamond grinding process, similar to that commonly used in America, to provide a cost-effective method of restoring the surface friction characteristics of concrete pavements (Figure 1-1).

Figure 1-1 The grinding convoy (grinding machine left, and slurry tanker right)

One characteristic of the diamond grinding process is the removal of the remaining laitance and the exposure of the bulk material, which would typically incorporate coarse aggregate with relatively low PSV[1] (Polished Stone Value) such as flint or limestone. This creates uncertainty as to the likely skid resistance properties of the treated surfaces over time. Furthermore, the nature of the macrotexture after grinding is unlike other materials in the UK and it is not known how this might influence skid resistance at higher speeds. Therefore, while the diamond grinding technique potentially offers an effective treatment for worn concrete pavements, close monitoring of skid resistance performance is required to verify that it provides adequate surface friction and that this is maintained when exposed to heavy traffic.

To assess the skid resistance properties of longitudinally ground concrete surfaces over time, two trial sites are being monitored using several skid resistance testing devices. The first of these, a 500m length of the A12 Chelmsford bypass at Boreham, was treated in March 2009 and the same process was used at a second site, on the A14 between Whitehouse and Copdock, during March and April 2010.

As part of the assessment of these trial sections, TRL was commissioned to carry out measurements of surface friction using the Sideways-force Coefficient Routine Investigation Machine (SCRIM) and the Pavement Friction Tester (PFT), a specialist friction measurement device. In addition, regular measurements have been carried out

[1] A measure of an aggregate stone's ability to maintain its skid resistance when trafficked

by the Area 6 Maintaining Agent using a GripTester, and these have been reviewed within this report.

The field testing has been supplemented by, a programme of laboratory study carried out to assess any textural changes on longitudinally ground pavement specimens as the result of accelerated wearing.

A consequence of the longitudinal texture provided by the grinding process is that it may not be adequately measured by routine TRACS measurements, which are made using a single-spot laser moving longitudinally over the surface. If the diamond ground surfaces prove satisfactory in terms of their friction performance, it will be necessary to establish whether texture depth can be monitored satisfactorily using current measurement methods, or whether a different approach will be needed. Although a detailed study of this aspect was beyond the scope of the current work, the laboratory study provided an opportunity to assess the suitability of different texture measuring techniques.

This Interim report summarises the results of the friction measurements on the trial sites and the laboratory studies that had been completed by the end of the summer of 2010, and discusses the implications of these in relation to the road surface properties and the future research programme. Further PFT measurements are planned for October 2010, the results of which will be incorporated into a final report.

2 The diamond grinding process

As concrete road surfaces age, the combined effects of trafficking and weathering can cause pavements to suffer from reductions in surface texture and skid resistance, increased stepping, cracking and other more serious structural ailments. Structural faults usually require costly depth related treatments, as areas below the pavement surface are usually affected. However, if a pavement is structurally sound but suffers from undesirable surface characteristics, a surface treatment can be an adequate restoration technique.

In the UK, a number of techniques are used to restore surface texture and skid resistance on concrete road surfaces, such as surface dressing, transverse grooving, mechanical roughening or thin bonded surface repairs (HD 32/94 - Maintenance of concrete roads (DMRB 7.4.2), 1994). In recent years asphalt overlays have become more frequently used to take advantage of their improved acoustic properties. However, in other countries, such as the USA, longitudinal diamond grinding is commonly used as a surface restoration technique. Previous studies have shown that, longitudinal diamond grinding can also offer improvements to a pavement's skid resistance and acoustic performance. It is claimed that diamond grinding can offer several advantages over asphalt overlays. Unlike overlaying, diamond grinding can be confined to specific areas that require treatment, and with minimal disruption to existing infrastructure such as street furniture. A further advantage is that the only consumables used by this technique are water and the diamond grinding blades, any waste material being collected and recycled.

The grinding process involves passing a rotating profiled drum (shown in Figure 2-1) over the pavement surface. The drum is constructed of a number of diamond blades of different diameters, arranged to create the desired profile.

Figure 2-1 Profiled diamond grinding drum

During the grinding process the drum is pulled along the surface at a constant speed in the direction of traffic as it revolves rapidly under pressure from a vertical load forcing the drum onto the pavement surface. The blades cut a texture into the pavement surface whilst removing a thin layer (3-10mm), which has the effect of smoothing the megatexture. To reduce the temperature at the drum / pavement interface, and to control any dust created during the process, water is continually applied to the interface from an on-board tank. The arisings are collected and transferred to a separate slurry tanker using an on-board vacuum before being taken to a recycling plant where they are processed into a product suitable for reuse.

The resulting surface texture consists of longitudinal grooves approximately 2-3mm wide, 3-4mm apart and 0.5-1.5mm deep. Figure 2-2 gives an example of the surface finish that was achieved on the A12 trial site.

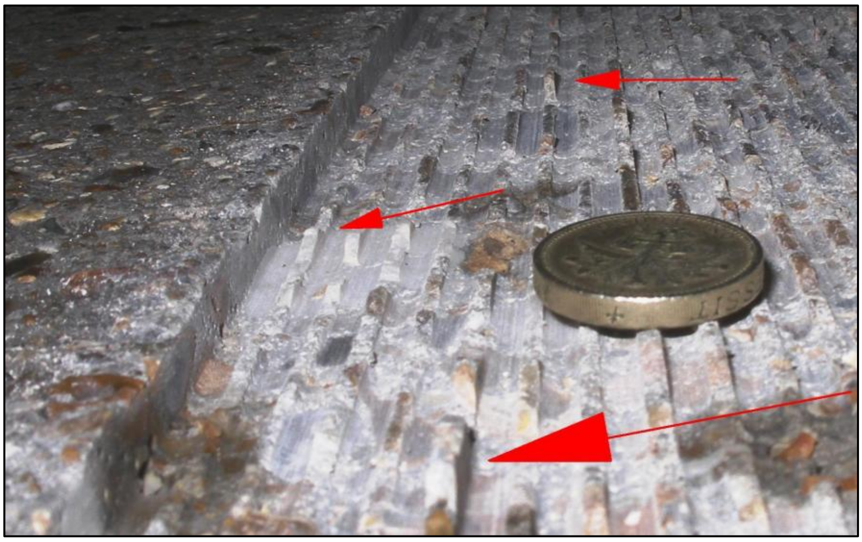

Figure 2-2 Surface finished achieved with diamond grinding technique

Figure 2-2 shows an untreated length of concrete surface on the left of the picture and a treated length on the right. As can be seen, a feature of the diamond grinding process is the creation of sharp ridges or fins (highlighted by the red arrows). These fins could contribute to the frictional performance of the surface; however, they could also be removed by the process of trafficking.

This surface texture differs significantly from that provided by conventional transverse grooving The first, most obvious, difference is that the longitudinal diamond grinding technique results in grooves that run parallel rather than perpendicular to the direction of traffic. It is likely, therefore, that the characteristics of road/tyre interaction for the two techniques will differ, which could result in different frictional properties. The second difference is that transverse grooving cuts grooves into the pavement surface leaving a portion of the original surface intact, whereas the longitudinal diamond grinding technique removes the entire surface, providing a fresh, un-trafficked surface and exposing the coarse aggregate.

There are two specific aspects related to the different surface finish whose consequences for frictional characteristics are unknown:

- The effect of exposing low PSV aggregates that are typically used in concrete carriageway construction.
- The structural strength of texture providing flanges generated by the grinding process.

Removal of any residual laitance from the surface means that the exposed coarse aggregate becomes the primary source of microtexture. Thus, the polishing resistance of the aggregate becomes of particular importance. Many concrete roads, especially in the south and east of England, were built using flint gravel or limestone as coarse aggregate and both types have a low PSV and are prone to polishing by traffic. Therefore, it is likely that these aggregate types could quickly polish, with a consequent reduction in skid resistance, thus counteracting one of the reasons why the grinding treatment might have been originally applied. However, it might also be the case that, with the different form of texture, such polishing action might be less marked or slower to take effect.

The longitudinal flanges created by the grinding technique replace the original brushing as the primary source of macrotexture. There are two issues here: what influence the different texture form has on friction performance at higher speeds and whether the flanges could harbour residual weaknesses which could mean that they break off under traffic, reducing macrotexture, with a potential deterioration in whatever frictional performance is originally achieved.

A further issue that arises from the different texture form relates to the suitability of current techniques for the assessment of surface texture. The volumetric (patch) method is vulnerable to the influence of a relatively small number of peaks within the area of the patch and might therefore overestimate the effective texture depth where a few high-spots caused by one or two flanges have an undue influence on the measurement. Laser displacement techniques (such as that used by TRACS or fitted to some SCRIMs) rely on measuring a sequence of points in the longitudinal direction to establish a profile from which the texture depth parameter is calculated. The directional nature of the profile generated by the grinding process could make this meaningless, since the laser spot might follow along the bottom of a groove for significant distances and fail to sample the overall profile.

It was to investigate the potential effect of these unknown influences on the skid resistance and texture of concrete carriageways that the programmes of friction testing on the trial sites and a laboratory accelerated wear assessment were carried out. The laboratory study also allowed a limited comparison of texture measurement techniques to be made.

3 Monitoring of trial sites

To assess the changes in skid resistance properties of longitudinally diamond ground concrete surfaces, a study programme was set up to monitor two diamond ground trial sites using a number of different measurement techniques. At the time of writing this interim report, monitoring is continuing, with the most recent data on one site recorded some 16 months after initial treatment.

3.1 Test equipment

3.1.1 SCRIM

SCRIM is the standard device for monitoring the skid resistance condition of the UK trunk road network and is also used by many local authorities (Figure 3-1). Measurements from this device provide data that can be used to compare the performance of the surfacings with the skidding standards for the sites concerned.

Figure 3-1 SCRIM testing a section of the TRL test track

SCRIM uses an instrumented test wheel angled at 20^{o} to the direction of travel, generating a relative slip ratio. Therefore, the effective speed at which the tyre contact patch moves over the surface (the slip speed) is 17km/h at the normal operating speed of 50km/h. The vertical and horizontal loads acting on the test wheel are recorded, analysed using an on-board system and reported as a SCRIM Reading. On high-speed dual carriageways (which includes the trial sties for this study), for safety reasons a target speed of 80 km/h is used and a correction factor is applied to the results to give values equivalent to measurements made at the standard speed of 50km/h. After some other adjustments, the processed values are known as “SCRIM Coefficient” (SC).

3.1.2 GripTester

GripTester is a small trailer used by many local authorities for measuring wet low speed skid resistance (Figure 3-2). Like SCRIM, this device operates under the fixed slip principle, but in this case the test wheel is in-line with the direction of travel. The test wheel is mechanically linked via a chain and sprocket to two ‘drive wheels’, geared so that the test wheel is forced to rotate at a speed slower than that of the drive wheels, thereby generating slip between the test tyre and pavement. Water is applied to the road/tyre interface from a tank on the towing vehicle to provide wet skid resistance data.

Figure 3-2 GripTester

Results provided by GripTester from tests at a standard 50km/h test speed can have a conversion factor of 0.85 applied to them so they report values on a similar scale to SCRIM Coeffient. Such values are referred to in this report as Equivalent SCRIM (E.SCRIM) values. GripTester was used as part of this project to provide additional measurements of low speed wet skid resistance at times when SCRIM measurements could not be made.

3.1.3 Pavement Friction Tester

The PFT (Figure 3-3) is a friction testing device, used as a standard measurement technique in the USA. The PFT is owned by the Highways Agency and operated on its behalf by TRL.

Figure 3-3 Pavement Friction Tester

During a test, the towing vehicle maintains a constant test speed while the trailer mounted test wheel is forced to lock, the lock is then held for a short interval before being released. Whilst testing, the load and drag forces on the test wheel are measured every 0.01 seconds throughout the braking cycle. This produces a result that usually follows the form shown in Figure 3-4.

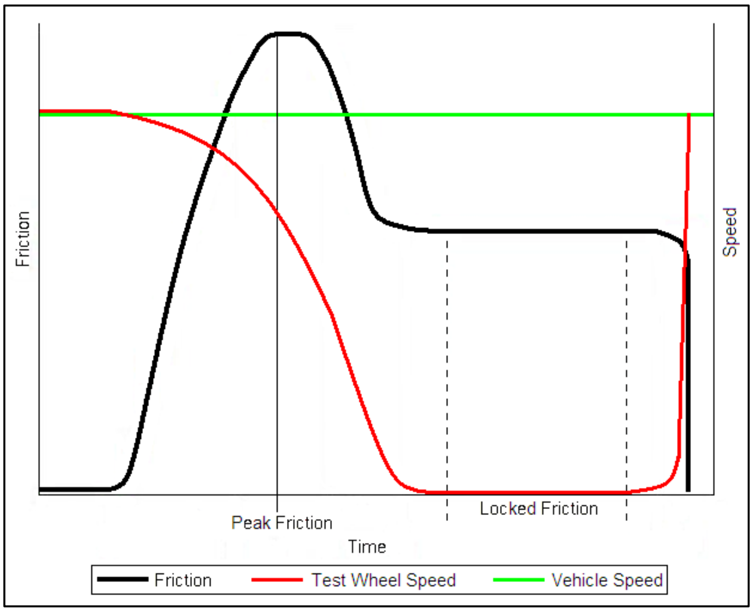

Figure 3-4 Idealised graph of an average wet PFT skid test

The test results are reported as values of peak friction[2] and average locked wheel friction[3].

Measurements can be made up to speeds of approximately 120km/h using a number of test configurations, depending on the testing being undertaken. For the purpose of this study, the tests were conducted using a water film thickness of 1mm and a standard, smooth ASTM tyre.

[2] The maximum friction value reached as the tyre begins to slip (smoothed using a 5 point moving average to reduce spikes in the data)

[3] The average friction value recorded over a period of 1 second, beginning 0.5 seconds after the wheel has locked

3.2 Measurements

3.2.1 A12 trial site

The A12 trial site is a 2-lane dual carriageway between the Boreham and Sandon interchanges. A 500m length within this section was treated with a longitudinal diamond grinding technique during March 2009, on both lanes and in both directions. Table 3-1 shows when each measurement technique was used on this site.

Table 3-1 Testing carried out on the A12

Surfacing age since grinding (months)	SCRIM	GripTester	PFT
-1		✔	
1		✔	
2		✔	
3		✔	
4		✔	
5		✔	
6		✔	
7	✔	✔	✔
16	✔		
19 (Proposed testing in Oct 2010)			✔

TRL collected skid resistance data using SCRIM and the PFT. GripTester measurements were carried out by the Area 6 Maintaining Agent and were provided to TRL as values of equivalent SCRIM Reading.

3.2.2 A14 trial site

The A14 trial site is a 2-lane dual carriageway located between Junctions 52 and 56 (Claydon - Wherstead). A diamond grinding technique similar to that applied to the A12 was applied to both lanes, in both directions between Junctions 53 and 55 (Whitehouse - Copdock) (aprox. 6km).

Due to issues regarding traffic management it was not possible to operate the PFT on this site. SCRIM measurements were therefore made five months after the treatment was applied.

3.3 Results of skid resistance tests

3.3.1 Low speed skid resistance

Figure 3-5 and Figure 3-6 show data gathered from the A12. GripTester results collected at monthly intervals (reported as E.SCRIM) and SCRIM Coefficient data collected by TRL.

The ground section (shown between the vertical lines) extends from chainage 200m to 700m and is flanked by untreated sections.

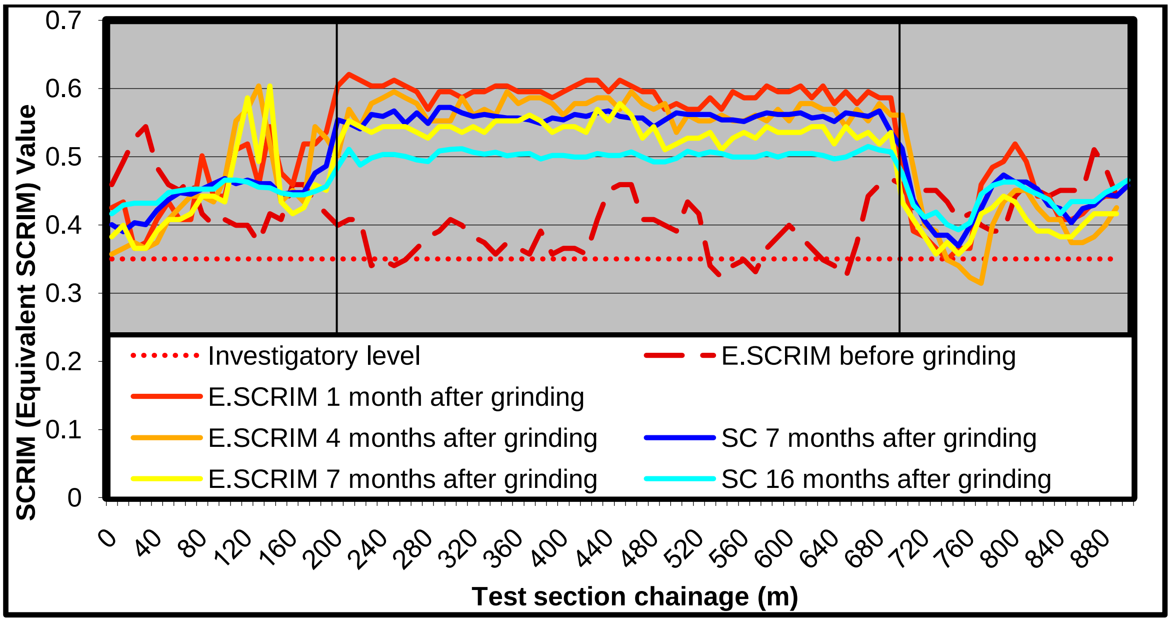

Figure 3-5 Northbound A12 SCRIM and E.SCRIM

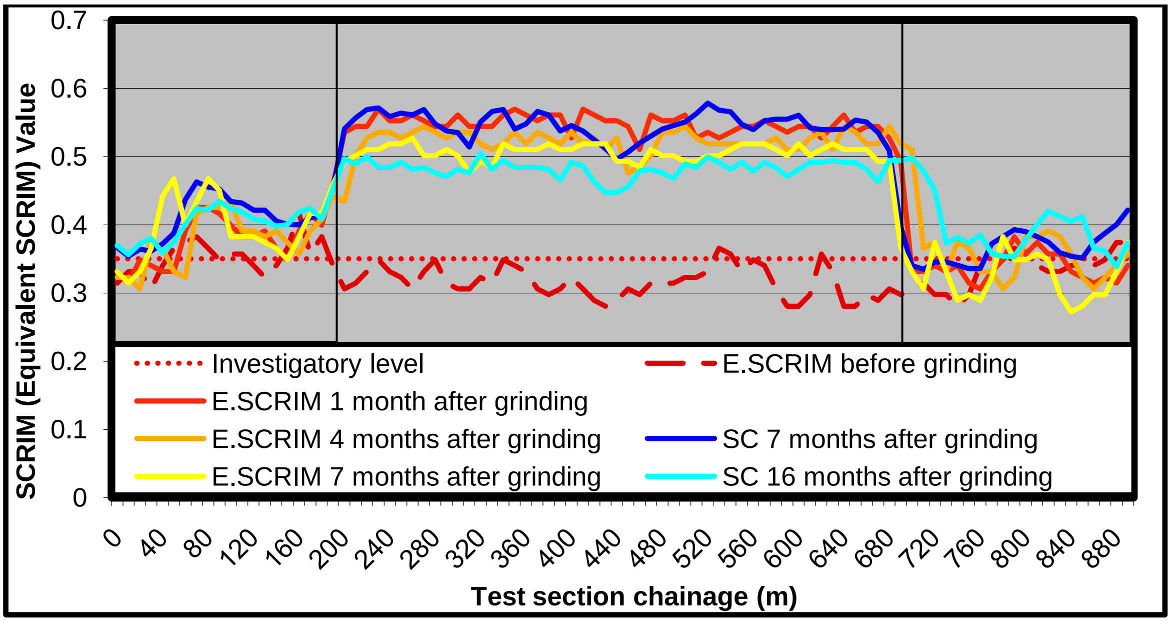

Figure 3-6 Southbound A12 SCRIM and E.SCRIM

Figure 3-5 and Figure 3-6 show that before the grinding treatment was applied, skid resistance values were close to the Investigatory Level (IL) in the northbound direction, and consistently below the IL in the southbound direction. A marked improvement in skid resistance is shown after the grinding treatment was applied, whereas skid resistance levels on the untreated sections remain relatively low. These results are consistent with the SCRIM results gathered from the A14 shown in Table 3-2.

Table 3-2 SCRIM results gathered from the A14, 5 months after grinding

Direction	Ground / unground	Average SC
EB	Ground	0.50
WB	Ground	0.50
EB	Unground	0.37
WB	Unground	0.36

These data also show that the longitudinally ground section provided skid resistance values markedly higher than those provided by the un-ground sections. Furthermore these values are very similar to those observed on the A12.

Figure 3-5 and Figure 3-6 show a reduction in skid resistance on the ground section of the order 0.5 units after 16 months in service. The data from the un-ground section, however, show a consistency over time that indicates that this untreated area of the road is at its equilibrium skid resistance level. The reduction in skid resistance, therefore, is almost certainly evidence of the newly-exposed surface being polished by traffic.

It will therefore be important to ascertain whether the skid resistance will continue to decrease and, if so, to what extent and over what timescale.

3.3.2 Changes in friction with speed

3.3.2.1 Locked wheel friction

Locked wheel friction results are shown in Figure 3-7 and Figure 3-8. Within this report locked wheel friction results are referred to as Fn: this is the term conventionally used in the UK for the friction coefficient (the ratio of vertical and horizontal forces experienced by the test wheel) between the pavement and test tyre as measured with the PFT.

These figures include bands displaying the range of typical Fn values for concrete and Hot Rolled Asphalt (HRA) surfaces. These bands were derived from data collected from a wide range of surfaces in an earlier study (Roe et al., 1998). They do not necessarily imply acceptable performance; rather, they demonstrate the friction range found on the network.

Figure 3-7 and Figure 3-8 show that the diamond grinding resulted in an improvement in friction over the whole speed range, with the greatest improvement occurring at the slower speeds. There is some scatter in the data, particularly on the control sections, but the improvement is typically between 0.1 and 0.15 units in the medium speed range (50km/h) and up to 0.1 units at higher speeds (80-100km/h).

Comparing the values with the ranges previously observed, it can be seen that the levels of friction on the untreated sections are generally towards or at the bottom of the historic range for concrete roads. The grinding appears to have increased the overall friction a level near the middle of the concrete range or the bottom of the HRA range.

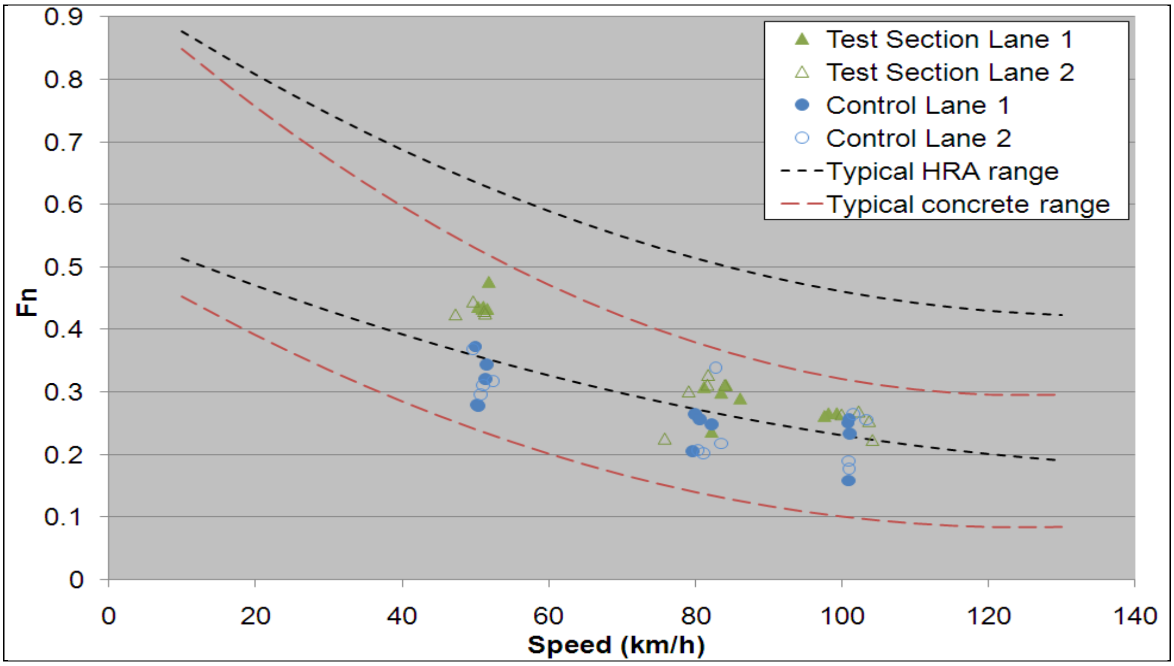

Figure 3-7 Locked-wheel friction northbound after 7 months

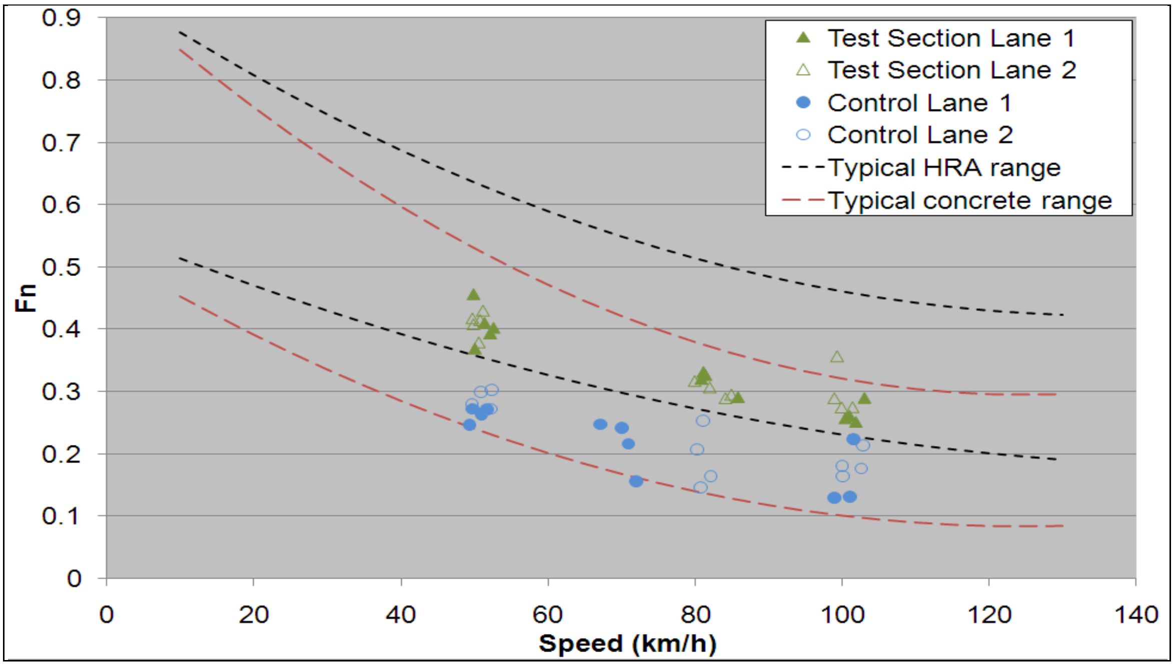

Figure 3-8 Locked-wheel friction southbound after 7 months

3.3.2.2 Peak friction

Peak friction results are reported in Figure 3-9 and Figure 3-10, showing the Fn values on the northbound and southbound carriageways respectively, for the individual skids at each target speed. Trend lines based on the data from the two lanes combined have also been included.

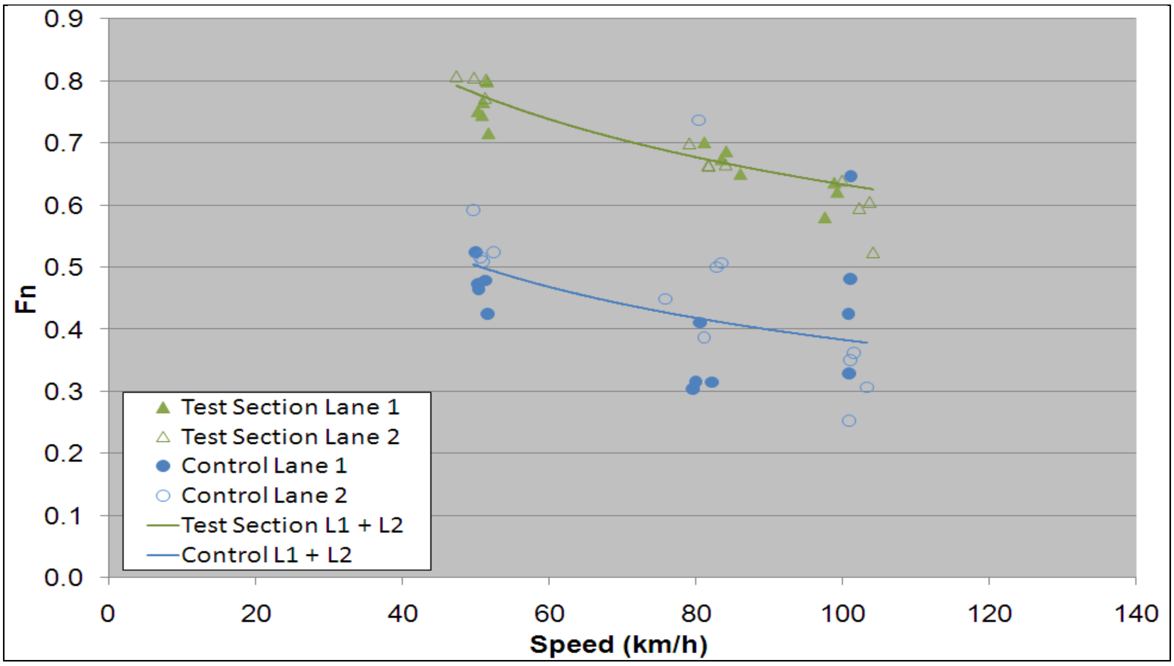

Figure 3-9 Peak friction northbound after 7 months

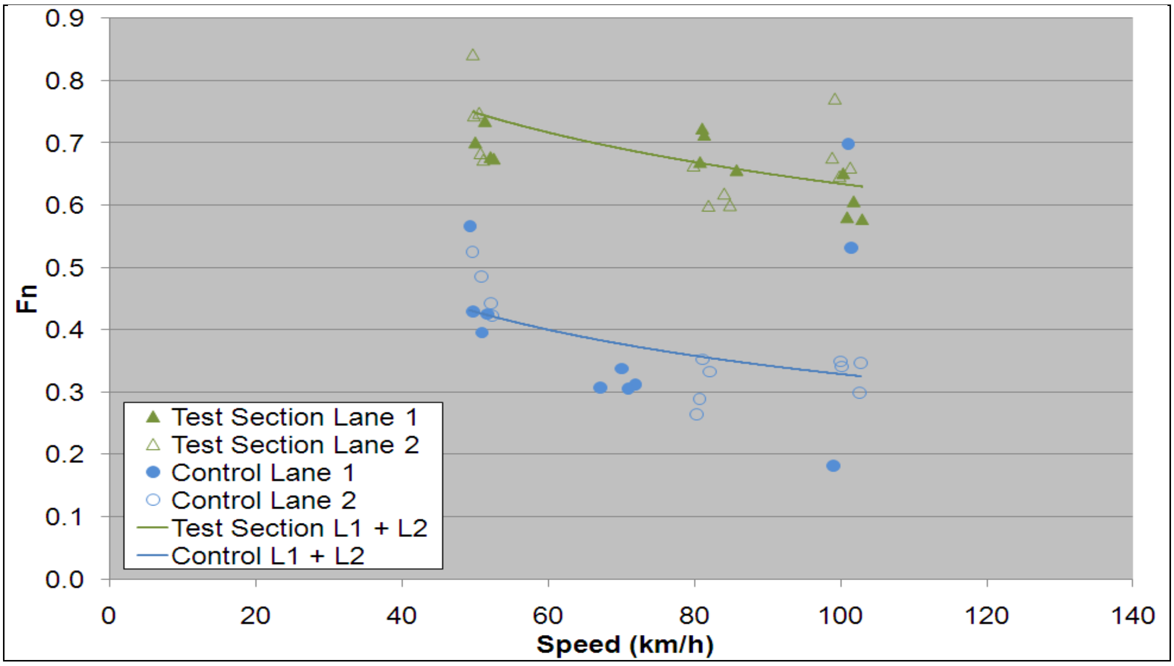

Figure 3-10 Peak friction southbound after 7 months

Figure 3-9 and Figure 3-10 both show that peak Fn levels on the treated sections are much greater than those on the control lengths: Figure 3-9 shows an increase in friction of the order 0.2 units whereas Figure 3-10 shows a greater increase, of the order 0.3 units.

Comparing the values in these two graphs with those in Figure 3-7 and Figure 3-8, it can be seen that, as expected, the peak Fn levels are relatively greater than the locked-wheel values on both the test and the control sections but on the treated lengths the actual difference between locked-wheel and peak Fn is relatively greater than on the untreated. On the ground sections, the relative difference between peak Fn and locked Fn is of the order of 50% of the peak value across the speed range. However, on the un-ground surface the equivalent value is of the order of 30%, which is fairly typical of older surfacings found in previous studies.

In considering possible reasons why the peak friction data show relatively greater improvement at all speeds as a result of diamond grinding, it is of interest to observe that in making the measurements on the newly-ground surface there was noticeable damage to the surface of the tyre (Figure 3-11).

Figure 3-11 – Photograph of the PFT test tyre after testing.

While tyres used for locked-wheel testing generally suffer some deterioration, the extent of damage observed here during normal wet tests is unusual. It appears that the sharp fins and ridges created by the grinding process (Figure 2-2) have cut into the surface of the test tyre, mirroring the profile of the ground pavement. A consequence of this may be that more kinetic energy than normal is converted during the "peak" phase of the skid profile; giving a higher traction force and therefore a greater peak friction than would normally be observed.

The data show that there is a necessity to continually monitor this site for any changes in peak and locked-wheel friction. Repeat testing using the PFT is planned for the Autumn of 2010. The data gathered from this visit will be provided as part of a full report.

4 Laboratory testing

4.1 Scope of the programme

A short programme was devised to simulate and accelerate the effects of trafficking in the laboratory. Cores were taken from the A14 trial site to provide examples of both the diamond-ground surfaces for use in this work, which was intended to assess:

- Any textural changes with time.
- The ability of the residual fins and ridges formed in the concrete to withstand the effects of trafficking.
- The suitability of current texture measurement techniques for use on longitudinally diamond ground surfaces.

Six cores were taken: four (numbered 1 to 4) were initially removed to represent the un-trafficked newly-ground surface and the contractor removing the cores was asked to take examples that were broadly representative of the surface condition. Two more were removed from the same general area after one month of traffic, one from Lane 2 (core 5) and one from Lane 1 (core 6) to represent different levels of trafficking.

On closer examination, it was later noted that cores 3 and 4 had been removed from an area in which megatexture had influenced the extent to which the grinding process had cut into the concrete surface, with rather variable shallow grooving across the width of the cores being the result. Consequently, these two cores were set aside and the laboratory programme was continued using Cores 1, 2, 5 and 6 only.

As this programme of study was experimental, there was no standard methodology or device currently available that had been designed specifically for work of this type. Therefore, equipment readily available at TRL that was usually used as part of other laboratory tests involving accelerated wear or trafficking was considered. Two potential candidates were identified:

- The Small Wheel Tracker (SWT) machine, which is used to assess the durability of surface treatments such as high friction surfacings.
- The Wehner-Schulze (WS) machine, which is used to assess the polishing of aggregate and asphalt samples under traffic.

A pilot study was carried out to investigate whether either device was suitable for the work in mind in which the un-trafficked cores 1 and 2 were used, one in each device, and subjected to five standard treatment periods. It was soon found that the SWT, which has a severe scuffing action to simulate the effects of braking traffic in high-stress locations, was not suitable. The grooves and ridges in the core caused excessive damage to the test tyre (rather as had been observed in the PFT tests) and the scuffing action had no discernable influence on the texture of the core, so this technique was not pursued and core 2 was held in reserve. The WS machine, however, in spite of its limitations (see below) showed promise and it was decided to continue the programme using this equipment.

The programme of work (described in more detail in the following sections) has comprised subjecting the three cores with different initial trafficking levels to various degrees of polishing and measuring any changes in texture that could be observed. Cores 5 and 6, with their levels of traffic in the road would be compared with the progressive effects of polishing the initially un-trafficked core 1.

This programme is continuing at the time of writing. The techniques being used and some preliminary results are described in the following sections; a fuller analysis will be included in the final report in due course.

4.2 Traffic simulation using the Wehner-Schulze machine

The WS machine illustrated in Figure 4-1 is a development of original devices built during the 1960s in Germany, at the Technical University of Berlin (TUB), as an alternative to the Polished Stone Value test for assessing the polishing of aggregates in road surfacings. It is usually used to assess the effect that the polishing action of traffic on samples of asphalt or aggregate has on skid resistance.

Figure 4-1 – The Wehner Schulze machine

The WS machine comprises two "stations": one for accelerated polishing of the test specimen and one for testing the friction of the polished surface. The normal procedure is carried out in two stages: a period of polishing to simulate trafficking by heavy goods vehicles is followed by a measurement of friction on the polished surface. The polishing action is generated using a rotary head with loaded rollers that rotate around a circular test specimen.

The specimen (a 225mm diameter core) is attached firmly to the mounting table so that the table and specimen surfaces are accurately parallel. During the polishing operation, an abrasive suspension is pumped onto the specimen surface to replicate the detritus on a road surface and assist in the polishing process. Three rubber-covered conical rollers are lowered into contact with the specimen; each is independently forced onto the surface at a contact pressure typical to that of a commercial vehicle. Although the rollers are free to rotate, there is some drag, giving a slight slip of 0.5 to 1.0%. Grooves are cut into the rollers to simulate tyre treads.

During a standard test, the roller head is rotated at 500 rpm for 1 hour, giving a total of 90,000 roller passes over the specimen. The polishing head and rollers can be seen raised above the left-hand side of the machine in Figure 4-1, with the abrasive tank placed to the left of the main bench.

In its standard application, the process is very similar to that which was required for this study. A potential drawback of the technique in the present context is that on the samples of diamond-ground surfaces, the rotary action polishes the test samples in directions either mainly parallel or mostly perpendicular to the grooves, whereas in normal traffic the polishing action would normally only be trafficked parallel to the grooves. However, truck tyres are known to impart a "kneading" action as well as a polishing action so for the specific purposes of this initial investigation this was not regarded as a critical problem.

It would have been possible in principle to measure friction on the concrete specimens after polishing, as would normally be done when assessing aggregates or asphalt. However, this process also involves a rotary action and it was uncertain as to how that would relate to friction as normally experienced by vehicles braking in-line with the grooves. For this reason, friction measurement has not been attempted at the time of writing; the work is concentrating on repeated use of the polishing phase of the operation of the machine only to simulate the cumulative passage of traffic.

4.3 Texture measurement

4.3.1 Texture depth using the volumetric technique

The standard technique for measuring the texture depth of new road surfaces in the UK is the volumetric patch test (defined in BS EN 13036-1: 2010). This technique consists of applying a known volume of small glass beads to a surface and spreading them so that they fill the texture of the surface in a roughly circular patch. Once the level of the beads reaches the top of the surface, multiple measurements of the diameter of the patch are made, allowing a mean diameter, and hence the patch area, to be determined. A value of Mean Texture Depth (MTD) is then calculated by dividing the known volume of beads by the patch area.

A known difficulty with this technique is that it is potentially heavily influenced by the presence of a few peaks in the surface, which was considered likely to occur in the grooved texture structure created by the grinding process. This was likely to generate an unknown level of variability in the measurements. Further, the polishing action of the WS machine was concentrated on the outer part of the cores, leaving an area at the centre of the core (which would be included in the glass-bead patch) un-trafficked. This would introduce further uncertainty into the measurements.

For these reasons, although the measurements were made as a matter of course, they have not been included in the analysis of the laboratory tests to assess the effects of traffic.

4.3.2 Texture profile using the Circular Texture Meter

This device operates by using a triangulation laser to measure the displacement from the laser source to the road surface. The laser is mounted on a rotating arm which moves in a 180mm diameter circular path[4]. During this revolution, 1024 displacement samples are taken and the CTM software converts these raw distance measurements into values of Mean Profile Depth (MPD) and Root Mean Square (RMS) following the principles set out in BS EN ISO 13473-1:2004[5]. It is also possible to obtain raw displacement data in

[4] The version of the device used by TRL has been specifically adapted by the manufacturer to be compatible with the diameter of cores used in the Wehner-Schulze test.

[5] RMS is analogous to the sensor-measured texture depth (SMTD) used by Highways Agency and other road authorities in the UK to assess texture depth on in-service roads with data from laser-based measurement systems.

the form of a comma-separated values (.csv) file for input and analysis using commercial spreadsheet software such as Microsoft Excel®.

For the purposes of this experiment, it was considered that the values for texture depth normally reported by the CTM would not be directly useable because of the directional nature of the texture profile.

Therefore, two data processing techniques were used to differentiate between the parts of the rotary texture measurement path that were essentially transverse (i.e. approximately perpendicular to the normal traffic direction) and those which were essentially longitudinal.

The procedure used to assess transverse profile was as follows:

1. Once a test had been completed the .csv output was obtained from the CTM software.
2. This was then imported into a bespoke programme that removed any sinusoidal variation due to the device not being perfectly parallel to the core sample. (This step was used to provide a data set that was capable of being viewed quickly, aiding the manual removal of obvious anomalies).
3. The data were then divided into sections, as illustrated in Figure 4-2 representing the segments of the core where the texture on the path followed by the rotating laser head was essentially transverse (nominally labelled A and F) or essentially longitudinal (G and H). The segment sizes (the first 205 points, and points >511 and <718 in the case of segments A and F respectively) were chosen based on the lengths normally used by the CTM software which, following the MPD standard, divides the profile into 100m lengths.

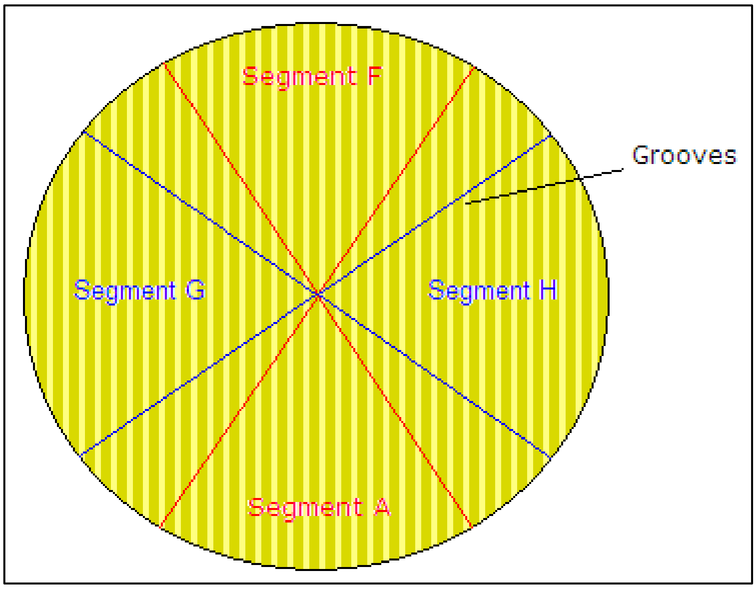

Figure 4-2 Diagram of analysed data segments

4. To review the results, the profile height along the segment length was simply plotted against the number of points data were plotted.

The typical way in which the texture profile varies depending on its orientation is clearly illustrated by the examples in Figure 4-3, for profiles perpendicular to the grooving direction, and in Figure 4-4, for profiles measured in the same general direction as the grooving. The x-axes in these two graphs represent a sequence of 200 point measurements (over approximately 100mm of swept path) and the y-axes represent a relative displacement recorded by the device rather than an absolute measure.

In Figure 4-3, the repeating pattern of the grooves is clearly evident in both segments, with some variation in groove height, probably representing the different heights of the ridges between the grooves in the path of the sensor. However, in Figure 4-4, the effect of the laser sensor sweeping around the curved path and then along the grooves can be clearly seen. At each end of the segment, the grooves appear wide as the laser spot passes across them at an angle. However, in the middle of the segment (the area bordered by the dashed lines in the Figure), the laser spot tends to follow closely the line of the grooves. In this part of the profile the spot may be passing predominantly along the relatively smooth bottom of a groove (Segment H) or passing along the top of a flanged ridge (segment G). The effect of curvature of the swept path tending to make the grooves appear wider can also be discerned, albeit less markedly, at the ends of the transverse segments in Figure 4-3.

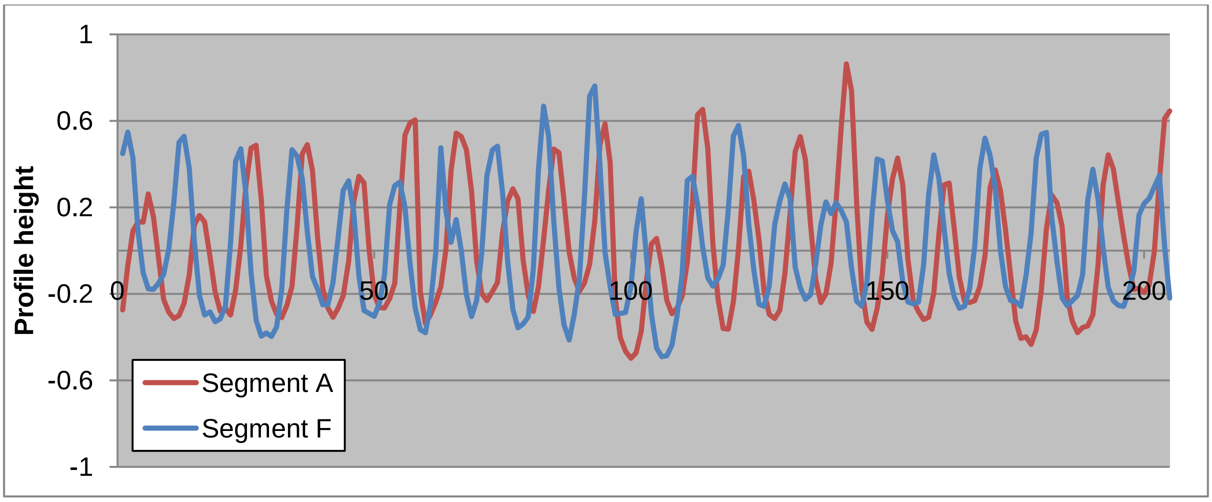

Figure 4-3 CTM data for Core 1 Cycle 11 test 3 – transverse segments

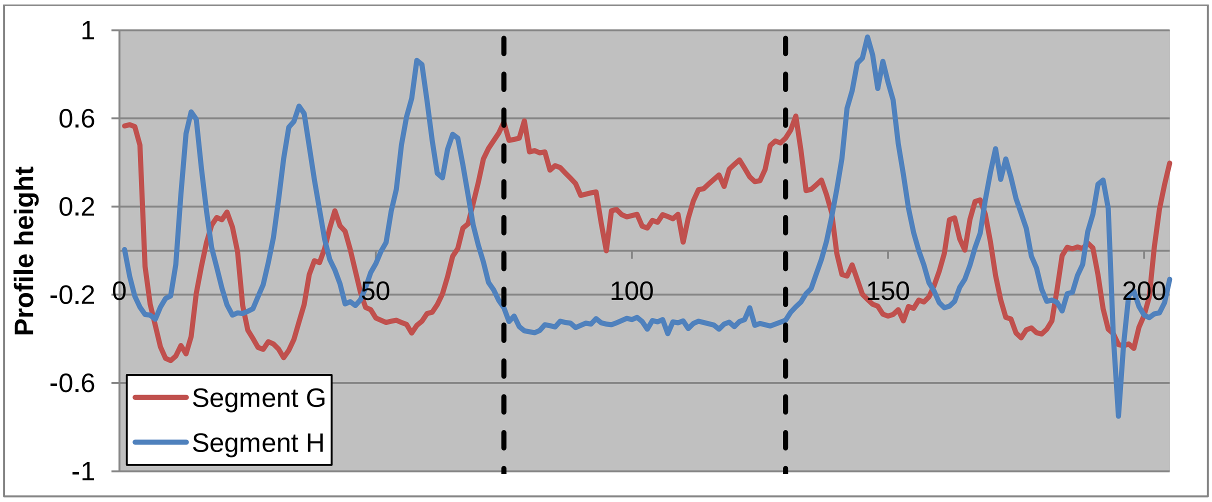

Figure 4-4 CTM data for Core 1 Cycle 11 test 3 – longitudinal segments

The patterns illustrated in these two figures represent what might be recorded using current techniques for measuring in-service texture depth with spot lasers mounted on vehicles. Figure 4-3 is analogous to measurements on transverse sawn grooving whereas Figure 4-4 is close to what would be experienced on longitudinally ground surfaces. In the latter case, the vehicle-mounted sensor will tend to follow a path along a groove, on top of a ridge or gradually drift from one to the other as the vehicle moves down the road: clearly, it will be uncertain what the resulting SMTD measurement actually represents.

For the present study, a numerical representation of the overall texture was needed, in order to make an objective comparison of the effects of simulated trafficking, but MPD or RMS values were considered inappropriate. This approach taken, therefore, was to analyse the data in accordance with BS EN ISO 4287:1998 to calculate the Mean Profile Element Height (MPEH) for the transverse segments of the texture. This parameter compares the average difference in height between the top of a ridge with the adjacent valley over the sampling length.

To sample the core, three measurement scans were made with the CTM. Between tests, the core position was adjusted slightly so that the laser passed over a different line on the core while maintaining the same orientation of the grooves. The average results from the two segments (A and F) from each of three tests were used to calculate the average MPEH for the core after each period of polishing.

4.4 Test programme

The test programme comprised a series of periods of polishing on the WS machine for each core. Each core's texture profile was assessed using the CTM after each period of cumulative polishing, as set out in Table 4-1.

Table 4-1 - Initial polishing rates for untrafficked samples

Cycle number	WS passes
1	0
2	30
3	90
4	300
5	900
6	3,000
7	9,000
8	30,000
9	90,000
10	180,000
11	270,000
12	360,000

Profile samples were taken more frequently at the beginning of the process in order to capture any sudden changes that might have occurred within this period. Polishing then continued, sampling at the standard testing period of 90,000 passes until the results reached a plateau. Within this regime, core 1 was subjected to its first 90,000 passes as part of the pilot assessment and then built up to 360,000 passes as in Table 4-1.

One possible objective of this programme included assessing how the polishing in the WS machine compared with the effects of trafficking and whether that this technique might be therefore be used to assess the likely longer-term performance of the ground surface. As the results were analysed, it became clear that to provide data for this possible use, core 1 (the originally un-trafficked core) would have to be subjected to further wear. This cores was therefore subjected to a further 360,000 passes in the WS machine, with samples taken at 90,000 pass intervals. Core 1 will also be subjected to further cumulative wearing, which will be reported as part of the final report.

4.5 Early results

The absolute mean profile element height data for each of the three cores is shown in Figure 4-5.

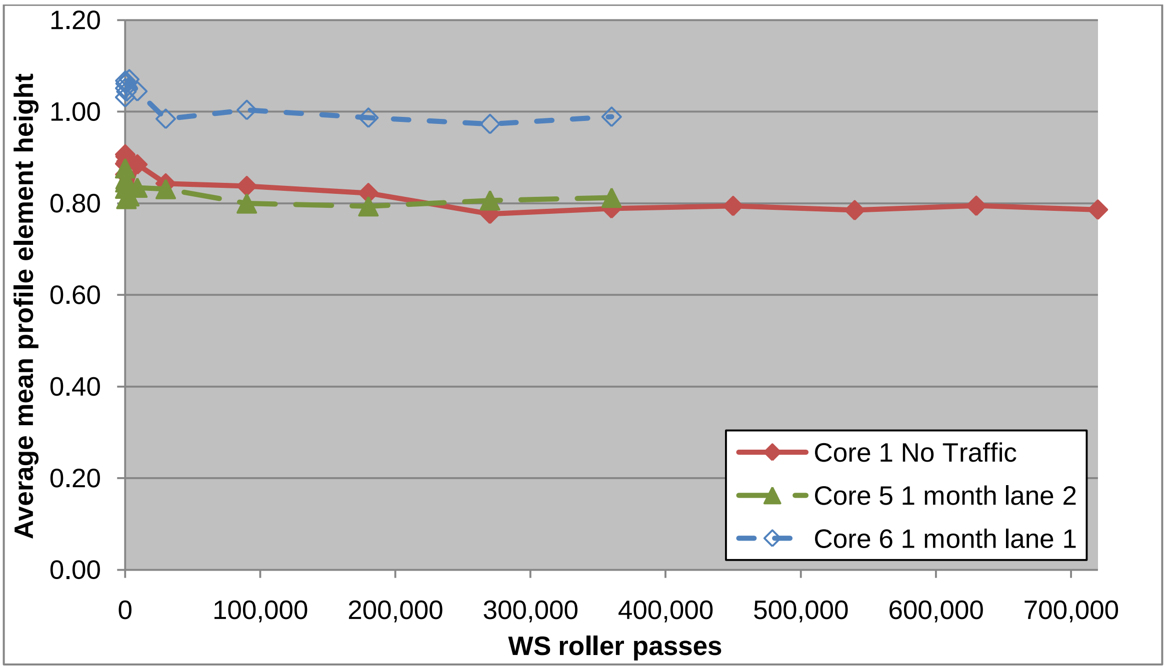

Figure 4-5 – Mean profile element height absolute values

It can be seen that there were some differences between the MPEH on three cores at the start of the testing process. Core 5 had a lower profile height than core 1, which might have been expected since it had been trafficked prior to testing. However, core 6 taken from Lane 1 would have carried even heavier traffic yet it had a greater MPEH than either of the other two cores. This may simply reflect a difference in the initial ground texture on core 6 compared with cores 1 and 5.

The tests show that there was a small reduction in the MPEH on all three cores during the early part of the testing in the WS machine. After the initial period, the average MPEH measured on core 1 reduces slowly until approximately 270,000 passes, after which the results are fairly consistent. Similarly, core 5 reduces slightly over the first 90,000 passes after which it appears to reach an equilibrium level. Despite the difference in absolute values, a similar behaviour is also shown in core 6, although the rate of change in MPEH seems to be greater, reaching equilibrium after 30,000 passes.

However, it should be noted that, for core 1 and core 5, the reduction in average MPEH is not noticeably greater than the range of initial variability. This could suggest that what is shown as a reduction and plateau in average MPEH is simply the result of a co-incidental natural variability, and that the WS machine is providing insufficient levels of wearing for these samples.

The potential deterioration of texture due to simulated trafficking will be considered further in the final report after further periods of polishing.

5 Discussion and interim conclusions

Most concrete roads in the UK were built with a brushed finish in the laitance on the surface. The sand in the mortar provided microtexture to develop low-speed skid resistance and the brushing action provided some macrotexture to limit the reduction of skid resistance at higher speeds. However, the action of heavy traffic over a long service life results in wearing away of the original laitance, reducing macrotexture to low levels and exposing the coarse aggregate which is then polished, reducing the overall microtexture. Consequently, on many older concrete roads, low-speed skid resistance performance may be lower than desired and the high-speed friction may also be low.

Longitudinal diamond grinding is a process that has been proposed as a potential treatment to restore skid resistance and improve the macrotexture of older concrete roads as an alternative to treatments such as asphalt overlays. The process completely changes the form of the surface texture. It removes the original transverse brush marks and concrete mortar, exposing the coarse aggregate across the whole of the treated area and cutting shallow longitudinal grooves separated by narrow ridges that vary in height depending on the way in which the mortar and aggregate particles fracture as the grinding drum passes over the surface. This radical change in the surface finish has a marked initial impact on the skid resistance characteristics.

As a first stage in assessing its potential for use in the UK, trials of the process have been carried out on two sites, the A12 in Essex and the A14 in Suffolk. TRL has carried out a programme of measurements of low-speed skid resistance and high-speed friction, to assess the effects of the treatment on these sites together with some laboratory studies in an attempt to assess the potential longer-term influence of trafficking.

Initial measurements of skid resistance on the trial sites have demonstrated that:

- On the surfaces treated, diamond grinding produced a marked increase in low speed skid resistance compared with the untreated surface.
- However, as might be expected, after 16 months of traffic the older of the two sites was showing signs that the surface was polishing under the influence of traffic and the skid resistance was reducing.
- On the untreated concrete surfaces, the original brushed texture had been worn away and these sections, as expected from previous studies, showed very low locked-wheel friction at higher speeds. The grinding process had a beneficial influence on high-speed friction, increasing it to a level comparable with the lower end of the range typically observed on older asphalt surfaces.

The improvements in low-speed skid resistance and high-speed locked-wheel friction observed here may have been influenced by sharp asperities in the ridges of the concrete and, particularly, in the exposed aggregate particles left after grinding. These appear to have had a strong interaction with the test tyres, scoring them in the case of some of the locked-wheel tests. However, this may be a characteristic of the flint aggregate used in the concrete at the trial sites and its reaction to the grinding action rather than a general feature of the results of the grinding process.

The high-speed friction characteristics of road surfaces are strongly linked to texture depth and previous work has shown that low levels of high-speed friction can be expected on brushed concrete with low texture depth. The improvement in high-speed friction seen so far on the ground surfaces in these trials probably results from two components: the marked increase in low-speed skid resistance due to improved microtexture and the change in texture form.

Normally, a measurement of texture depth is used as a surrogate for high-speed skid resistance, both in specifying new surfacings and in monitoring them in service. However, this approach may not be applicable for this type of surface finish for a number of reasons, for example:

- The form of texture is unusual and it is unlikely to follow the same relationship with high-speed friction as has been observed on other surfaces.
- The volumetric measurement technique can be very variable as a result of the peaks, flanges and troughs creating the texture and consequently may not characterise the texture adequately.
- Routine laser-based measurements made in the longitudinal direction may not characterise the texture adequately.

In this work, a small-scale laboratory study has used an alternative methodology to assess changes in the profile on cores taken from the trial site. Early results are suggesting that there may be a reduction in the texture depth of the ground surfaces under traffic.

The initial results from the trials are encouraging and the improvement in low-speed skid resistance is potentially of benefit in terms of reducing accident risk, especially where the initial skid resistance is at or below a CSC investigatory level of 0.40 or 0.35. However, there is already evidence that the surfaces are polishing under the influence of traffic and that skid resistance is decreasing again. Continued monitoring is needed to assess how far and how rapidly the levels will fall.

Although high-speed friction has improved as a result of the modified texture of the surface, it remains at a comparatively low level in its early months in relation to other types of surfacing after many years in service. If the texture also decreases over time, either as a result of direct wear or of fracturing of the ridges in the ground pattern (there is some evidence from the USA that this could be expected over a period of two years (Federal Highway Administration, 2007)), this might negate any benefit achieved in terms of high-speed friction. As with the low-speed skid resistance, further monitoring is required to assess this.

The present trials are on sites in which the coarse aggregate in the concrete was flint gravel, a material that naturally has low microtexture and is prone to polishing. However, if the process is to be used more widely, other coarse aggregates will be encountered and exposed, typically limestone, which may also have poor resistance to polishing. Further trials on such sites should therefore be considered.

The difficulty of measuring texture depth routinely on surfaces with a longitudinal form, and the influence that this form of texture has on high-speed friction, require further attention before appropriate specifications for the initial treatment and in-service monitoring of such services can be developed.

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