The performance of re-textured concrete pavements
An assessment of surface characteristics

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</tr>
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</table>

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Executive summary

The work discussed in this report follows on from that carried out in 2013 (Sanders & Brittain). Both pieces of work seek to enhance the understanding of the performance of re-texturing treatment options as a means of restoring the surface characteristics of concrete pavements which have deteriorated as a result of long service.

Measurements of sideways-force skid resistance, high speed friction, texture depth and noise were made on existing trial sites during June 2015, July 2015 and March 2016. Historical data were also collated for the trial sites to allow performance trends to be determined. The following re-texturing treatments are the focus of this work:

- Fixed head Longitudinal Diamond Grinding (LDG)
- Floating head LDG
- Shot blasting (large and small shot)
- Bush hammering
- Fine milling

The findings of the work are summarised below.

Summary of most recent measurements

- The average sideways force skid resistance measured on all materials is above the 0.35 investigatory level for non-event dual carriageways, but some individual measurements fall below this value.

- The floating head LDG and fine milling treatments (measured at approximately 2 and 3.5 year’s service respectively) provide the highest levels of high speed friction of the sites measured. The values provided by these treatments are within the range expected of concrete materials.

- High speed friction measurements made on materials treated with fixed head LDG after approximately 5.5 to 6 year’s service, bush hammering and shot blasting after 4 years were at the bottom of the range expected on concrete materials.

- The fine milling treatment, after approximately 3.5 year’s service, provided the highest texture depth values. Texture depths measured on the bush hammering and shot blasting treatments (after approximately 4 year’s service) were towards the bottom end of HD28 condition category 3.

- Noise levels measured on fixed head (approximately 6 to 6.5 year’s service) and floating head (approximately 2.5 year’s service) LDG treatments were well within the expected range for concrete.

Updated to estimated service lives

- No change in estimated service life (15 months) is recommended for the shot blasting and bush hammering treatments.

- An increase in estimated service life of 13 months is recommended for the fine milling treatment, resulting in an estimated service life of 49 months.
• An increase in the maximum expected service life of the fixed head LDG treatment of 20 months is recommended, resulting in the expected service life of this treatment being between 36 and 72 months.

Comparison of the performance of longitudinal diamond grinding techniques

• The floating head treatment affected the sideways-force skid resistance properties of the pavement measured differently to the fixed head treatment. A greater improvement in skid resistance was identified and the reduction in skid resistance was lower over time than that of the fixed head treatment. However, this could also be related to other factors not assessed in this work such as traffic flow.

• Both fixed and floating head treatments showed a similar high speed friction performance.

Comparison of the performance of shot blasting techniques

• The sideways-force skid resistance and high speed friction of the small and large shot treatments were similar.

• The large shot treatment produced marginally greater texture depth values than the small shot treatment. However, as with the LDG treatments, this could also be due to other variables such as differences in the underlying material.
1 Introduction

This report presents work commissioned by Highways England under package order 484(4/45/12)HALC – Modernising the specification for concrete roads. The work presented in this report is aimed at characterising the performance of six concrete re-texturing treatments, applied to a total of nineteen trial sites. The performance of each treatment was characterised in terms of sideways-force skid resistance, high speed friction, texture depth and noise.

Measurements were made on existing trial sites during June 2015, July 2015 and March 2016. Historical results were also collated for the trial sites to allow performance trends to be determined.

The following re-texturing treatments are the focus of this work:

- Fixed head longitudinal diamond grinding
- Floating head longitudinal diamond grinding
- Shot blasting (large and small shot)
- Bush hammering
- Fine milling

The Longitudinal Diamond Grinding (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 load and the drum is pulled along the surface in the direction of traffic. This results in the creation of a new surface texture consisting of longitudinal ridges.

The fixed head technique uses a drum that is held at a specified depth below the nominal level of the road surface. The result is that whilst some of the longer wavelength undulation is removed, small areas that fall below the grinding head can go untreated. The floating head technique however allows the drum to move with the changes in the height of the carriageway. This treats more of the areas that would fall below the drum in the fixed head technique, but has a lesser effect on the longer wavelength undulation.

Shot blasting and bush hammering are abrasive techniques designed to affect the aggregate of a road surface and create new sharp asperities on the aggregate particles. During shot blasting the road surface is impacted by steel shot propelled by a rotating wheel. As well as texturing any exposed aggregate, the shot can erode the cementitious matrix of concrete pavements to restore texture. The shot and arisings are collected and separated so the shot can be re-used.

The bush hammering process uses a similar principle, the road surface is struck with a number of impact heads containing hardened tip chisel ended hammers to erode the cement matrix of concrete pavements and texture the aggregate.

The fine milling process is an adaptation of the cold milling process which uses a rotating profiled drum to remove surface material. The fine milling process differs from cold milling in that the drum is constructed from hundreds of point attack tools arranged in a grid pattern with spacings less than 8 mm; cold milling spacings are generally larger than this.
During milling, the rapidly revolving drum is forced into the pavement surface and is pulled along the road at a constant speed. The milling drum cuts a fine texture into the road surface and also removes some of its large scale undulation.

The aims of the work carried out are to:

- Present and discuss the results of measurements made at the time of testing.
- Update the knowledge gained in TRL report PPR677 (Sanders & Brittain, 2013).
- Compare the performance of fixed head and floating head longitudinal diamond grinding.
- Compare the performance of shot blasting using large and small shot.

This report will present the results of the measurements made and provide some discussion pertaining to the measurements and the performance of the materials tested at the time of testing. In addition, this report seeks to update knowledge gained as part of previous work, reported in TRL report PPR677 (Sanders & Brittain, 2013). The goal of the work reported in PPR677 was to ascertain the likely service lives of bush hammering, shot blasting, fine milling and fixed head longitudinal diamond grinding. This was achieved by characterising the performance of these treatments at different trial sites over a 36 month period. Some of the sites tested as part of this work are the same as those tested as part of the work reported in PPR677; measurements made on these sites will therefore be compared with the historical measurements to ascertain if the service lives determined previously are still suitable.

A third aim of the testing was to compare the performance of the two different longitudinal diamond grinding treatments. The performance of the fixed head treatment had been assessed previously but relatively little is known about the floating head system. Measurements made on these two treatments were compared to assess the performance of each treatment.

Finally, the performance of materials treated with different shot blasting techniques was assessed by making a more in-depth assessment of the measurements made on materials treated with shot blasting.
2 Test locations

Table 2-1 summarises the test sites used in this work, maps detailing the locations of each trial site can be found in Appendix A. Sites were selected based on their historical context to the project, and the treatments used at each site.

<table>
<thead>
<tr>
<th>No.</th>
<th>Site Name</th>
<th>Road</th>
<th>Direction</th>
<th>Marker posts</th>
<th>Treatment</th>
<th>Date of treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Kelvedon bypass</td>
<td>A12</td>
<td>NB</td>
<td>147/1 to 147/8+50m</td>
<td>Fixed head LDG</td>
<td>October – November 2009</td>
</tr>
<tr>
<td>1.2</td>
<td></td>
<td></td>
<td>SB</td>
<td>147/9 to 148/1</td>
<td>Fixed head LDG</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>Whitehouse to Copdock</td>
<td>A14</td>
<td>WB</td>
<td>187/9+50m to 181/5</td>
<td>Fixed head LDG</td>
<td>March – April 2010</td>
</tr>
<tr>
<td>2.2</td>
<td></td>
<td></td>
<td>EB</td>
<td>183/2 to 187/9+50m</td>
<td>Fixed head LDG</td>
<td></td>
</tr>
<tr>
<td>3.1</td>
<td>Chelmsford bypass</td>
<td>A12</td>
<td>NB</td>
<td>127/2 to 127/7</td>
<td>Fixed head LDG</td>
<td>March 2009</td>
</tr>
<tr>
<td>3.2</td>
<td></td>
<td></td>
<td>SB</td>
<td>127/7 to 127/2</td>
<td>Fixed head LDG</td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td>Sixhills to Widmerpool</td>
<td>A46</td>
<td>NB</td>
<td>N/A to N/A</td>
<td>Floating head LDG</td>
<td>July 2013</td>
</tr>
<tr>
<td>6.1</td>
<td>Southampton East</td>
<td>M27</td>
<td>WB</td>
<td>24/0 to 24/5+80m</td>
<td>Fine milling</td>
<td>October 2011</td>
</tr>
<tr>
<td>6.2</td>
<td></td>
<td></td>
<td>EB</td>
<td>24/6+20m to 24/0+40m</td>
<td>Fine milling</td>
<td></td>
</tr>
<tr>
<td>6.3</td>
<td></td>
<td></td>
<td>EB</td>
<td>25/0+30m to 24/6+20m</td>
<td>Bush hammering</td>
<td>June 2011</td>
</tr>
<tr>
<td>6.4</td>
<td></td>
<td></td>
<td>EB</td>
<td>25/3+20m to 25/0+30m</td>
<td>Shot blasting</td>
<td></td>
</tr>
<tr>
<td>6.5</td>
<td></td>
<td></td>
<td>WB</td>
<td>24/5+80m to 25/2+80m</td>
<td>Fine milling</td>
<td></td>
</tr>
<tr>
<td>7.1</td>
<td>Southampton North</td>
<td>M271</td>
<td>NB</td>
<td>10/9 to 11/8</td>
<td>Fine milling</td>
<td>October 2011</td>
</tr>
<tr>
<td>7.2</td>
<td></td>
<td></td>
<td>SB</td>
<td>11/8 to 10/9</td>
<td>Fine milling</td>
<td></td>
</tr>
<tr>
<td>8.1</td>
<td>Southampton South</td>
<td>M271</td>
<td>NB</td>
<td>12/4+10m to 11/0+10m</td>
<td>Fine milling</td>
<td>October 2011</td>
</tr>
<tr>
<td>8.2</td>
<td></td>
<td></td>
<td>SB</td>
<td>10/9+20m to 12/0+40m</td>
<td>Fine milling</td>
<td></td>
</tr>
<tr>
<td>9.0</td>
<td>Oakhampton</td>
<td>A30</td>
<td>EB</td>
<td>162/7 to 163/0</td>
<td>Shot blasting (large shot)</td>
<td>March 2015</td>
</tr>
</tbody>
</table>
3 Equipment used

3.1 Skid resistance development platform

The Sideways-force Coefficient Routine Investigation Machine (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. The Highways England Skid Resistance Development Platform (SkReDeP) incorporates SCRIM equipment and is shown in Figure 3-1. Measurements from this device provide information that can be used to compare surfacings with the requirements for skid resistance laid out in the Design Manual for Roads and Bridges (DMRB) (Department for Transport, 2015).

![Figure 3-1 Skid resistance development platform, incorporating SCRIM](image)

SCRIM uses a smooth test tyre angled at 20 degrees to the direction of travel, mounted on an instrumented axle to record a SCRIM Reading (SR) for every 10 m length of road. The SR is the average ratio between the measured sideways force and the vertical load, which is dynamically measured, multiplied by 100.

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

SCRIM readings are speed-corrected to the standard test speed if necessary and converted into SCRIM Coefficient (SC), by applying a correction factor, for reporting and comparison with the relevant standards.
3.2 Pavement friction tester

The Pavement Friction Tester (PFT) (Figure 3-2) is a locked-wheel road surface friction testing device comprising a tow vehicle and trailer. The trailer holds the test wheel, which is mounted on an instrumented axle. The test wheel can be independently braked and the forces acting upon it measured to determine the friction between the test tyre and road surface. The PFT can be used in a number of configurations; testing can be carried out under wet or dry road conditions using different test tyres and at a variety of test speeds. For the purposes of this study the PFT was used with a smooth ASTM test tyre under wet conditions at 90 km/h.

During testing, the tyre contact patch slides over the surface at the same speed as the towing vehicle (i.e. test speed is the same as slip speed). During testing, the load and drag forces on the tyre are measured every 0.01 seconds throughout the braking cycle and from this the peak\(^1\) and locked-wheel\(^2\) friction are determined.

Figure 3-2 Pavement friction tester

The use of the PFT is described in ASTM standards (ASTM, 2011) and (ASTM, 2008), which were used as reference throughout the monitoring. PFT results are normally compared with pertinent historic measurements.

---

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

\(^2\) Locked-wheel fiction is the friction generated between the surface and test tyre when the wheel is locked.
3.3 Highways Agency Road Research Information System 2

The Highways Agency Road Research Information System (HARRIS) 2 is used to demonstrate the application of state of the art technology to the assessment of pavement condition at traffic speed. This vehicle is equipped with high resolution systems for the measurement of road shape and visual condition along with the additional capabilities of ground penetrating radar and road marking retro-reflectivity measurements. HARRIS 2 uses a combination of image gathering and laser displacement measurements to:

- Measure road alignment in terms of crossfall, gradient and curvature
- Measure texture at user-definable longitudinal intervals as short as 0.2 mm
- Measure transverse road profile using a single scanning laser at 1000 points across a 4 m width of traffic lane
- Measure longitudinal road profile along twenty-five measurement lines, coincident with the measuring points for transverse profile, at 50 mm longitudinal intervals
- Collect road surface images at a resolution better than 2 mm over a survey width of 3.5 m in order to detect surface defects
- Collect wide angle forward facing images using three cameras and on board real time image stitching.

Figure 3-3 HARRIS 2
3.4 TRITON

Measurements of tyre/road noise levels on the various road surfaces under assessment in the study were taken using TRL's dedicated tyre/road noise measurement vehicle TRITON (see Figure 3-4). The vehicle is based around a truck chassis and has a specially designed semi-anechoic (soundproof) chamber which encloses a dedicated test wheel, running in the nearside wheel path, and an array of measurement microphones around the test wheel. The test wheel is fitted with a specific reference tyre (denoted P1, this is referred to as a Standard Reference Test Tyre (SRTT) and is a P225/60R16 specified in ASTM standard F2493-14 (ASTM, 2014)). Use of this reference tyre allows the acoustic properties of the road surfaces to be characterised in a similar manner were measurements to be taken using the majority of passenger car tyres.

![Figure 3-4 TRITON tyre/road noise measurement vehicle](image-url)
3.5 Breuckmann SmartSCAN HE

Detailed 3-D measurements of a number of cores of the pavement surface from Site 2.1 were taken using TRL’s Breuckmann SmartSCAN HE device. This apparatus uses two cameras and a light source to project a series of known light patterns onto a surface or object of interest. The system uses knowledge of the camera geometries, and the actual patterns projected to compare the patterns of light present within the images. From this it is able to produce highly detailed 3-D representations of the imaged surfaces. The system must be static while collecting data, and is capable of imaging objects of almost 1m x 1m. Figure 3-5 shows the system projecting light and collecting data on an in-service pavement.

![Figure 3-5 Breuckmann SmartSCAN HE](image-url)
4 Measurements made

4.1 Sideway-force skid resistance

Sideway-force skid resistance measurements were made using SkReDeP at a test speed of 80 km/h. These measurements were speed corrected using the methodology stated in HD28/15 (Department for Transport, 2015) and are therefore presented as values of SC(50). SC(50) values, and the 90th percentile range of measurements, are presented for each site in the following chapter. Reference is made to the Investigatory Level (IL) for motorways and non-event carriageways with one-way traffic as stated in HD28/15 (Department for Transport, 2015).

In addition to the measurements made as part of this work, measurements from Highways England’s routine annual skid resistance surveys were obtained from their Pavement Management System (HAPMS) database. These were collected to supplement the measurements made as part of this work and to provide information where it could not be collected separately.

4.2 High speed friction

High speed friction measurements were made with the PFT using a smooth ASTM tyre at a test speed of 90 km/h, presented as P-Fn90 and L-Fn90, representing peak and locked-wheel friction respectively. The average of at least five measurements of peak and locked-wheel friction, and the 90th percentile range of measurements, are presented for each site in the following chapter. High speed friction measurements do not have a standard to which they can be compared. To add context to the results, high speed friction results are presented with reference to the typical performance ranges expected for the material being tested.

The performance ranges given, represent the 90th percentile range of many thousand measurements made. They have been included to contextualise the results only and do not imply safe, nor, acceptable values.

4.3 Texture depth

Measurements of road surface texture depth were made using HARRIS 2, and texture depth results from routine annual surveys were gathered from HAPMS. The measurements are presented in the next chapter as average Sensor Measured Texture Depth (SMTD) values. Average SMTD values are presented for all of the sites tested and are compared to the pavement condition categories given in HD29, shown in Table 4-1 (Department for Transport, 2008).
Table 4-1 Road condition categories from HD 29/08 (Department for Transport, 2008)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sound – no visible deterioration.</td>
</tr>
<tr>
<td>2</td>
<td>Some deterioration – lower level of concern. The deterioration is not serious and more detailed (project level) investigations are not needed unless extending over long lengths, or several parameters are at this category at isolated positions.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate deterioration – warning level of concern. The deterioration is becoming serious and needs to be investigated. Priorities for more detailed (scheme level) investigations depend on the extent and values of the condition parameters.</td>
</tr>
<tr>
<td>4</td>
<td>Severe deterioration – intervention level of concern. This condition should not occur very frequently on the motorway and all-purpose trunk road network as earlier maintenance must have prevented this state from being reached. At this level of deterioration more detailed (scheme level) investigations should be carried out on the deteriorated lengths at the earliest opportunity and action taken if, and as, appropriate.</td>
</tr>
</tbody>
</table>

4.4 Noise

CPX measurements were made in accordance with the methodology specified in ISO/DIS 11819-2:2015 (ISO, 2015) using the 2 mandatory microphone positions specified in the standard and a target reference speed of 80 km/h.

On dual carriageways or roads with more than 2 lanes on a given carriageway, measurements were restricted to the nearside lane unless indicated otherwise. On single carriageway roads where the surface was laid on both lanes, measurements were taken on both carriageways. At least three passes were made over each road section unless weather/traffic conditions prohibited this.

The resultant data provides overall tyre/road noise levels for each 20 m section of the road surface under assessment. Each pass was assessed in terms of the vehicle speed and any 20m segment not complying with the speed requirements in ISO/DIS 11819-2:2015 (ISO, 2015) was discarded. The results were then averaged over all passes to determine the overall CPX noise level, $L_{CPX,P1,80}$ for the road section. The average noise level, and the 90th percentile range of measurements, is presented in the following chapter.
4.5 Measurement regime

Table 4-2 summarises the measurements made at each test site, the date that the measurements were made, and the time which has elapsed between the application of the treatment and the collection of the test data.

Note that texture measurements on sites treated with LDG have been marked as Non-Applicable (N/A). This is because the LDG technique cuts peaks and troughs into the surface which are orientated in the direction of travel. The method for measuring texture employs a single point triangulation laser to make measurements of surface texture in the direction of travel. This method of measurement is therefore not suitable for LDG as it is possible for the laser to follow a peak or trough for long periods and therefore not characterise all of the available surface texture.

Table 4-2 Measurements made, date of collection and time since treatment

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sideway-force skid resistance</th>
<th>High speed friction</th>
<th>Texture</th>
<th>CPX</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>06/07/2015 (68 months)</td>
<td>06/07/2015 (68 months)</td>
<td>N/A</td>
<td>19/02/2016 (68 months)</td>
</tr>
<tr>
<td>1.2</td>
<td>07/04/2016 (72 months)</td>
<td>07/04/2016 (72 months)</td>
<td>N/A</td>
<td>23/3/2016 (71 months)</td>
</tr>
<tr>
<td>2.1</td>
<td>06/07/2015 (76 months)</td>
<td>06/07/2015 (76 months)</td>
<td>N/A</td>
<td>13/10/2015 (79 months)</td>
</tr>
<tr>
<td>2.2</td>
<td>06/07/2015 (24 months)</td>
<td>06/07/2015 (24 months)</td>
<td>N/A</td>
<td>22/02/2016 (31 months)</td>
</tr>
<tr>
<td>3.1</td>
<td>08/07/2015 (44 months)</td>
<td>08/07/2015 (44 months)</td>
<td>22/07/2015</td>
<td></td>
</tr>
<tr>
<td>3.2</td>
<td>08/07/2015 (49 months)</td>
<td>08/07/2015 (49 months)</td>
<td>22/07/2015</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>07/07/2015 (44 months)</td>
<td>07/07/2015 (44 months)</td>
<td>21/07/2015</td>
<td></td>
</tr>
<tr>
<td>3.4</td>
<td>07/07/2015 (44 months)</td>
<td>07/07/2015 (44 months)</td>
<td>21/07/2015</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td>01/10/2015 (7 months)</td>
<td>29/03/2016 (12 months)</td>
<td>18/08/2015 (5 months)</td>
<td></td>
</tr>
<tr>
<td>3.6</td>
<td>03/07/2014 (-8 months)</td>
<td>08/01/2014 (-14 months)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3 Measurement made as part of routine annual surveys.
5 Results

The four aims of this work were to:

- Present and discuss the results of measurements made at the time of testing.
- Update the knowledge gained in PPR677.
- Compare the performance of fixed head and floating head longitudinal diamond grinding.
- Compare the performance of shot blasting using large and small shot.

The results presented in this chapter are split into four sub-sections, which pertain to each of the above aims in turn. Average sideways-force skid resistance, high speed friction and texture depth measurements made as part of this work are presented in Section 5.1.

Section 5.2 presents measurements made as part of this work with historical results for sites 1, 2, 3, 6, 7 and 8. This is in order to update the knowledge gained of the performance of different re-texturing techniques presented in TRL report PPR677 (Sanders & Brittain, 2013).

Section 5.3 presents measurements made as part of this work, with historical measurements, for sites 1 to 5. In this section, the performance of the fixed head and floating head longitudinal diamond grinding techniques are compared.

Measurements made on the materials treated with shot blasting are presented in more detail in Section 5.4. The performance of treatments using large and small shot sizes are also compared.

5.1 Results of measurements made

5.1.1 Sideway-force skid resistance

Average sideways-force skid resistance measurements, Figure 5-1, show that the test sites are performing above the Investigatory Level (IL) generally applied to motorways and non-event carriageways with one-way traffic (Department for Transport, 2015), represented by the broken horizontal line. Despite the average values being above the IL, the range of values measured means that the 5th percentile on four sites (Sites, 2.1, 3.2, 8.1 and 6.4) has fallen below the IL. The highest skid resistance values were measured on the floating head LDG treatment on Site 5.0.
5.1.2 High speed friction

Average L-Fn90 and P-Fn90 values, and the 90th percentile range of results, displayed by the error bars, are shown in Figure 5-2 and Figure 5-3 respectively. The red and grey shaded areas represent the typical range of measurements expected on concrete and thin surface course systems (TSCS).

Figure 5-2 shows that the average locked-wheel friction results collected from the fixed head LDG sites were consistent at around 0.19. This value is similar to the average values measured on the sites treated with bush hammering and shot blasting. Measurements made on the sites treated with floating head LDG, and fine milling, were more typical of concrete carriageways.

The peak friction results (Figure 5-3) are more variable than the locked-wheel friction results. This however is normal as the measurement length used for the peak friction measurements is much shorter than that of the locked-wheel measurement. Figure 5-3 shows the surfaces treated with fixed head LDG to be performing towards the bottom of the typical concrete range. The site treated with bush hammering is also at the bottom of this range. Surfaces treated with floating head LDG and the fine milling sites are performing towards the middle of the typical concrete range.
The performance of re-textured concrete roads

Figure 5-2 Average locked-wheel high speed friction results

Figure 5-3 Average peak high speed friction results
5.1.3 **Texture depth**

Average texture depth measurements are shown in Figure 5-4 for all sites not treated with LDG. As previously stated, the SMTD is not suitable for pavements treated with LDG (see section 4.5).

Included in Figure 5-4 are representations of the categories used to assess the condition of road surfaces, as stated in HD29/08 of the DMRB (Department for Transport, 2008). The results show that the sites treated with bush hammering and shot blasting are providing the lowest texture values. The sites treated with fine milling are providing rather more variable values ranging from 0.81 to 0.59.

![Figure 5-4 Average texture depth results](image)
5.1.4 Noise

The results of the noise measurements are summarised in Figure 5-5; the blue diamond series markers represent the average measurement made over the length of the section, and the error bars the 5th and 95th percentile of the measurements made. The red squares and green triangle series represent historical measurements made on some of these sites a number of weeks before and after the treatments were applied. Graphs plotting the \( L_{CPX:P1,80} \) levels for the individual 20 m segments on each site are included in Appendix B of this document.

For the fixed head treatment, the average CPX noise levels for each site ranged from 99.0 to 101.7 dB. For the floating head treatment levels were only measured on single sites, giving an average \( L_{CPX:P1,80} \) value of 100.5 dB 7 dB.

On Site 2.1 and 2.2 the average CPX level prior to treatment was 103 dB, this reduced to 98 dB after treatment. This indicates that average CPX noise levels have increased by 1.7 dB and 2.0 dB on Sites 2.1 and 2.2 respectively over a period of approximately 7 years, with the current levels being approximately 3 dB lower than those prior to treatment.

On Site 3.1 and 3.2, the average CPX levels prior to treatment were 102.8 dB and 102.6 dB respectively; this reduced to 97.7 dB and 98.8 dB respectively after treatment. This indicates that average CPX noise levels have increased by 4 dB and 2.7 dB on Site 3.1 and 3.2 respectively over a period of approximately 7 years, with the current levels being approximately 1 dB lower than those prior to treatment.
5.1.5 3-D measurement of core profiles

A number of cores were taken from the A14 (Site 2.1) shortly after the LDG retexturing was completed and have been stored at TRL since collection. Additional cores were collected in October 2016 from the same site. Visual, and tactile, inspection of the cores strongly suggested that the effect of the retexturing treatment had been significantly reduced in the time between treatment (2010) and the collection of the new set of cores (2016). However this assessment was purely subjective and hard to quantify. In order to provide some objective and quantifiable data on the reduction of the profile heights, and the changes in the profile shape TRL’s Breuckmann SmartSCAN system was used to collect 3-D images of the original cores (taken at the time of the retexturing treatment), and the trafficked cores (taken after approximately 6 years of trafficking).

The SmartSCAN system was used, in conjunction with MountainsMap software to collect and process 3-D data. Each core was imaged, then the data was levelled and the surface of interest was extracted. A profile line, perpendicular to the direction of grooving treatment, was extracted from the 3-D data, and these extracted profiles were smoothed to remove pavement shape effects, leaving only the grooved profile of the surface for analysis.

Figure 5-6 shows the measured 3-D data for one of these cores (core 6) taken from the A14 after 6 years of trafficking following the retexturing treatment.

![Figure 5-6 Measured 3-D shape of trafficked core 6, showing approximate position of extracted profile line.](image-url)
The performance of re-textured concrete roads

Figure 5-7 shows an example of an extracted, measured, profile; the average core shape across the extracted profile line; and the residual texture profile showing the size and shape of the grooving still present on the pavement surface after 6 years.

![Figure 5-7](image)

**Figure 5-7** Extracted profile line, average shape of core and residual texture profile for trafficked core 6.

Figure 5-8 shows a selection of plotted profile lines, following the removal of pavement shape, from the untrafficked cores, extracted from the pavement shortly after application of the retexturing treatment.

![Figure 5-8](image)

**Figure 5-8** Residual texture profiles for untrafficked cores A and B.
Figure 5-9 shows a selection of plotted profile lines, following the removal of pavement shape, from the trafficked cores, extracted from the pavement approximately 6 years after the LDG treatment was applied.

![Figure 5-9 Residual texture profiles for trafficked cores 1 – 7.](image)

It is clear that the profiles from the untrafficked cores show larger fins and grooves, and are more consistent in terms of the fin/groove shape. Those extracted following 6 years of trafficking show much smaller grooves, with more variation in the shape of fin left behind.

Figure 5-10 presents histograms showing differences between the measured profiles and the mean profiles for the two core groups (trafficked and untrafficked). It is clear that the untrafficked core profiles show a wider range of profile heights than the untrafficked cores, reflecting the deeper grooves present on the cores.
The performance of re-textured concrete roads

It is clear from inspection of the 3-D profile data that the effect of the treatment has degraded as a result of trafficking. What is not known, however, is the time period over which the deterioration occurred – for example the profile resulting from the LDG treatment may have quickly changed from the untrafficked to the trafficked profiles, and then stabilised, or they may have resisted change for a number of years before succumbing to damage.

5.2 Update to PPR 677

TRL report PPR677 (Sanders & Brittain, 2013) assessed the performance of four concrete re-texturing treatments:

- Bush hammering (Site 6.3)
- Shot blasting (Site 6.4)
- Fine milling (Sites 6.1, 6.2 and 6.5)
- Fixed head LDG (Sites 1, 2 and 3)

Sideways-force skid resistance, high speed friction, texture and noise measurements were made on these surfaces and appropriate service lives were derived from the measurements using the high speed friction information. PPR677 concluded that:

"Measurements of high speed friction showed a reduction with time on all of the surfaces measured. The reduction in high speed friction was used to estimate service life for each of the treatments by calculating the period of time during which the
friction on the treated sections was higher than on the adjacent un-treated sections. This analysis estimated the following service lives to the re-texturing options:

- *Bush hammering and shot blasting* – 15 months
- *Fine milling* - <36 months
- *LDG* – 36 to 52 months”

This section seeks to update, or verify, the knowledge gained from the work reported in PPR677. Average values of sideways-force skid resistance and high speed friction are presented with historical measurements made as part of other works.

### 5.2.1 Bush hammering, shot blasting and fine milling

The sideways-force skid resistance measurements for the sites treated with bush hammering, fine milling and shot blasting are performing above the investigatory level for non-event carriageways with one-way traffic. The results are showing a flat trend over the last 25 months.

Average high speed friction results (Figure 5-12 and Figure 5-13) show that the shot blasting and bush hammering materials are performing similarly over the monitoring period. These treatments have a service life of 15 months (Sanders & Brittain, 2013), values since this time have continued to fall and are now at the bottom of the typical concrete range. This behaviour verifies the 15 month service life applied in PPR677.
“The surfaces treated with fine milling have a service life of 36 months” (Sanders, et al., 2012).

This was based on the assumption of a reducing trend in the high speed skid resistance values between 10 and 36 months, measurements up to 29 months were available at the time of writing PPR677. Measurements made as part of this work have shown high speed friction at 49 months to be comparable to that measured at 29 months. The reducing trend assumed in PPR677 was not observed, and as such the service life for the fine milling treatment can be extended to 49 months. Further monitoring will be useful to observe future trends on this surface and to identify if the service life could be extended further.

![Average high speed locked-wheel friction trend, Site 6](image)

**Figure 5-12 Average high speed locked-wheel friction trend, Site 6**
The performance of re-textured concrete roads

5.2.2 Fixed head LDG

The sideways-force skid resistance measurements made on the sites treated with fixed head LDG are shown in Figure 5-14, Figure 5-15 and Figure 5-16. These figures all show the same general trend; a relatively stable skid resistance performance in the first few years, followed by a gradual reduction in later months. The exception to this is the 72 months measurement on Site 2, which suggests a levelling off in performance. The worst case scenario is that the skid resistance on these sites continues to reduce, if this is the case the values would fall below the IL on sites 1 and 3 after approximately 100 months, and on Site 2 after 70 months (although from the measurements on Site 2 after 72 months, this does not appear to be the case).
The performance of re-textured concrete roads

Figure 5-14 Average sideways-force skid resistance trend, Site 1

Figure 5-15 Average sideways-force skid resistance trend, Site 2
The performance of re-textured concrete roads

Figure 5-16 Average sideways-force skid resistance trend, Site 3
The high speed friction results for the fixed head LDG sites are shown in Figure 5-17 to Figure 5-22. For the majority of the sites tested the treatment has shown an improvement in peak and locked-wheel high speed friction in the early months of service. The general trend in material performance is that the high speed friction on the treated sections is now either equal to, or below, that of the control section.

PPR677 derived a service life of between 36 and 52 months, siting the performance of Site 3 between 36 and 52 months as a potentially decreasing trend. However, the trend alluded to in PPR677 has not been observed during subsequent measurements and so the service life of 36 to 52 months is no longer appropriate.

Measurements made as part of this project have shown the performance of the treated sections falling below that of the untreated sections between 52 months, for the peak friction on Site 3, and 72 months for the peak friction measurements on Site 2. It is therefore more reasonable to assign a service life of 52 to 72 months for the fixed head LDG treatment.

![Figure 5-17 Average high speed locked-wheel friction trend, Site 1](image)
The performance of re-textured concrete roads

Figure 5-18 Average high speed locked-wheel friction trend, Site 2

Figure 5-19 Average high speed locked-wheel friction trend, Site 3
Figure 5-20 Average peak high speed friction trend, Site 1

Figure 5-21 Average peak high speed friction trend, Site 2
The performance of re-textured concrete roads

5.2.3 Summary of service lives

Table 5-1 summarises the service lives derived from the most up to date set of measurements and compares them with those derived in PPR677.

<table>
<thead>
<tr>
<th>Material</th>
<th>New service life (months)</th>
<th>Service life from PPR677 (months)</th>
<th>Difference (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shot blasting</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Bush hammering</td>
<td>15</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td>Fine milling</td>
<td>49&lt;sup&gt;4&lt;/sup&gt;</td>
<td>&lt;36</td>
<td>+13</td>
</tr>
<tr>
<td>Fixed head LDG</td>
<td>36 to 72&lt;sup&gt;5&lt;/sup&gt;</td>
<td>36 to 52</td>
<td>0 to +20</td>
</tr>
</tbody>
</table>

<sup>4</sup>This performance is based on the available empirical evidence. It is possible that the performance of this treatment may extend beyond 49 months but as this has not been observed, and as there is no trend that could be extrapolated to provide an estimate a limit of 49 months has been applied for pragmatic reasons.

<sup>5</sup>The wide range of service lives for this treatment is indicative of the difference in performance observed on different sites and for different parameters. This service life was assigned after considering the sideways-force skid resistance, high speed friction and noise information.
5.3 Comparison of longitudinal diamond grinding techniques

TRL report PPR607 (Sanders P., 2012) sited a potential issue of the fixed head LDG technique as the possible production of untreated areas that fall below the grinding head due to local variances in profile. This limitation prompted the development of the LDG technique resulting in the floating head system.

This system has the capability to follow local undulations in road surface and therefore, potentially, a greater amount of the surface will be treated. This technique is less established than the fixed head technique and this section seeks to compare the performance of the two techniques. The following figures present the average of all the sideways-force skid resistance and high speed friction measurements made on surfaces using the two techniques to date.

Average sideways-force skid resistance results (Figure 5-23) show that the floating head technique applied to Site 5 is providing the highest values of all the sites. The floating head technique appears to be reducing linearly with time. Whereas over the same surfacing ages the sites treated with the fixed head technique reduced more substantially, but then levelled off after approximately 15 months in service.

![Average sideways-force skid resistance comparison](image)

The high speed friction results (Figure 5-24 and Figure 5-25) show a similar performance between Sites 5, 1 and 3. The magnitude and reductions in friction observed are similar for these sites between 0 and 25 months of service.
The performance of re-textured concrete roads

Figure 5-24 Average high speed locked-wheel friction comparison

Figure 5-25 Average peak high speed friction comparison
5.4 Comparison of shot blasting techniques

This section compares the performance of materials treated with shot blasting techniques. Within the context of this document the term “shot blasting (large shot)” refers to a development of the original “shot blasting” technique. It is understood that multiple amendments have been made in the shot blasting (large shot) technique, one of which is an increase in the size of the shot used.

Historical measurements of sideways-force skid resistance, high speed friction and texture were gathered from previous works reported in TRL report PPR677 (Sanders & Brittain, 2013). These measurements, the blue series in Figure 5-26, Figure 5-28, Figure 5-29 and Figure 5-31 allowed the performance of materials treated with shot blasting with standard sized shot to be characterised. Included with these results are measurements made on a surface treated with shot blasting (large shot) (Site 9).

In addition to these historical measurements, a more in-depth view is taken of the skid resistance and texture measurements extracted from HAPMS on Site 9. Figure 5-27 and Figure 5-32 show the distribution of sideways-force skid resistance and texture measurements along the length of Site 9 and an adjacent section of un-treated concrete to act as a control.

5.4.1 Sideways-force skid resistance

Average sideways-force skid resistance measurements (Figure 5-26) show that after 7 months’ service, measurements made on the surface treated using the large shot technique are lower than those made on the surface treated with the standard technique. However after 15 months’ service the skid resistance value measured on the surface treated with large shot is greater than that using the standard technique. This discrepancy in performance is also highlighted in Figure 5-27 which shows that the performance of both the treated and control sections of site 9 experience a reduction and then recovery in skid resistance performance.

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6 The treatment supplier provided a statement regarding the performance of the treatment characterised by these measurements, this may be found in Appendix C.

7 Sideways-force skid resistance measurements in HAPMS are reported as Characteristic Skid Coefficient (CSC) values. This measure corrects the measurements made for seasonal variability using a Local Equilibrium Correction Factor (LECF). Seasonal variability on concrete roads is however unpredictable and so an LECF of 1.0 is applied to measurements made on all concrete pavements. The measure of CSC reported is therefore synonymous with the SC(SO) measure used throughout this work.
The Site 9 skid resistance profile (Figure 5-27) shows that measurements made after the site was treated were lower than those made before treatment. The performance of the treated and control sections after seven months are markedly below that of the before treatment measurement. The effect of the treatment is therefore likely to have a minimal effect on the skid resistance performance.

The measurements made fifteen months after the treatment was applied are on the whole similar to those prior to treatment for the control section. However, measurements made on the treated section are approximately 0.05 units lower than those made eight months before the treatment was applied. This suggests that after fifteen months the treatment has a negative effect on the performance of the surface.
5.4.2 **High speed friction**

High speed friction values (Figure 5-28 and Figure 5-29) show that the performance of the material treated with large shot has the same performance after 12 months, and 20 months, as the material treated with standard sized shot. The high speed friction performance of Site 9, 20 months after treatment is shown in Figure 5-30. This shows that the performance of the treated and control sections are at the bottom of the typical range of values expected on concrete. Furthermore, the average measurement for the control section (the series marker) is within the range of measurement made on the treated section (the error bars).
The performance of re-textured concrete roads

Figure 5-28 Average locked-wheel friction values for shot blasting

Figure 5-29 Average peak friction values for shot blasting
5.4.3 Texture

Average SMTD values (Figure 5-31) show that after 5 and 17 months’ service the treatment using large shot is providing texture values higher than those provided by the standard sized shot treatment. Values for both treatments are however at the lower end of TRACS category 3 and so indicate a warning level of concern.

The texture profile for Site 9 (Figure 5-32) shows that the treated section is providing higher levels of texture depth than the control for all of the measurements made. The measurements made post-treatment indicate a subtle increase in texture after 5 and 17 months compared to the texture before treatment.

Figure 5-32 shows a large peak in measurements around 300 m, this indicates the start of the treated section. Given that this measurement is clearly not indicative of the performance of the control or treated sections, it has been ignored in the analysis.
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Figure 5-31 Average texture depth values for shot blasting

Figure 5-32 Texture depth profile, Site 9
6 Conclusions

From the work carried out, conclusions pertaining to the following aims can be made.

Present and discuss the results of measurements made at the time of testing

- The average SC(50) values measured on all materials is above 0.35, but the 5\textsuperscript{th} percentile of measurements made on some surfaces is below this value.
- The floating head LDG and fine milling treatments provide the highest levels of high speed friction of the sites measured. The values provided by these treatments are within the range expected of concrete materials.
- High speed friction measurements made on materials treated with fixed head LDG, Bush hammering and shot blasting were at the bottom of the range expected on concrete materials.
- The fine milling treatment provided the highest texture depth values. Texture depths measured on the bush hammering and shot blasting treatments were towards the bottom end of HD28 condition category 3.
- Noise levels measured on fixed and floating head LDG treatments were well within the expected range for concrete.

Update the knowledge gained in PPR677

- No change in estimated service life is recommended for the shot blasting and bush hammering treatments.
- An increase in estimated service life of 13 months is recommended for the fine milling treatment, resulting in an estimated service life of 49 months.
- An increase in the maximum expected service life of the fixed head LDG treatment of 20 months is recommended, resulting in the expected service life of this treatment being between 36 and 72 months.

Compare the performance of longitudinal diamond grinding techniques

- The floating head treatment affected the sideways-force skid resistance properties of the pavement measured differently to the fixed head treatment. A greater improvement in SC(50) was identified and the reduction in skid resistance was lower over time than that of the fixed head treatment. However, this could also be related to other factors not assessed in this work such as traffic flow.
- Both fixed and floating head treatments showed a similar high speed friction performance.

Compare the performance of shot blasting using large and small shot

- The sideways-force skid resistance and high speed friction of the small and large shot treatments were similar.
- The large shot treatment produced marginally greater texture depth values than the small shot treatment. However, as with the LDG treatments, this could also be due to other variables such as differences in the underlying material.
Appendix A  Test location maps

Figure 6-1 Site 1 Kelvedon bypass
Figure 6-2 Site 2 Whitehouse to Copdock
The performance of re-textured concrete roads

Figure 6-3 Site 3 Chelmsford bypass

Figure 6-4 Site 5 Sixhills to Widmerpool
The performance of re-textured concrete roads

Figure 6-5 Site 6 Southampton East

Figure 6-6 Site 7 and 8 Southampton North and South
The performance of re-textured concrete roads

Figure 6-7 Site 9 Oakhampton
Appendix B  Detailed CPX noise level measurement results

The following graphs present the CPX noise levels, $L_{CPX,P1,80}$, as measured for each 20 m segment for each of the road sections included in the measurement programme.

An x-axis range of 800 m has been used wherever possible to allow ease of comparison of the variation in levels on the different surfaces; for those surfaces where the road section was significantly longer, an appropriate x-axis range has been selected.

Figure B.1: A12, Chelmsford Bypass (EB) – CPX levels, $L_{CPX,P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)

Figure B.2: A12, Chelmsford Bypass (WB) – CPX levels, $L_{CPX,P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)
Figure B.3: A12, Kelvedon (EB) – CPX levels, $L_{CPX:P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)

Figure B.4: A12, Kelvedon (WB) – CPX levels, $L_{CPX:P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)
The performance of re-textured concrete roads

Figure B.5: A14, Sproughton (EB) – CPX levels, $L_{CPX,P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)

Figure B.6: A14, Sproughton (WB) – CPX levels, $L_{CPX,P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)
Figure B.7: A46, Six Hills (NB) – CPX levels, $L_{CPX,P1,80}$ (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)

Figure B.8: A46, Six Hills (SB) – CPX levels, LCPX:P1,80 (dB) per 20 m segment along the tested road section (Dashed lines show 5th and 95th percentile levels)
Appendix C  Background to historical shot blasting measurements

Below is a statement from the supplier of the shot blasting and shot blasting (large shot) treatment regarding the application of the shot blasting treatment. For the purposes of confidentiality this statement has been made anonymous.

“The time that we were given for completing these works was reduced significantly on the night the works were carried out. The traffic management was put out late resulting in our working window being reduced. This resulted in us having to run our machinery at a much faster rate in order to complete our works.

Since the works on the M27 we have developed new methods of retexturing concrete road surfaces and have found that this gives a greater improvement in texture depth and skid resistance.

At the time of the M27 trial we did not have access to the on-site testing equipment that we have now - this equipment allows us to monitor the effectiveness of our treatment and to be able to adjust it as necessary to get the maximum benefit for the client.”
The performance of re-textured concrete pavements

Many of the concrete road surfacings in the UK have been in service for over 30 years and are starting to demonstrate reductions in skid resistance and texture. This report updates the knowledge gained from previous works into the applicability of concrete re-texturing techniques as a method of restoring road surface skid resistance and texture.

Other titles from this subject area

PPR677 Surface treatment options for concrete roads. P D Sanders and S Brittain. 2013


PPR676 Surface monitoring of re-textured concrete on the M27 and M271 – August 2011 to October 2013. P D Sanders, A Dunford and H E Viner. 2013