



Frictional properties of longitudinally
diamond ground concrete on the A12
Chelmsford bypass

by P D Sanders and H E Viner

CPR672

CLIENT PROJECT REPORT



CLIENT PROJECT REPORT CPR672

Frictional properties of longitudinally diamond ground concrete on the A12 Chelmsford bypass

by P D Sanders and H E Viner (TRL)

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

Copyright Transport Research Laboratory March 2010

This Client Report has been prepared for the Highways Agency It is an unpublished report prepared to assist the Client in managing the road network and should not be disseminated (electronically or otherwise) for any other purpose without the issue of a TRL PPR number.

The views expressed are those of the author(s) and not necessarily those of Highways Agency.

	Name	Date Approved
Project Manager	John Chandler	11/3/2010
Technical Referee	Peter Roe	1/3/2010

When purchased in hard copy, this publication is printed on paper that is FSC (Forestry Stewardship Council) and TCF (Totally Chlorine Free) registered.

Contents

Executive summary	ii
Abstract	1
1 Introduction	2
2 Description of the site	3
3 Measurement equipment used	4
3.1 Pavement Friction Tester	4
3.2 SCRIM	5
3.3 GripTester	6
4 Measurements carried out	6
5 Results	7
5.1 Low speed skid resistance	7
5.2 Changes in friction with speed	9
5.2.1 Locked wheel friction	9
5.2.2 Peak friction	9
6 Discussion	13
7 Conclusions and recommendations	15
Acknowledgements	15
References	16

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 surface friction characteristics of worn, but structurally sound concrete pavements. In March 2009, a 500m length of the A12 Chelmsford bypass at Boreham was treated with a longitudinal diamond grinding technique. As part of the assessment of this trial section, TRL was commissioned to carry out measurements of surface friction using the Pavement Friction Tester (PFT), a specialist friction measurement device.

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 to create the desired profile. The drum is rapidly spun over the pavement surface with pressure applied by a vertical force and while being pulled along the surface in the direction of traffic at a constant speed. The resulting surface texture consists of longitudinal grooves approximately 2-3mm wide and 3-4mm apart.

In addition to the PFT measurements, SCRIM and GripTester data have been analysed as part of this study. The data show that, seven months after treatment the diamond ground surface is providing a significant improvement in low-speed skid resistance (as measured by SCRIM) and peak friction compared with the untreated concrete surface. The level of locked wheel friction reached has improved, but not to the same extent as would be expected by applying a typical asphalt overlay; the level reached is just above the lower end of the range observed on HRA surfaces.

Results gathered from GripTester show a relatively small loss of skid resistance following treatment, as expected, as the new surface is polished by traffic. It will be essential to continue monitoring the trial section to determine whether this trend has reached equilibrium or whether a further loss is experienced. In addition, loss of texture depth with time could reduce both peak and locked wheel friction values at higher speeds.

If the current performance is maintained over time, the diamond grinding process could represent a cost-effective treatment solution to worn concrete pavements. However, the loss of microtexture and texture depth could result in the treated surface reverting to a similar or lower friction performance than the untreated section. As it is not possible to accurately quantify this risk, it is recommended that future trial treatments are confined to areas where the existing friction performance is poor.

It is recommended that the frictional properties of both the treated and untreated sections of the A12 trial continue to be monitored over time, as planned, using GripTester, SCRIM and the PFT to assess the length of time for which the improvement in friction continues. Other trial sections should, similarly, be monitored closely until the performance is better understood.

Should the diamond grinding technique become widely adopted, it will be necessary to review the approach to measuring texture depth in routine TRACS surveys, since the longitudinal measurements currently used may not adequately characterise the longitudinally texture surface.

Abstract

TRL have carried out surface friction measurements on a section of the A12 Chelmsford bypass between the Boreham and Sandon interchanges. A 500m length of the site had been treated with a longitudinal diamond grinding technique used to restore surface texture and skid resistance. Measurements of locked wheel friction were made over a range of speeds on treated and un-treated surfaces, seven months after the grinding process. TRL have also analysed the low speed skid resistance results that were taken before and at one month intervals after the grinding process was applied. This report presents the results of the measurements and discusses their implications.

1 Introduction

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 worn, but structurally sound concrete pavements. In March 2009, a 500m length of the A12 Chelmsford bypass at Boreham was treated with a longitudinal diamond grinding technique. As part of the assessment of this trial section, TRL was commissioned to carry out measurements of surface friction using the Pavement Friction Tester (PFT), a specialist friction measurement device. This programme of study was designed to assess the frictional properties of the diamond ground surface.

The two main properties of the surface that influence the wet friction performance are the microtexture and texture depth (macrotexture). On a concrete surface, these are normally provided by the sand present in the laitance (providing microtexture) and the transverse brush marks (providing macrotexture). The action of heavy traffic removes much of the laitance over time and reduces the texture depth within the wheel paths exposing the coarse aggregate. This leads to poor frictional properties and the requirement for a surface treatment to restore them. The diamond grinding process is intended to compensate for this by providing macrotexture.

However in doing so removes the remaining laitance and exposes the remainder of the bulk material, which would usually consist of relatively low PSV (Polished Stone Value) stone such as flint and limestone. The nature of the macrotexture after grinding is unlike other materials in the UK, and it was not known how this would influence the friction performance at higher speeds. Therefore, while the diamond grinding technique potentially offers an effective treatment for worn concrete pavements, it requires close monitoring of the friction performance to ensure that it provides adequate surface friction, and that this is maintained when exposed to heavy traffic.

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 laser moving longitudinally over the surface. If the diamond ground surfaces prove satisfactory, it will be necessary to establish whether the texture can be measured satisfactorily by current methods, or whether a different approach will be needed. This is not within the scope of the current work, however.

Within this project, TRL have carried out friction testing on the A12 using the PFT and SCRIM. In addition, regular GripTester measurements have been carried out by the Area 6 Maintaining Agent, and these have been reviewed within this report. This interim report details the frictional data gathered up to October 2009 and discusses the implications for road surface properties and the future research programme. Further PFT and SCRIM measurements are planned in 2010 and this report will be updated with these results once available.

2 Description of the site

The trial site is located on a section of the A12 between the Boreham and Sandon interchanges. The road over this length is a 2-lane dual carriageway. A 500m section was treated during March 2009 using the diamond grinding technique, on both lanes and in both north and southbound directions.

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 to create the desired profile. The drum is rapidly spun over the pavement surface with pressure applied by a vertical force and while being pulled along the surface at a constant speed in the direction of traffic. The resulting surface texture consists of longitudinal grooves approximately 2-3mm wide and 3-4mm apart. Figure 2-1 gives an example of the surface finish that was achieved on the A12.



Figure 2-1 Surface finished achieved with diamond grinding technique

Figure 2-1 shows an untreated length of concrete surface on the left 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 flanges (highlighted by the red arrows). These flanges could contribute to the frictional performance of the surface; however they could also be removed by the process of trafficking.

3 Measurement equipment used

3.1 Pavement Friction Tester

The PFT (Figure 3-1) is a locked wheel road surface friction testing device owned by the Highways Agency and operated on its behalf by TRL. The PFT can be used in a number of configurations for testing surfaces under wet or dry conditions or testing differing tyres. For the purpose of this study tests were conducted with a water film thickness of 1mm and a standard, smooth ASTM tyre.



Figure 3-1 - Pavement Friction Tester

During a test, the vehicle maintains a constant test speed while the test wheel is forced to lock, the lock is then held for a short interval before being released. This device can measure skidding resistance at any practical speed up to approximately 120km/h. Whilst testing, the load and drag forces on the tyre are measured every 0.01 seconds throughout the braking cycle. This produces a graph that usually follows the form shown in Figure 3-2.



Figure 3-2 - Idealised graph of an average wet PFT skid test

The test results are reported as values of peak friction¹ and average locked wheel friction².

3.2 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 3-3). Measurements from this device provide data that can be used to compare surfacings with the skidding standards for the sites concerned. SCRIM was used in this study to record low-speed wet skidding resistance.



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

SCRIM is configured and operates according to DD CEN/TS 15901-6:2009 and BS 7941-1:2006. This document states that the test wheel should be angled at 20° to the direction of travel, 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. In some situations (such as testing high speed carriageways such as motorways) this is not practical, as was the case when testing as part of this study. In this case, testing is undertaken at 80km/h, and the correction factor shown in Equation 3-1 applied to the results so they become representative of measurements taken at 50km/h (HD28/04 - Skid resistance (DMRB 7.3.1)).

$$SC_{(50)} = SC_{(s)} + (s \times 2.18 \times 10^3 - 0.109)$$

Where:

$SC_{(50)}$ is the SC corrected to 50km/h

$SC_{(s)}$ is the sc measured at test speed, s

Equation 3-1 – SCRIM speed correction factor

¹ The maximum friction value reached as the tyre begins to slip (smoothed using a 5 point moving average to reduce spikes in the data)

² The average friction value recorded over a period of 1 second, beginning 0.5 seconds after the wheel has locked

3.3 GripTester

GripTester is a small trailer used by many local authorities for measuring wet low speed skid resistance (Figure 3-4). This device operates under the fixed slip principle, with the test wheel of the GT mechanically linked via a chain and sprocket to two 'drive wheels'. The gearing ratio of this system is such 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 the road.



Figure 3-4 – GripTester

4 Measurements carried out

TRL collected friction data using the PFT and SCRIM in both directions of travel and on both treated and un-treated surfaces.

PFT measurements of peak and locked wheel friction were carried out on 28 October 2009, approximately 7 months after grinding was carried out. Tests were carried out at a range of different vehicle speeds, from 50 to 100km/h with a police rolling block to provide traffic management (normal procedure for PFT testing). However, low speed PFT testing was not undertaken in this case owing to concerns about the high speed of some of the A12 traffic.

SCRIM was used to gather low speed skid resistance data at the same time as the PFT testing. In addition, Characteristic SCRIM Coefficient (CSC) data for the 2008 and 2009 standard summer testing periods were extracted from the Highways Agency Pavement Management System (HAPMS). CSC data have generally been corrected for seasonal effects on skid resistance. However, as no seasonal correction is currently applied to concrete surfaces, the values extracted in this case will be as recorded, with no adjustment. The 2008 and 2009 CSC data give before and after measurements for the test section.

GripTester measurements were carried out by the Area 6 Maintaining Agent and were provided to TRL as values of equivalent SCRIM Reading (E.SCRIM), by applying a conversion factor of 0.85 (Frankland, 2004). Measurements were made before the diamond grinding was carried out and then at one a month intervals after treatment. This enabled a direct before and after comparison to be made as well as monitoring the continual effects of the treatment.

5 Results

5.1 Low speed skid resistance

Figure 5-1 and Figure 5-2 show GripTester results collected at monthly intervals (reported as E.SCRIM), SCRIM data collected from the HAPMS database (reported as CSC) and SCRIM data collected by TRL (SFC). The trial section extends from 200m to 700m in the charts and can be compared with the untreated sections either side, shown in shadow.

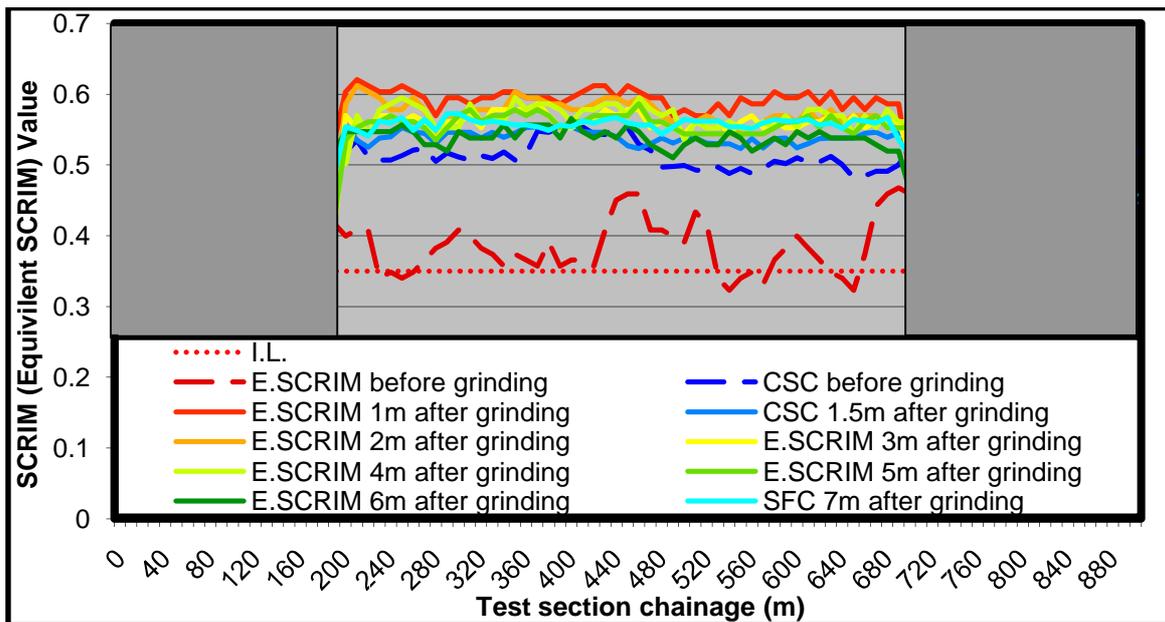


Figure 5-1 – Northbound SCRIM and E.SCRIM

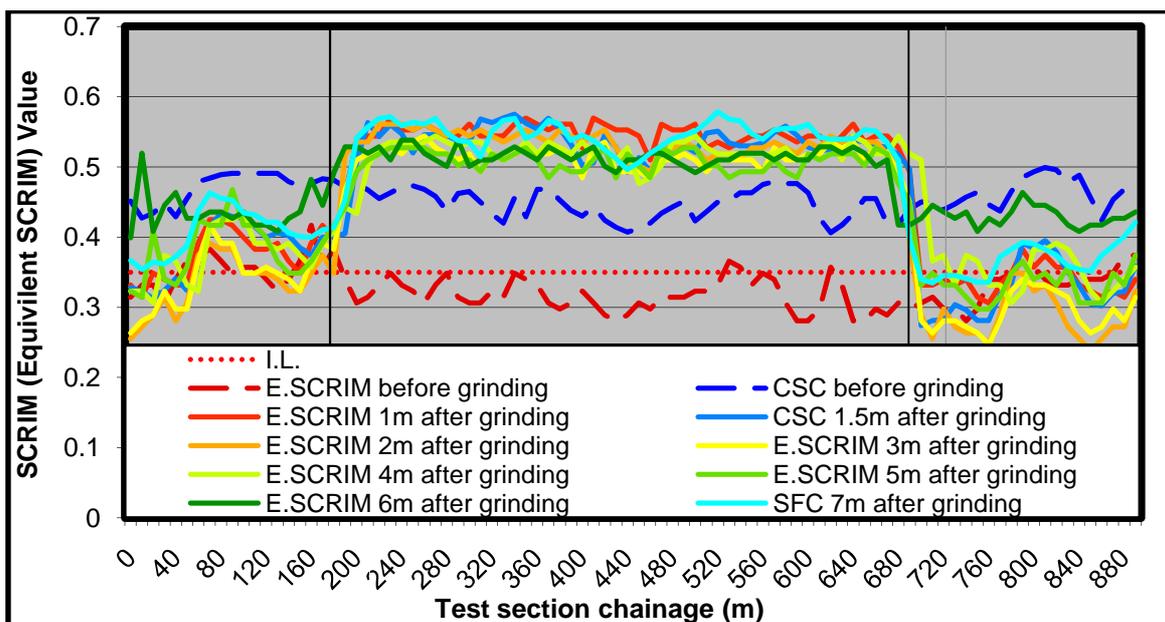


Figure 5-2 – Southbound SCRIM and E.SCRIM

Before the grinding treatment was undertaken, Figure 5-1 and Figure 5-2 show GripTester results equivalent to a SCRIM value close to the Investigatory Level (IL) in the northbound direction, and consistently below the Investigatory Level in the southbound direction. The CSC values reported from the routine SCRIM survey in the summer test season before treatment were much higher than the grip tester results, remaining clearly above the IL.

Normally the summer result would be expected to be lower than an out-of-season result, particularly from a measurement in early spring, which is understood to be when the GripTester measurements were made before grinding. However, the SCRIM CSC values will not have been corrected for seasonal variation and so could have been influenced by local seasonal factors at the time of the survey. It should also be noted that conversion between GripTester and SCRIM data is not exact and has not been calibrated on these surfaces, which is another possible source of the differences observed.

Both SCRIM and GripTester show an improvement in skid resistance on the treated section, whereas friction levels on the untreated sections remain relatively low. Although the CSC before treatment was higher than the skid resistance measured with GripTester before treatment, the SCRIM and GripTester results are fairly consistent after treatment. Figure 5-3 shows the changes in average GripTester results for the grooved section with time.

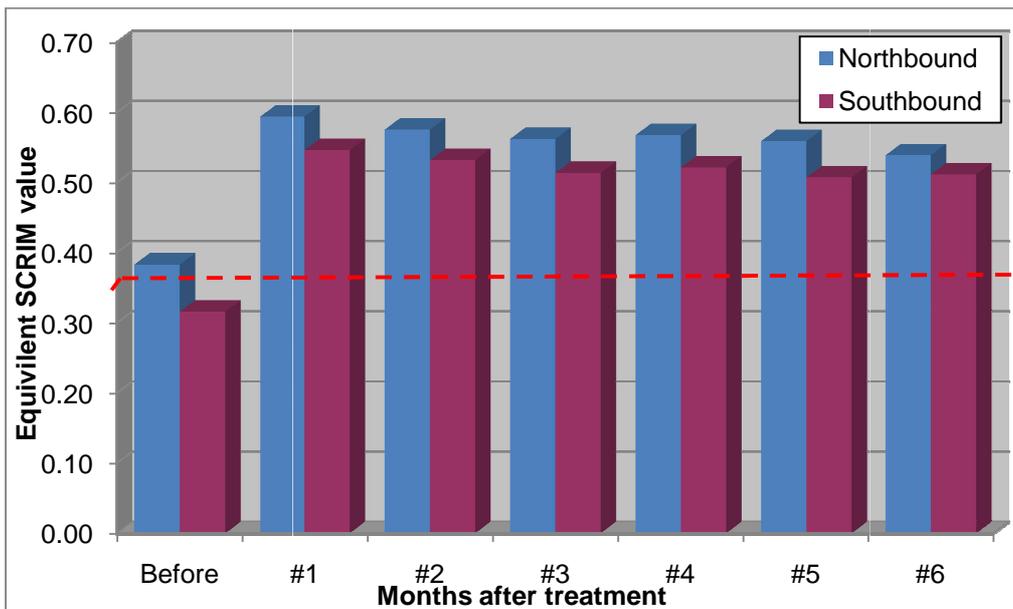


Figure 5-3 – E.SCRIM values for the grooved test section.

This shows that after the grinding treatment was applied there was a marked improvement in friction levels on both carriageways. This improvement appears to decrease by a small amount over the first three months.

5.2 Changes in friction with speed

5.2.1 Locked wheel friction

The locked wheel friction results gathered using the PFT are shown in Figure 5-4 and Figure 5-5. Within this report locked wheel friction results are referred to as F_n which is the friction coefficient of the surface (the ratio of vertical and horizontal). Both graphs include the range of friction values that have been recorded on other surfaces, for comparison. These bands were derived from the data collected from a wide range of surfaces in an earlier study (Roe et al., 1998) and do not necessarily imply acceptable performance; they rather demonstrate the friction range found on the network. While the range shown here is for HRA, a similar spread has subsequently been found for other asphalt surfaces, including proprietary thin wearing course materials.

Figure 5-4 and Figure 5-5 show that the diamond grinding has resulted in an improvement in friction at all test speeds from the low values recorded on the untreated section. There is some scatter in the data, particularly in the control sections, but the improvement is typically between approximately 0.1 and 0.15 units in the medium speed range (50km/h) whereas the improvement at higher speeds (80-100km/h) is smaller, up to 0.1 units.

The overall level of friction after treatment is comparable with the bottom of the HRA range and the mid to lower levels of the concrete range indicated in the figures.

5.2.2 Peak friction

The peak friction results gathered using the PFT are reported in Figure 5-6 and Figure 5-7.

Figure 5-6 shows an increase in friction of approximately 0.22 units at medium speeds and an increase of approximately 0.20 at higher speeds. Figure 5-7 shows a greater increase in friction than was observed in the data from the northbound carriageway, with an increase of approximately 0.3 units between the treated and untreated sections.

The peak friction data demonstrate a greater degree of improvement than the locked wheel friction data, at all test speeds, as a result of diamond grinding. It is possible that this is related to the surface cutting into the test tyre, which was observed in this case.

Figure 5-8 shows the condition of the test tyre after testing. While tyres used for locked wheel testing generally suffer some deterioration, the extent of damage observed here is unusual. This damage is most likely caused by the sharp edges and ridges that result from the grinding process (Figure 2-1). It appears that these surface ridges and flanges scored the surface of the test tyre in a way that mirrors the profile of the ground section of pavement. A consequence of this process may be that more work than normal is being done during the "peak" phase of the skid profile, giving a higher reaction force and therefore a greater peak friction than would normally be observed on a surface of this type.

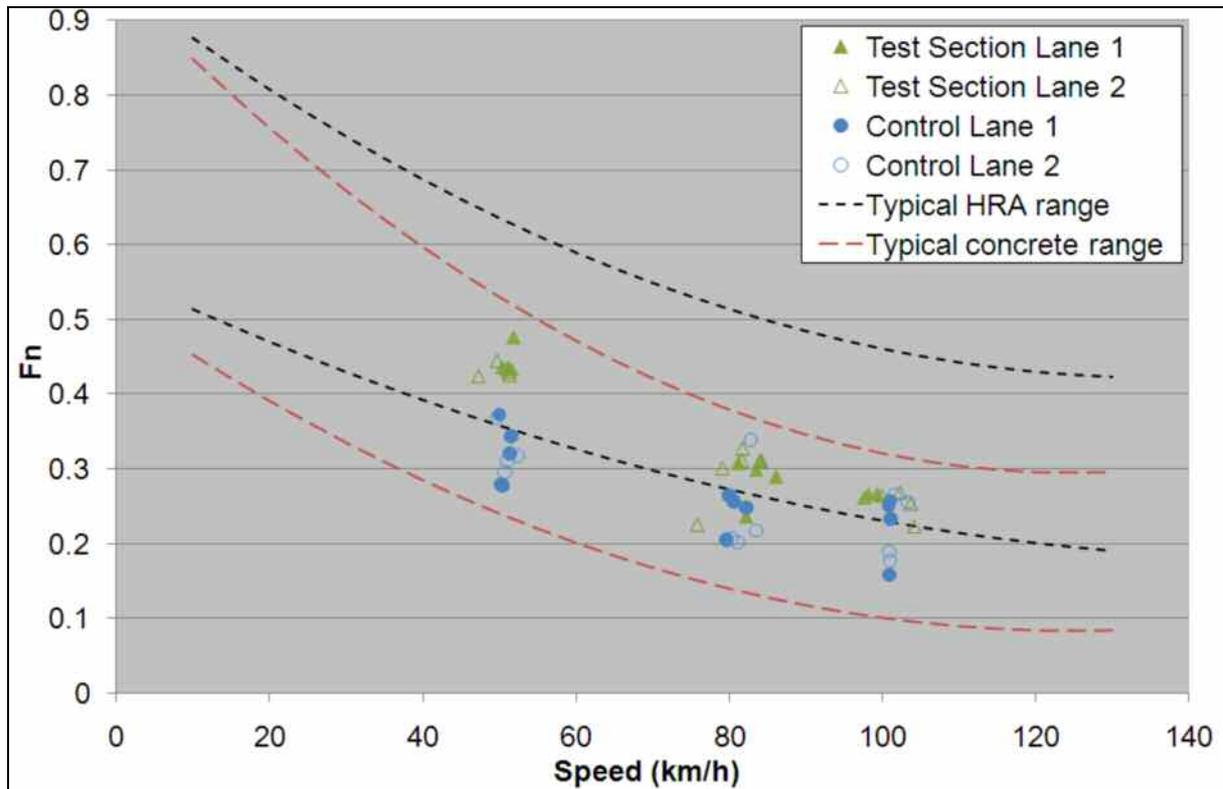


Figure 5-4 – Locked friction northbound after 7 months

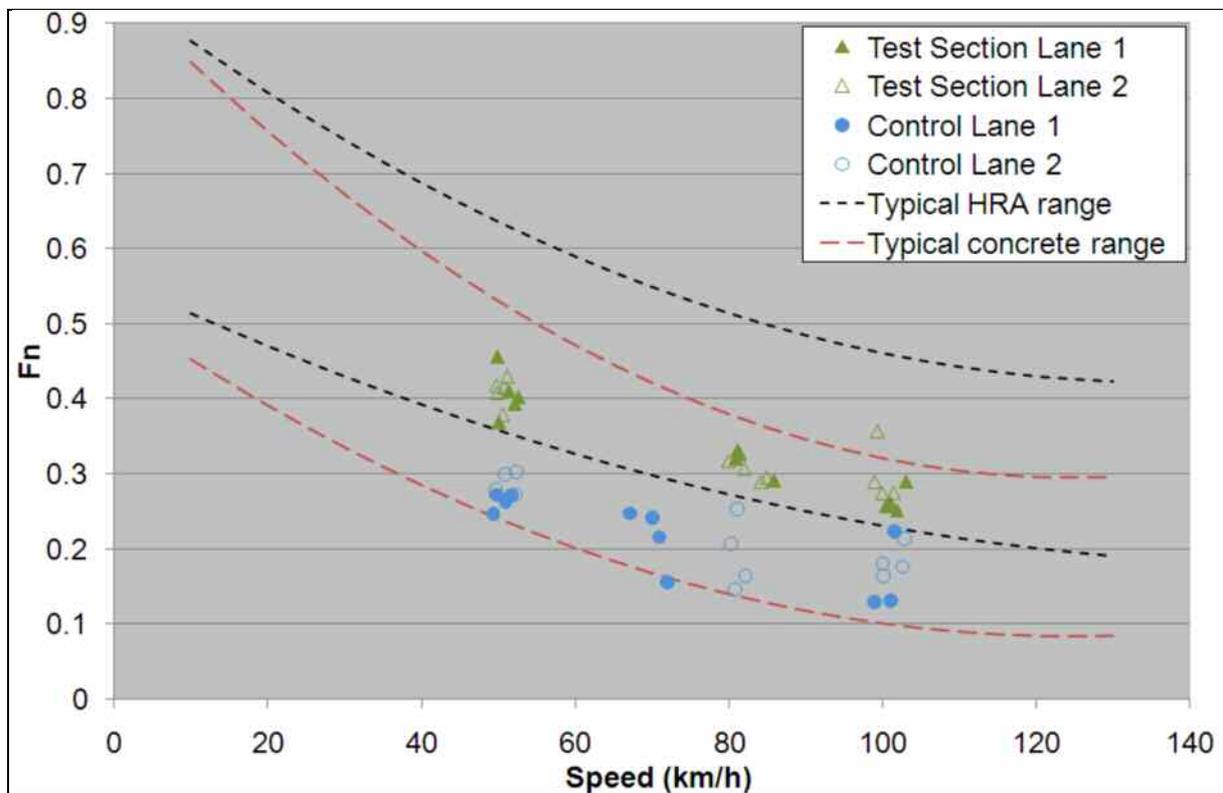


Figure 5-5 – Locked friction southbound after 7 months

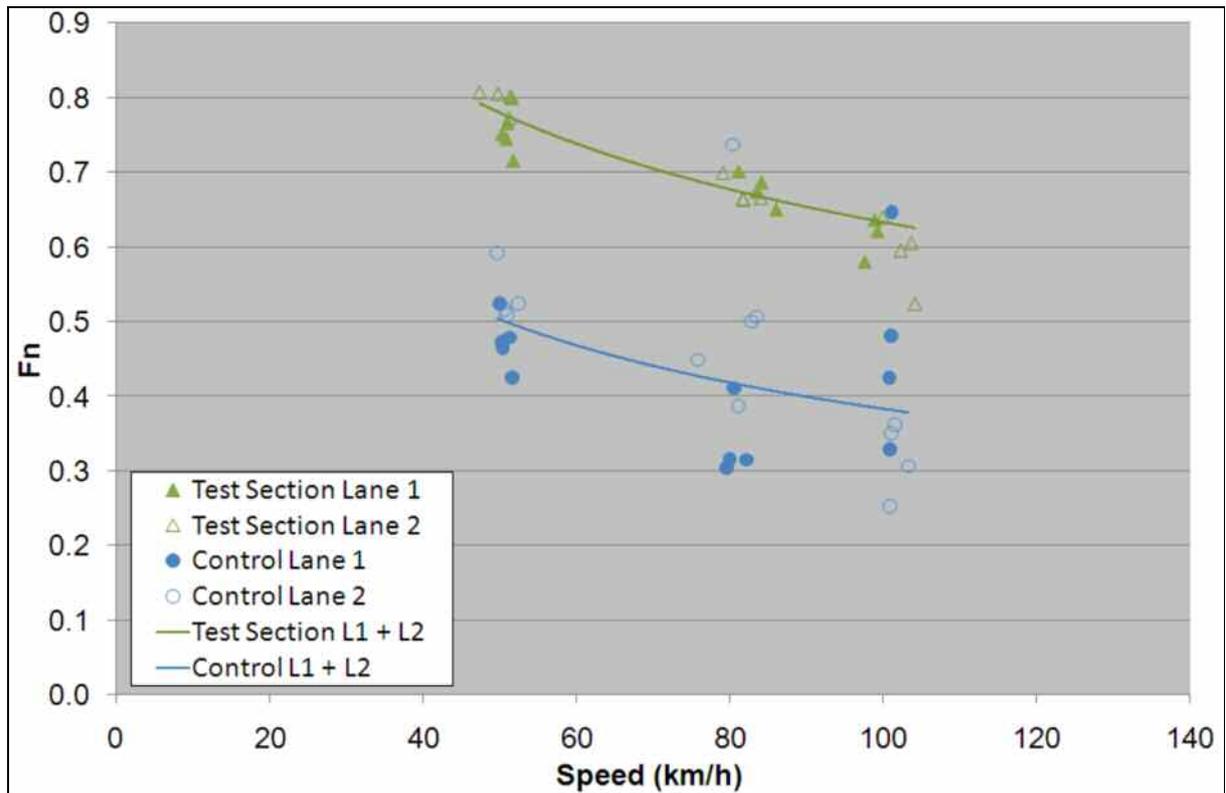


Figure 5-6 - Peak friction northbound after 7 months

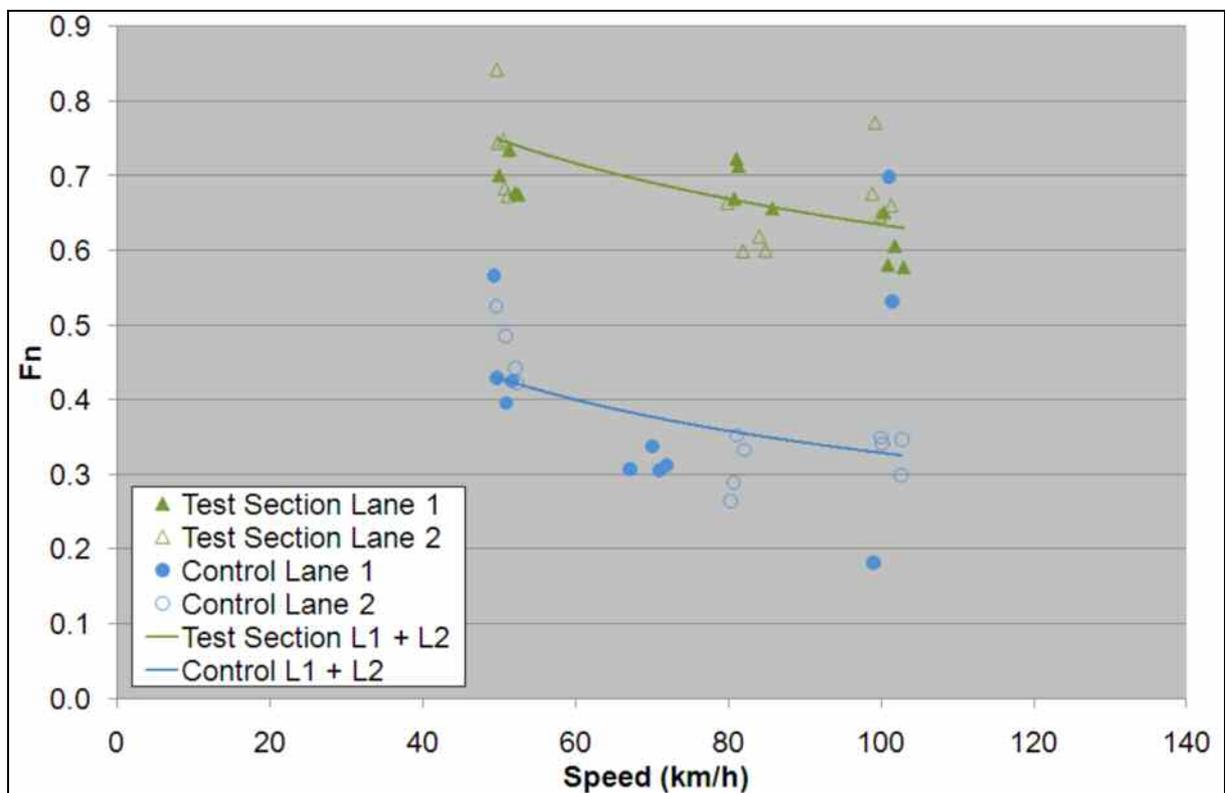


Figure 5-7 - Peak friction southbound after 7 months



Figure 5-8 – Photograph of the PFT test tyre after testing.

6 Discussion

The SCRIM and GripTester data recorded on the trial section prior to diamond grinding are somewhat inconsistent, the GripTester data collected soon before the treatment suggesting a lower value than was measured by the routine survey during the previous summer. The value from the routine survey indicated that the existing surface appeared to be providing skid resistance well above the Investigatory Level. However, there are a number of possible reasons for the difference, which are noted in section 5.1.

In any case, both devices suggest a significant improvement in low speed skid resistance as a result of the treatment. After 6 months, the improvement remains significant although it has reduced by a small amount, which is to be expected as a result of the polishing action of traffic.

The PFT data indicate that the untreated section of concrete surface exhibits rather variable friction values, which was also evident from the SCRIM and GripTester data. The variability of peak friction is particularly marked; Figure 5-7 shows that at 100km/h peak friction values were recorded between 0.19 and 0.7 on the untreated section whereas values between 0.58 and 0.77 were recorded on the treated section at the same test speed. Individual values of peak or locked wheel friction values can be very low, particularly at higher test speeds. While the values generally remain within the lower part of the envelope that has previously been observed on concrete surfaces, this does not necessarily imply an acceptable level of performance.

The diamond grinding technique has improved the locked wheel friction to a level comparable to the bottom of the range observed for HRA surfaces. While remaining at a fairly low level, this nevertheless represents an improvement over the untreated section. Furthermore when compared to the typical concrete bands generated from (Roe, Parry, & Viner, 1998) reported in Figure 5-4 and Figure 5-5 the treated sections produce locked friction values typically at the higher end of the range. The untreated sections however produce friction values towards the bottom end of this range. This is particularly prominent at higher speeds.

There is a marked improvement in peak friction, possibly related to the energy required to cause the damage to the test tyre. Taken together, the improvement in peak and locked wheel friction resulting from treatment is considered to be a useful improvement, which could prove to be a more cost-effective option than resurfacing for a worn concrete surface.

Although the results at 7 months are promising, it has yet to be demonstrated that the improvement in friction is maintained over time. A loss of either microtexture or texture depth could worsen the current friction performance. Loss of microtexture could occur if the aggregates exposed by the grinding procedure, likely to be of low PSV, become polished and loss of texture depth could occur if the flanges noted in Figure 2-1 break off under trafficking. There is some evidence from the USA that this latter effect could be expected over a period of a couple of years (Federal Highway Administration, 2007).

Microtexture is the dominating factor for the frictional properties at low slip speeds, such as those used in SCRIM and GripTester measurements. As well as the possible link to the high peak friction values, noted above, the importance of texture depth in maintaining locked wheel friction at higher sliding speeds is shown in Figure 6-1. This figure is drawn from an extensive study of PFT data for the Highways Agency, which demonstrated a clear relationship between surface texture and high speed locked wheel friction on a number of different surfacings (Roe, Parry, & Viner, 1998). The figure shows a range of friction measurements at 100km/h recorded on surfacings with

differing texture depths (reported as SMTD³), clearly indicating the reduced friction recorded for surfaces with SMTD values below approximately 0.7mm.

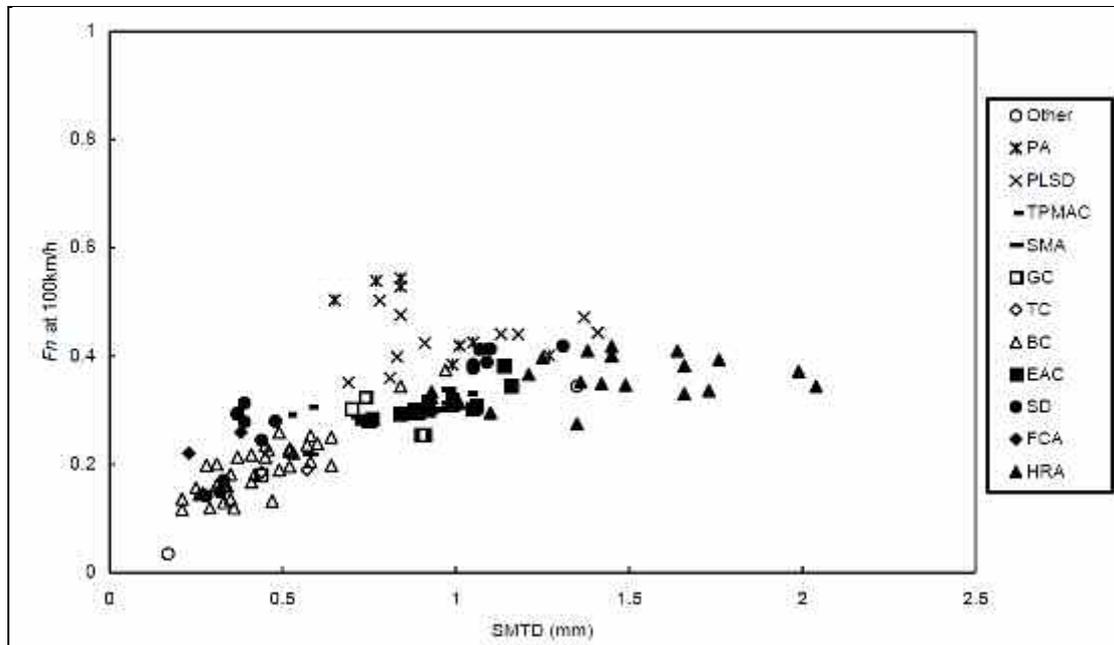


Figure 6-1 Relationship between locked-wheel friction and texture depth at 100km/h⁴

³Texture depth, measured using laser devices, and reported as sensor measured texture depth (SMTD)

⁴Key to surface types for Figure 6-1:

- | | |
|--|------------------------------------|
| PA - porous asphalt | PLSD – paver-laid surface dressing |
| TPMAC – thin polymer-modified asphalt concrete | SMA – stone mastic asphalt |
| GC – grooved concrete | TC – tined concrete |
| BC – brushed concrete | EAC – exposed aggregate concrete |
| SD – surface dressing | FCA – fine cold asphalt |
| HRA – hot-rolled asphalt with pre-coated chippings | |

7 Conclusions and recommendations

The SCRIM, GripTester and peak friction Pavement Friction Tester data show that, seven months after treatment the diamond ground surface is providing a significant improvement in low-speed skid resistance (e.g. SCRIM) and peak friction compared with the untreated concrete surface. The level of locked wheel friction reached has also improved, but not to the same extent as would be expected by applying a typical asphalt overlay; the level reached is just above the lower end of the range observed on HRA surfaces.

Results gathered from GripTester show a relatively small loss of skid resistance following treatment, as expected, as the new surface is polished by traffic. It will be essential to continue monitoring the trial section to determine whether this trend has reached equilibrium or whether a further loss is experienced. In addition, loss of texture depth with time could reduce both peak and locked wheel friction values at higher speeds.

If the current performance is maintained over time, the diamond grinding process could represent a cost-effective treatment solution to worn concrete pavements. However, the loss of microtexture and texture depth could result in the treated surface reverting to a similar or lower friction performance than the untreated section. It is not possible to accurately quantify this risk; exposure to it could be reduced by confining future trial treatments to areas where the existing friction performance is already poor.

It is recommended that the frictional properties of both the treated and untreated sections continue to be monitored over time, as planned, using GripTester, SCRIM and the PFT to assess the length of time for which the improvement in friction continues. Other trial sections should, similarly, be monitored closely until the performance over time is better understood.

Should the diamond grinding technique become widely adopted, it will be necessary to review the approach to measuring texture depth in routine TRACS surveys, since the longitudinal measurements currently used may not adequately characterise the longitudinally textured surface.

Acknowledgements

The work described in this report was carried out in the Infrastructure Division of the Transport Research Laboratory under a Halcrow framework contract for the Highways Agency. The author is grateful to Peter Roe who carried out the technical review and auditing of this report.

References

BS 7941-1:2006 Methods for measuring the skid resistance of pavement surfaces - Part 1: Sideways force coefficient routine inspection machine. London: BSi.

DD CEN/TS 15901-6:2009 Road and airfield surface characteristics Part 6: Procedure for determining the skid resistance of a pavement surface by measurement of the sideways force coefficient (SFCS): SCRIM.

Federal Highway Administration. (2007). Concrete pavement rehabilitation guide for diamond grinding. FHWA.

Frankland, D. (2004). Report on Correlation of SCRIM with the Mark 2 GripTester Trial at TRL, Crowthorne 21 April 2004. Glasgow: Jacobs Babbie.

HD28/04 - Skid resistance (DMRB 7.3.1). In Design Manual for Roads and Bridges. London: The Stationery Office.

Roe, P. G., Parry, A. R., & Viner, H. E. (1998). High and low speed skidding resistance: the influence of texture depth. (TRL367). Crowthorne: Transport Research Laboratory.

Viner, H. E., Roe, P. G., Parry, A. R., & Sinhal, R. (2000). High and low-speed skidding resistance: The influence of texture on smooth and ribbed tyre friction. IVth International symposium on pavement surface characteristics. Nantes.