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Long term friction performance of longitudinally diamond ground concrete

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Frictional properties of diamond ground concrete

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Executive summary

The Highways Agency is investigating the potential of a Longitudinal Diamond Grinding (LDG) 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 LDG process involves passing a rotating profiled drum over the pavement surface. The drum is constructed from a number of circular diamond blades, 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 3 mm and 10 mm of the original pavement surface creating a new surface course. The new surface consists of longitudinal ridges approximately 2-3 mm wide, 3-4 mm apart and 0.5-1.5 mm deep.

In March 2009, a 500 m length of the A12 Chelmsford bypass at Boreham was treated with a longitudinal diamond grinding technique; the same treatment was applied on a 6 km section of the A14 during March and April 2010, and a section of the A12 at Kelvedon during October and November 2009.

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, initial GripTester measurements have been carried out by the Area 6 Maintaining Agent, and these have been reviewed within this report.

To supplement these results, data collected as part of the annual skid resistance assessment have been analysed for a fourth trial site; a section of the A11 at Ketteringham which was treated during October 2009.

This report summarises friction data collected from the trial sites up to April 2012. Measurements of skid resistance on the trial sites have demonstrated that:

- Low speed skid resistance values have improved as a result of grinding, although some of the measured improvement may be as a result of the directional nature of the treatment and not necessarily representative of the skid resistance experienced by vehicles
- Low speed skid resistance is variable; in local areas levels of skid resistance close to the investigatory levels were measured
- Peak friction has been improved markedly as a result of the treatment but this improvement decreases over time; after approximately 30 months of service it reduces to relatively low levels
- Locked wheel friction has shown only marginal improvement as a result of treatment and remains at low levels on all measured sites
- High speed skid resistance data collected from the A14 is concerning and it is as yet unknown why its performance differs to the A12 sites
- There is a need to better understand the factors that contribute to the performance of treated surfaces before the technique is more widely adopted.
Abstract
TRL have carried out surface friction measurements on two sections of the A12 Chelmsford bypass, and a section of the A14 between Whitehouse and Copdock. Each section had been treated with a longitudinal diamond grinding technique used to restore surface texture and skid resistance. Low speed skid resistance measurements were made on each of these sites up to 36 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, at several intervals after grinding. This report presents the results of the measurements to date and discusses their implications for the widespread adoption of this technique across the Highways Agency network.
1 Introduction

Two properties of a road surface that influence its skid resistance performance (the pavement’s contribution to friction) are its microtexture and its macrotexture (measured as texture depth). On a concrete surface, texture is normally provided by the sand present in the laitance (microtexture) and by transverse brush marks (macrotexture). The action of heavy traffic can remove much of the laitance and some of the brush mark texture, especially within the wheel paths, thus exposing the coarse aggregate which can then become polished. This may lead to poor skid resistance and the requirement for a surface treatment to restore a satisfactory level of performance.

The Highways Agency is investigating the potential of a longitudinal diamond grinding (LDG) process, similar to that commonly used in America, to provide a cost-effective method of restoring the skid resistance 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 resistance to polishing - as measured in the Polished Stone Value (PSV) test - 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 adequate surface friction is achieved and that it is maintained when the treated pavement is exposed to heavy traffic.

To assess the skid resistance of longitudinally ground concrete surfaces over time, trial sites are being monitored using several skid resistance testing devices. The first of these, a 500 m length of the A12 Chelmsford bypass at Boreham, was treated in March 2009. The same process was used at a second site, on the A12 at Kelvedon, during
October and November 2009. A significant length (approximately 6 km) of the A14 between Whitehouse and Copdock was also treated during March and April 2010.

As part of the assessment of these trial sections, TRL was commissioned to carry out measurements of skid resistance using the Sideway-force Coefficient Routine Investigation Machine (SCIRM) and the Pavement Friction Tester (PFT), a specialist friction measurement device. In addition, initial measurements have been carried out by the Area 6 Maintaining Agent using GripTester, and these have been reviewed within this report.

To supplement these results, measurements made as part of routine annual skid resistance assessments with SCRIM have been analysed for a fourth trial site; a section of the A11 at Ketteringham, which was treated during October 2009.

This report summarises the results of measurements made on the trial sites, and discusses their implications, in relation to road surface properties, for the widespread adoption of the LDG technique. So that a complete overview of the performance of this type of treatment can be presented, statistical pass-by noise measurements made on one of the sites after treatment, as part of another project, have also been included.
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. Remedial treatments for structural faults are usually expensive because they require extensive work to repair elements below the pavement surface. 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 improve a pavement’s skid resistance and acoustic performance (Rao, Yu H, & Darter, 1999) and (Roads and traffic authority, 2008). It is claimed that diamond grinding can offer several advantages over asphalt overlays. Diamond grinding can be confined to specific areas that require treatment, with minimal disruption to existing infrastructure and street furniture. A further advantage is that the only consumables used by this technique are water and the diamond grinding blades: any waste material is collected and recycled.

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

![Profiled diamond grinding drum](image)

During the grinding process the revolving drum is forced onto the pavement surface under a vertical load and pulled along at a constant speed in the direction of traffic. The blades cut a macrotexture into the pavement surface whilst removing a thin layer
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(3-10 mm), which has the added effect of smoothing some of the longer-wavelength roughness (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 to be processed into a product suitable for reuse.

The resulting surface texture consists of longitudinal grooves approximately 2-3 mm wide, 3-4 mm apart and 0.5-1.5 mm deep. Figure 2-2 gives an example of the surface finish that was achieved on the A12 trial site. An untreated length of concrete surface is shown on the left of the picture and a treated length is shown 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). The presence of these fins could help improve skid resistance but they might be removed by the process of trafficking.

![Figure 2-2 Surface finished achieved with diamond grinding technique](image)

This surface texture differs significantly from that provided by conventional transverse grooving. The first, most obvious, difference is that the LDG technique results in grooves that run parallel rather than perpendicular to the direction of traffic. It is likely, therefore, that the road/tyre interaction mechanisms for the two techniques will differ, which could result in different frictional characteristics. The second difference is that transverse grooving cuts grooves into the pavement surface leaving a portion of the original surface intact, whereas the LDG 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 aggregates with low resistance to polishing, which are typically used in concrete carriageway construction
- The structural strength, and therefore longevity, of texture-providing fins 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 low resistance to polishing by traffic. Therefore, it is likely that these aggregate types could quickly polish, with a consequent reduction in skid resistance, counteracting one of the potential reasons for applying the grinding treatment. However, it might also be the case that, given the different form of texture, such polishing action might be less marked or be slower to take effect.

The longitudinal fins 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 fins could break off under traffic, reducing macrotexture and causing 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 in the presence of a few high-spots caused by one or two fins. 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 a texture depth parameter is calculated. The directional nature of the profile generated by the grinding process could make this meaningless if the laser spot follows the bottom of a groove for significant distances and fails to sample the overall profile.

The programme of friction testing on the trial sites was carried out to investigate the effect of these unknown influences on the skid resistance of concrete carriageways.
3 Test Equipment and methodology

3.1 SCRIM

SCRIM is the standard device for monitoring the skid resistance condition of the UK trunk road network; it 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 (HD 28/04 - Skid resistance (DMRB 7.3.1), 2004).

Figure 3-1 SCRIM carrying out skid resistance testing

SCRIM uses an instrumented test wheel angled at 20 degrees to the direction of travel, generating a relative slip ratio. Therefore, at the normal operating speed of 50 km/h, the effective speed at which the tyre contact patch moves over the surface (the slip speed) is 17 km/h. The vertical and horizontal loads acting on the test wheel are recorded and analysed using an on-board system to give a SCRIM Reading. On high-speed dual carriageways (which includes the trial sites 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 50 km/h. After some other adjustments, the processed values are known as “SCRIM Coefficient” (SC).
3.2 PFT

The PFT (Figure 3-2) is a friction testing device, used as a standard measurement technique in the USA (E274/E274M-11 Standard test method for skid resistance of paved surfaces using a full scale tire).

![Pavement friction tester](image)

**Figure 3-2 Pavement friction tester**

During a test, the towing vehicle maintains a constant test speed while the trailer mounted test wheel is forced to lock 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 3-3.

![Idealised graph of an average wet PFT skid test](image)

**Figure 3-3 Idealised graph of an average wet PFT skid test**
The test results are reported as values of peak friction\(^1\) and average locked wheel friction\(^2\).

Measurements can be made up to speeds of approximately 120 km/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 1 mm and a standard, smooth (American Society of Testing Materials) ASTM E524 tyre.

### 3.3 GripTester

GripTester is a small trailer used by many local authorities for measuring wet low speed skid resistance (Figure 3-4). 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.

![GripTester](image)

**Figure 3-4 GripTester**

Between April 2004 and October 2009, results provided by GripTester from tests at a standard 50 km/h test speed were compared to skid policy documents, written in terms of SCRIM coefficient, by converting the relevant investigatory levels into GripNumber using a conversion factor of 0.85. 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.

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\(^1\) 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
3.4 Statistical pass-by noise measurements

Noise measurements were made as part of another project, under a contract with the maintaining agent appointed by Highways Agency for the management area. They were carried out as a condition of the departure from specifications allowing LDG treatment. Full details of the measurements made were reported to the maintaining agent and statistical pass-by measurements are reproduced in this report, for completeness, with their knowledge.

The statistical pass-by (SPB) method was originally developed at TRL in the 1970s (Franklin, Harland, & Nelson, 1979) and has been adopted by the International Organisation for Standardisation (ISO) as the preferred method for comparing noise emissions levels from vehicles travelling on different road surfaces (ISO, 2001).

The SPB method requires the simultaneous measurement of the maximum A-weighted pass-by noise levels and speeds of individual vehicles running in the nearside lane at a microphone position located at 7.5 m from the centre of the nearside lane and 1.2 m above the road surface. Vehicles are classified into 3 acoustically similar categories:

- **L** - Light vehicles consisting of passenger cars, car based vans, taxis etc.
- **H₁** - Heavy vehicles with 2-axles and an unladen weight exceeding 3.5 tonnes
- **H₂** - Heavy vehicles with more than 2-axles

Measurements were carried out at three locations alongside the A14, Whitehouse to Copdock, site between 6th July and 8th July 2010 – approximately three months after grinding. No SPB measurements were conducted prior to grooving due to roadworks impacting the background noise levels and the lower speed limits preventing any assessment as a high-speed road surface.

The road was classified as a high-speed road and vehicle noise levels for each vehicle category were determined at the recommended reference speeds of:

- 110 km/h for vehicle category L and
- 90 km/h for vehicle categories H₁ and H₂

as outlined in the HAPAS guidelines (BBA, 2008). This was done so that a road surface influence (RSI) value, as defined in HAPAS guidance, could be determined for the surface at each of the sites. The RSI value provides an estimate of the difference in traffic noise levels for typical traffic conditions on the grooved concrete compared with a reference surface. For example, a negative value indicates a reduction in traffic noise relative to the reference case. For high speed roads the reference case is a bituminous surface with a texture depth of 2 mm and in practice is generally considered as having the same acoustic performance as a new 20 mm Hot Rolled Asphalt (HRA) surface.
4 Trial Sites and Testing Programme

4.1 A12 Chelmsford By-pass

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Road Number</th>
<th>Direction(s)</th>
<th>Between Junctions</th>
<th>Date of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chelmsford Bypass</td>
<td>A12</td>
<td>NB + SB</td>
<td>18 -19</td>
<td>March 2009</td>
</tr>
</tbody>
</table>

![Figure 4-1 Chelmsford by-pass trial site](image)

3 All maps are provided by the Ordnance Survey.
4.2 A12 Kelvedon

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Road Number</th>
<th>Direction(s)</th>
<th>Between Junctions</th>
<th>Date of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelvedon</td>
<td>A12</td>
<td>NB + SB</td>
<td>22 - 25</td>
<td>October – November 2009</td>
</tr>
</tbody>
</table>

Figure 4-2 Kelvedon trial site
4.3  A14 Whitehouse to Copdock

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Road Number</th>
<th>Direction(s)</th>
<th>Between Junctions</th>
<th>Date of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whitehouse to Copdock</td>
<td>A14</td>
<td>EB + WB</td>
<td>52 - 56</td>
<td>March – April 2010</td>
</tr>
</tbody>
</table>

Figure 4-3 Whitehouse to Copdock trial site
4.4 A11 Ketteringham

<table>
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<tr>
<th>Site Name</th>
<th>Road Number</th>
<th>Direction(s)</th>
<th>Between Junctions</th>
<th>Date of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ketteringham</td>
<td>A11</td>
<td>NB + SB</td>
<td>B1135 – A47</td>
<td>October 2009</td>
</tr>
</tbody>
</table>

Figure 4-4 Ketteringham trial site
4.5 Skid resistance measurements made

Measurements have been made on each trial site at various times since treatment. Measurements made by TRL have been supplemented by measurements made as part of the annual skid resistance testing programme and measurements made by the Area 6 maintaining agent. Figure 4-5 summarises the measurements made at each trial site.

Figure 4-5 – Measurements made at each trial site
5 Results

5.1 Introduction

This chapter reports skid resistance and friction data collected from each of the trial sites during the monitoring period. For comparison, data collected from the ground sections are reported alongside data collected from adjacent, untreated, control sections. SCRM measurements are presented with reference to an estimated Investigatory Level (HD 28/04 - Skid resistance (DMRB 7.3.1), 2004) and PFT data are presented with reference to pertinent historic data. For one of the sites, the A12 Chelmsford Bypass, measurements made using a GripTester are also presented using a secondary vertical axis scaled appropriately using the correlation equation in use at the time of testing: 

\[ SC = 0.85 \times GN \]

where GN stands for GripNumber and SC stands for SCRM Coefficient (Frankland, 2004).

The low speed skid resistance and high speed peak and locked wheel friction values collected during the most recent survey are used to demonstrate variation in skid resistance across each site, or variation with test speed, while average values from each survey show the evolution of skid resistance over time. Noise measurements made on the A14 site, as part of another project are also briefly summarised.

5.2 Low speed skid resistance

This section reports low speed friction as measured by SCRM or GripTester. Data reported to show variation across each site are from the most recent survey (carried out in April 2012 on most sites and in August 2011 on the A11 site). Measurements made by TRL with SCRM were recorded at a resolution of 1 m, but for consistency are shown here using a 10 m moving average. For comparison, measurements made before the grinding treatment are also shown.

5.2.1 A12 Chelmsford bypass

Figure 5-1 and Figure 5-2 show data gathered from the A12 Chelmsford bypass site. Measurements made with GripTester are provided as a measurement of skid resistance before the grinding treatment was applied. These data show that before the application of the treatment, 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 as a result of grinding, whereas skid resistance levels on the untreated sections remain relatively low.

Figure 5-3 shows the progression of average SCRM Coefficient (and GripNumber) for the A12 Chelmsford bypass site with time. Data represented by the small markers are GripNumber values and the larger markers represent SCRM Coefficient values. A significant decrease in skid resistance is shown on the ground sections over the first 12-16 months of service. After this period the ground sections show a plateau in skid resistance which is higher than that of the control sections. Note that there is a dip in skid resistance measured during the summer of 2011 (approximately May) and this is probably due to seasonal variation.
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Figure 5-1 Northbound A12 Chelmsford bypass SCRIM and GripNumber

Figure 5-2 Southbound A12 Chelmsford bypass SCRIM and GripNumber
Frictional properties of diamond ground concrete

5.2.2 A12 Kelvedon

Figure 5-4 and Figure 5-5 show the data gathered from the A12 Kelvedon site using SCRIM. These data show that, after grinding, the ground sections deliver skid resistance values approximately 0.05 SC greater than were measured on the untreated sections, although this seems to be as a result of a reduction in skid resistance on the control sections rather than an increase in skid resistance on the ground sections. Note that although before-grinding measurements were made at approximately the same time of year as the most recent survey (i.e. May, compared with April), some between-year seasonal variation is expected. The values collected from the ground sites show a greater variability than those collected from the control sections.

Both figures show a local drop in skid resistance (chainage 1000 m in Figure 5-4 and chainage 80 m in Figure 5-5) towards the investigatory level. In Figure 5-4 the same drop in skid resistance can be seen within the data collected before grinding; this could suggest that this area has not been treated, perhaps because it lies below the grinder cutting drum. In Figure 5-5 the drop in skid resistance is not shown within the before-grinding data and could therefore be a direct result of the grinding process.

The average SCRIM values shown in Figure 5-6 show that the ground section is providing consistently higher values of skid resistance than the control sections. A reduction in skid resistance is shown here during April/May 2011, probably due to some seasonal variation.

Figure 5-3 A12 Chelmsford bypass average SCRIM and GripNumber with time
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Figure 5-4 Northbound A12 Kelvedon SCRIM

Figure 5-5 Southbound A12 Kelvedon SCRIM
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5.2.3 A14 Whitehouse to Copdock

Figure 5-7 and Figure 5-8 show that the A14 site is performing in a similar manner to the A12 Chelmsford bypass site. Before grinding, skid resistance values are consistently below the IL and highly variable. A marked improvement in skid resistance is shown after the grinding treatment was applied, and skid resistance levels on the untreated sections remain relatively low. Values on the ground sections are still highly variable and, as with the A12 Kelvedon site, a number of local areas show values close to the investigatory level.

Figure 5-9 shows a significant drop in skid resistance during the first 12-16 months of service, this is also a similar behaviour to the A12 Chelmsford bypass site. Despite local reductions in skid resistance, average values remain above the investigatory level and significantly higher than the control sections. Furthermore, with the exception of a drop in skid resistance during the April of 2011, after 16 months of service, average skid resistance values are fairly consistent.
Figure 5-7  Westbound A14 Whitehouse to Copdock SCRIM

Figure 5-8  Eastbound A14 Whitehouse to Copdock SCRIM
5.2.4 A11 Ketteringham

Data collected from this site are from the annual SCRIM survey only. During the March 2011 visit it was not possible to obtain a roadspace booking for this site. It was therefore agreed with the project sponsor to use the annual SCRIM survey data only, rather than testing on a single occasion, in April 2012.

Data collected from the A11 Ketteringham site are shown in Figure 5-10 and Figure 5-11. As observed on the A12 Kelvedon site, skid resistance on the ground section has not changed much before and after treatment, whereas skid resistance on the untreated section appears to have reduced significantly during the period after grinding. This may also be a result of seasonal variation insofar as the skid resistance measured in June 2011 is generally lower than it was when measured before grinding, in May 2009. The effect of this seasonal variation has been masked on the ground section, resulting in measurements on both occasions coinciding. The end result is that the skid resistance on the ground section is at a level higher than that of the control section.

Another feature illustrated in Figure 5-10 is that the skid resistance on the ground section progressively decreases over the length of the trial site. At the end of the site, skid resistance values are similar to that of the control section. This behaviour is also apparent in the before-grinding data, which suggests that this is a function of the underlying performance of the surface. It might have been expected that this behaviour would not be present after grinding as the process removes the existing surface; it is possible, therefore, that the original state of the surface has an influence on the performance of the surface after grinding.
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Figure 5-10 Northbound A11 Ketteringham SCRIM

Figure 5-11 A11 Ketteringham average SCRIM with time
5.3  High speed friction

This section reports high speed friction data collected using the PFT. Average friction measurements made on the A12 and A14 sites are reported against speed for the most recent survey, carried out in April 2012. Data are presented alongside historic PFT data, represented on each graph by shaded regions for typical HRA and concrete ranges. These typical ranges display the 90th percentile extent of several thousand individual friction tests measured on surfaces of these types. They have been included as a guide and do not necessarily imply safe or acceptable values. Average high-speed (90 km/h) measurements from each survey trip are then shown against time to highlight any change in performance since the surfaces were ground.

5.3.1  Peak friction

Peak friction measurements made on the A12 Chelmsford bypass site are shown in Figure 5-12. At intermediate speeds (between 50 km/h and 80 km/h), the ground sections are providing markedly higher peak friction values than the control sections. At higher speeds the variability in measurement values, which is typical of peak friction data, causes some overlap in the measurements from the ground and control sections. On average, measurements made on the ground sections remain higher than on the control sections.

The average peak friction values at 90 km/h from the A12 Chelmsford bypass site, shown in Figure 5-13 against the date on which they were measured, display a steady decline in peak friction on both the ground and control sections. Over 36 months the peak friction measured on the ground sections reduces by approximately 0.25 units to approximately 0.45 units. Whereas the control section reduced by approximately 0.12 units to 0.28 units.

Figure 5-14 shows peak friction data collected from the A12 Kelvedon site; all data collected from this site falls within the typical concrete range. The rate of change of friction with speed on this site is lower than that of the Chelmsford bypass site and the ground and control sections are more similar.

Figure 5-15 shows that the rate of change of friction with time is markedly higher on the ground section than the control section. On the ground section, peak friction reduces by approximately 0.20 units to approximately 0.40 units. Over the same period the control section reduces by approximately 0.10 units to 0.38 units. Should this trend continue, peak friction on the ground section will be the same as or lower than on the control section by 36 months after grinding.

Figure 5-16 shows that the control section on the A14 site is providing very low peak friction, whereas the ground section is providing peak friction within the typical concrete range (albeit towards the bottom end of the range). In this case the grinding treatment is providing an advantage in peak friction on a surface that might otherwise be considered unacceptable. There is a greater change in friction with speed on the eastbound ground section than on the westbound ground section although this seems to be as a result of particularly high measurements at 80 km/h.

Average friction results shown in Figure 5-17 reiterate that, in terms of peak friction, the grinding process is providing an advantage on a surface that might otherwise be unacceptable. Figure 5-17 also shows that the grinding process has provided consistently higher values over the monitoring period by approximately 0.20 units.
Frictional properties of diamond ground concrete

Figure 5-12  A12 Chelmsford bypass peak friction in April 2012, 36 months after grinding

Figure 5-13  A12 Chelmsford bypass average peak friction with time
Frictional properties of diamond ground concrete

Figure 5-14  A12 Kelvedon peak friction in April 2012, 30 months after grinding

Figure 5-15  A12 Kelvedon average peak friction with time
Frictional properties of diamond ground concrete

Figure 5-16  A14 Whitehouse to Copdock peak friction in April 2012, 25 months after grinding

Figure 5-17  A14 Whitehouse to Copdock average peak friction with time
5.3.2  **Locked wheel friction**

Figure 5-18 shows the most recent locked wheel friction data taken from the A12 Chelmsford bypass site. At lower speeds (50 km/h) the ground section is providing higher locked wheel friction than the control section. It is also shown that the decrease in friction with increasing speed on the ground section is higher than on the control section. The result is that at higher speeds the level of friction on the ground and control sections is comparable, and at the lower end of the typical concrete range.

The average locked wheel friction data for the A12 Chelmsford bypass site shown in Figure 5-19 shows that both the ground and the control sections had changed very little over the monitoring period, until the most recent survey when there was a slight drop in friction, particularly on the ground section. The two sections now provide very similar levels of high-speed locked wheel friction.

Figure 5-20 and Figure 5-21 show that there is almost no measureable difference between the ground and control sections on the A12 Kelvedon site. All measurements taken from this site sit within the typical concrete range. The changes in friction with speed and time are also nearly identical. Over the monitoring period the locked wheel friction values reduce by approximately **0.10 units** to **0.22 units**. Interestingly, the northbound control section seems to perform consistently, although marginally, higher than the other test sections.

The A14 locked wheel friction data shown in Figure 5-22 indicates a small improvement in friction on the ground section compared with the control section. The absolute values at higher speeds are below the typical concrete range. As with the peak friction data the eastbound ground section shows values which have a greater change in friction with speed than the westbound section and higher intermediate speed (80 km/h) values.

Figure 5-23 shows that the ground sections are providing a level of friction approximately **0.05 units** higher than the control sections throughout the monitoring period. A reduction in friction of approximately **0.10 units** on all sections means that, after 25 months in service, both control and ground sections are providing locked wheel friction lower than the typical range for concrete; this may be unacceptably low.
Frictional properties of diamond ground concrete

Figure 5-18  A12 Chelmsford bypass locked wheel friction in April 2012, 36 months after grinding

Figure 5-19  A12 Chelmsford bypass average locked wheel friction with time
Frictional properties of diamond ground concrete

Figure 5-20  A12 Kelvedon locked wheel friction in April 2012, 30 months after grinding

Figure 5-21  A12 Kelvedon average locked wheel friction with time
Frictional properties of diamond ground concrete

Figure 5-22 A14 Whitehouse to Copdock locked wheel friction in April 2012, 25 months after grinding

Figure 5-23 A14 Whitehouse to Copdock average locked wheel friction with time
5.4 Statistical pass-by noise measurements

The results from the SPB noise measurements made alongside the A14 (Whitehouse to Copdock) sites at three locations during July 2010 are presented in Table 5—1. A complete set of results were presented to the Area maintaining agent and they are summarised here with their knowledge.

Table 5—1 Results from SPB measurements and corresponding $RSI_H$ values

<table>
<thead>
<tr>
<th>Location</th>
<th>Wind speed (m/s)</th>
<th>Average Temperature (°C)</th>
<th>Reference pass-by noise level (dB(A))</th>
<th>HAPAS RSI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Air</td>
<td>Surface</td>
<td>L</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>23.3</td>
<td>23.4</td>
<td>80.4</td>
</tr>
<tr>
<td>2</td>
<td>1.9</td>
<td>23.3</td>
<td>24.8</td>
<td>80.7</td>
</tr>
<tr>
<td>3</td>
<td>1.9</td>
<td>24</td>
<td>25.7</td>
<td>82.1</td>
</tr>
</tbody>
</table>

Together with equations included within the HAPAS guidelines, reference noise levels have been used to determine the influence of the road surface on traffic noise in terms of $RSI_H$ (Road Surface Influence), where $RSI_H$ is the RSI for high-speed category roads.

Relative to a new HRA surface, the grooved concrete is observed to provide between 3.0 and 4.8 dB reduction in traffic noise under high-speed conditions. The current guidance in the Manual of Contract Documents for Highway Works (Highways Agency, 2008) specifies noise levels for new thin surfacings on roads in noise-sensitive areas and these are reproduced in Table 5—2.

Table 5—2 Road/Tyre noise levels for thin surfacings

<table>
<thead>
<tr>
<th>Level</th>
<th>Equivalence to traditional surfacing materials</th>
<th>Road surface influence RSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Very quiet surfacing material</td>
<td>-3.5 dB(A)</td>
</tr>
<tr>
<td>2</td>
<td>Quieter than HRA surfacing materials</td>
<td>-2.5 dB(A)</td>
</tr>
<tr>
<td>1</td>
<td>Equivalent to HRA surfacing materials</td>
<td>-0.5 dB(A)</td>
</tr>
<tr>
<td>0</td>
<td>No requirement</td>
<td>No requirement</td>
</tr>
</tbody>
</table>

The LDG treatment therefore results in a surface with noise levels equivalent to a thin surfacing, which in turn is ‘quieter than HRA surfacing materials’. In two of the three locations measured, the grooved sections could be considered equivalent to a ‘very quiet surfacing material’.
6 Summary and discussion

6.1 Introduction
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 the degradation of the original laitance, a reduction in macrotexture to low levels, and exposure of 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 skid resistance characteristics.

In assessing its potential for use in the UK, trials of the process have been carried out on four sites on the A12 in Essex, A14 in Suffolk and A11 in Norfolk. TRL has carried out a full programme of measurements of low-speed skid resistance and high-speed friction, to assess the effects of the treatment on these sites. The results from this assessment raise some important topics for discussion.

6.2 Low speed skid resistance
Measurements of low speed skid resistance are somewhat encouraging and demonstrated that:

- On the surfaces tested, the diamond grinding process provided an increase in average low speed skid resistance compared with untreated sections.
- Although an initial reduction in skid resistance occurs over the first 14-16 months of service, after this period the skid resistance values plateau for the remainder of the monitoring period.
- Despite the relatively high levels of average low speed skid resistance, there are local areas on some test sites where skid resistance values drop dramatically to levels comparable with the investigatory level.

As yet the factors causing the localised areas of low skid resistance are unknown. Should the diamond grinding technique be more widely adopted it will be necessary to understand the factors that contribute to this variability so that steps can be taken to mitigate the effects. Furthermore, because of the directional nature of the LDG technique, there is a possibility that the side-force measurement method employed by
SCRIM does not necessarily fully characterise the surface’s skid resistance in the direction of travel.

6.3 High speed friction

Measurements of high speed friction also show that peak friction is affected by the diamond grinding process. Initial measurements of peak friction show a significant improvement as a result of the grinding treatment. This is possibly attributed to the sharp asperities in the road surface generated by the diamond grinding treatment.

However, there is evidence that the benefit reduces with time, possibly as a result of the asperities becoming broken off or polished by trafficking. Data collected from the A14 trial site shows that, after 25 months, peak friction values are at the lower end of the 90th percentile range for concrete. If the current trend continues peak friction levels on this site will be the same for both ground and control sections, well below the typical range for concrete surfaces. Conversely, data collected from the A12 Chelmsford trial site show that after 36 months of service the ground section is providing peak friction levels comfortably within the typical concrete range.

Given the improvements demonstrated in high speed peak friction data, it would be expected that a similar improvement would also be present in the locked wheel friction data. Initial measurements of locked wheel friction differ for each site. The A12 Chelmsford bypass and the A14 sites show an improvement in locked wheel friction as a result of the diamond grinding process, although the improvement is marginal. The A12 Kelvedon site shows no improvement in locked wheel friction.

As with the peak friction, locked wheel friction reduces over time and on the A12 sites reached levels comparable with the untreated sections after between 30 and 35 months of service. On the A14 site the reduction in friction is more significant and very low levels of locked wheel friction have been reached after 25 months of service.

This inconsistency between the performance of the A12 and A14 sites could highlight variability in the LDG technique that was alluded to within the SCRIM data. Alternatively, it could be a result of environmental or intrinsic differences in the trial sites, such as variation between the original materials. As with the local SCRIM variation, understanding the difference in high speed friction performance will be essential should the LDG process be more widely adopted.

6.4 Routine Monitoring

The results collected as part of this monitoring have implications for the routine skid resistance assessment of these surfaces. Normally, SCRIM is used to monitor low speed skid resistance in conjunction with texture depth which acts as a surrogate for high-speed skid resistance. However, this approach may not be applicable for this type of surface finish for a number of reasons. For example:

- The use of SCRIM to characterise low speed friction may be inappropriate because the directional nature of the grinding treatment, combined with the angled wheel used by SCRIM to generate a relative slip, may result in an artificial increase in SCRIM reading
- 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, fins and troughs created by the grinding process and consequently may not characterise the texture adequately
• Routine laser-based measurements made in the longitudinal direction may not characterise the texture adequately.

6.5 Noise

As well as altering skid resistance and frictional properties, the LDG technique has an effect on noise generation. Noise tests were undertaken by TRL three months after the treatment had been applied on the A14 site (Morris & Muirhead, 2010). It was shown that the grooved surfacing is quieter than a nominal 20mm HRA surfacing (MCHW level 2 (Highways Agency, 2008)), and in some locations performed as well as a very quiet surfacing material (MCHW level 3 (Highways Agency, 2008)). This is in line with anecdotal reports of an improvement in noise generation from local residents and road users.

It should be noted that:

• The untreated concrete surfaces measured on the A14 generated more noise than a nominal 20mm HRA ‘reference surface’. The benefit of the LDG technique, in terms of noise reduction from the original surface, is therefore estimated at approximately 6.7 dB in this case
• The noise measurements presented here were made only three months after treatment and it is known that, for other surfacing materials, noise generation increases as they get older. It is likely that the noise properties of these treated concrete sections will change over time
• There is some significant variability between the noise measurements in three locations on the trial site (1.8 dB range). This may be due to variation in the surface itself or it may indicate variability in the measurement method.
Conclusions and recommendations

- Average low speed skid resistance, as measured by SCRIM, has improved as a result of grinding
- The uplift in skid resistance decreases slightly during the first few months after treatment but a significant enhancement has been retained throughout the monitoring period, up to 36 months (A12 Chelmsford bypass site). No effective lifetime for the treatment can be determined.
- Low speed skid resistance is variable; in local areas levels of skid resistance close to the investigatory levels were measured
- Peak friction has been improved markedly as a result of the treatment but this improvement decreases over time
- Locked wheel friction has shown only marginal improvement as a result of treatment and remains at low levels on all measured sites
- The effective lifetime of the treatment in terms of high-speed friction, because of the reduction in peak friction over time, is approximately 36 months
- High speed friction measurements made on one site (A14) are very low and it is not clear why performance at this location differs from other sites

There is still a need to better understand the factors that contribute to the performance of treated surfaces before the technique is more widely adopted. It is therefore recommended that the use of the treatment should be considered, on a site to site basis, as a departure from current specifications. Until such time as the performance of longitudinally ground surfaces is fully understood, and a method for characterising texture depth as a surrogate for high speed friction can be established, treated sites should be carefully monitored. It is suggested that, where a departure from specifications is granted for a particular site, the maintaining agent should make provision for annual monitoring, for a minimum period of 5 years, to include:

- Measurement of low speed skid resistance using SCRIM, with particular attention given to the detection of localised areas of low skid resistance
- Measurement of high speed locked- and peak-friction, using a device such as the pavement friction tester
- Measurement of texture depth using the volumetric patch technique
- Measurement of noise generation using the statistical pass-by method.

All data collected should be passed to the overseeing department.
**Acknowledgements**

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**References**


(2002). *BS EN 13036-1:2002 Road and airfield surface characteristics - Test methods.* BSI.


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


