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PUBLISHED PROJECT REPORT PPR677

Surface Treatment Options for Concrete Roads

P D Sanders and S Brittain

Transport Research Laboratory
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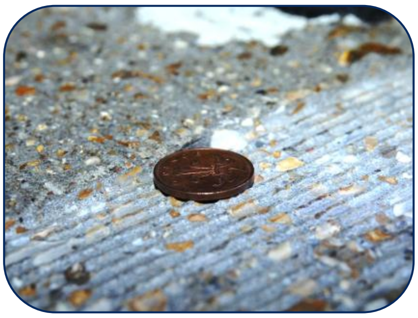

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P D Sanders and S Brittain

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Version	**Date**	**Description**	**Editor**	**Technical Referee**
1.0	12/09/2013	Changes made after TR review	PS	PL
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2.2	18/12/2013	Changes made after TR review	PS	AD
2.5	25/02/2014	Changes made after DPA review	PS	HV

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Executive summary

Approximately 3.5% of the Highways Agency network has a concrete surface construction; many of these roads have been in service for over 30 years. After an extended period of use, the surface laitance applied to concrete carriageways can be removed through the abrasive action of trafficking and weathering. Removal of surface laitance can lead to reductions in texture and skid resistance, a combination that has been shown to have a negative effect on road user safety.

To mitigate the risk to motorists, a number of actions can be taken to improve the surface characteristics of concrete carriageways. These actions can be separated into two main categories; bituminous overlay and re-texturing. TRL were commissioned to carry out a review of the re-texturing options available to road owners and provide information on the properties of each.

A review of Highways Agency databases was carried out to ascertain the state of the concrete carriageways in England. The analysis carried out concluded that the overall skid resistance of the network has remained relatively similar between 2005 and 2011. A small decrease in skid resistance was identified between 2008 and 2011. The average texture appeared to remain consistent between 2005 and 2009 but increased slightly after 2009.

Texture depth has been shown to be an important contributor to high speed friction generation and road user safety. A number of texture depth requirements are in place for the UK trunk road network for newly laid and in-service condition. A review of texture requirements found general agreement from various sources and that the current existing requirements are appropriate for the Highways Agency network.

A brief review of literature pertaining to the relationships between texture, high speed friction and accidents was also carried out. The limited amount of information that was found showed that texture depth and high speed friction are related for a number of road surfacing materials including concrete. All the studies identified confirmed that a relationship between texture, or high speed friction, and accident risk existed, but that this relationship includes a large amount of scatter. No information was found that supported a change to the current texture thresholds.

To maintain the texture of the road network to current guidelines, the use of concrete re-texturing options was explored. The current knowledge regarding some of the available re-texturing processes (shot blasting, bush hammering, longitudinal diamond grinding (LDG) and shallow fine milling) was summarised. Information was gathered from existing standards, guidelines, on-going research, site monitoring and anecdotal sources. Each technique was reviewed with regard to its associated hazards, noise characteristics and service life.

The knowledge base for the use of these techniques on concrete in the UK is fairly limited so further measurements of the performance of these surfaces were made. These included measurements of noise using the statistical pass by method on shot blasted, fine milled and bush hammered surfaces and measurements of high speed friction on all of the techniques.

The measurements made to date have shown that an improvement in low speed skid resistance and, to a lesser extent high speed friction, can be gained from each re-texturing technique when applied to a surface suffering from low skid resistance or high speed friction. The greatest average increases in skid resistance and friction were

recorded on surfaces treated with LDG and shallow fine milling. These treatments appear to have the greatest effect and have the potential to alter surface characteristics substantially.

However, both the LDG and shallow fine milling treatments can result in local areas with low skid resistance and low high speed friction. It has been speculated that the variability could be related to areas of carriageway that have been left untreated as a result of them lying below the level affected by the re-texturing tools.

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 treated sections was higher than on 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

Results of noise measurements showed that the LDG treatment produces a surface markedly quieter than the original surface. A reduction in noise of up to 6 dB was measured as a result of the LDG treatment. The fine milling treatment produced noise values that were generally comparable with those measured on a typical aged concrete surface. It may be possible that, depending on the original state of the surface, the fine milling treatment could increase the amount of noise generated. The bush hammering and shot blasting options showed that they may be able to offer a slight reduction in noise over an aged concrete surface but the measured values were s till relatively high.

There is, as yet, little experience in the UK with using the concrete re-texturing techniques discussed in this document. The information used in this report was gathered from a small number of sources and it is likely that the use of these techniques on different surfaces will generate different results depending on pavement construction. Caution should be exercised when using the estimated service lives because they have been calculated from observations made on a limited number of sites and the performance of the treatments may differ on other sites. Because the performance of the techniques on other surfaces is unknown it is necessary to monitor the skid resistance, friction and texture characteristics of new applications to ensure road user safety.

If these techniques become more widely adopted and further information is gathered, the understanding of the performance will also develop.

1 Introduction

Approximately 3.5% of the Highways Agency network has a concrete surface layer. Many of these concrete pavements have been in service for over 30 years and are suffering from a loss of surface texture which, combined with the polishing of the aggregates in the concrete, can lead to running surfaces with low friction characteristics. A popular treatment for the last 10 years has been to crack, seat and then thickly overlay with bituminous materials. This is an expensive process and where the concrete pavement is structurally sound may not represent best value for money.

The work detailed in this report continues from work carried out in 1998 TRL reports TRL 298 (Roe & Hartshorne, 1998) and TRL 299 (Roe & Hartshorne, 1998). That work assessed the effectiveness of a number of mechanical re-texturing techniques to restore the low speed skid resistance and texture properties of roads. The 1998 studies primarily assessed the effects on bituminous roads and concluded that:

"Useful benefits lasted for at least two and, in some cases, more than three full summers under rolling traffic on a dual carriageway trunk road carrying over three thousand commercial vehicles per day in lane 1."

The work detailed was, however, limited in the context of the present report because a small number of concrete roads were analysed and (by virtue of the necessary equipment not being available at that time) the effects on high speed friction were not taken into account. In more recent years the use of re-texturing techniques has been more widely adopted on concrete roads and equipment has become available allowing high speed friction measurements to be made.

The following chapters build on the knowledge gained in 1998 and seek to summarise the potential options for re-texturing concrete pavements with respect to their surface characteristics. Chapter 2 provides information about road surface condition monitoring techniques that are discussed later in the report. In Chapter 3, the extent of the potential issue (i.e. the amount of concrete on the HA network), and the current and developing condition of concrete surfacings in service, is presented. A brief review of texture depth requirements for various road surfacings in the UK, and elsewhere, was carried out to determine whether any evidence exists for a change to UK policy, and this is summarised in Chapter 4. Chapters 5 and 6 collate the information that was available at the start of this project about several re-texturing techniques, and describe efforts to fill any gaps in the information, particularly in knowledge of noise and high speed friction performance.

The key objective of this work is to provide advice on the use of retexturing techniques that can be implemented by highways engineers and this advice is summarised in the final chapter.

2 Surface condition information

Surface properties, such as low speed skid resistance, high speed friction, and pavement texture depth are discussed in detail in this report. The information in this chapter has been collated to provide context, and as an easy reference guide to some of the techniques discussed.

2.1 Low speed skid resistance

The development of the UK skid resistance policy in the 1960s and 70s was an important step in the management of the UK strategic road network. The policy ensures that the skid resistance performance of the network is monitored, and managed, to appropriate levels. Low speed skid resistance performance is monitored annually using a fleet of sideways force coefficient routine investigation machines. Figure 2-1 shows the Highways Agency Skid Resistance Development Platform, which incorporates sideways force coefficient measurement equipment.

Figure 2-1 Highways Agency Skid Resistance Development Platform

The sideways force coefficient routine investigation machine 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. This is therefore considered a measurement of low speed skid resistance.

The low speed skid resistance values measured during annual skid resistance surveys are compared with standards laid out in the Design Manual for Roads and Bridges (Department for Transport). An investigatory level of skid resistance is assigned to each section of carriageway: if the skid resistance of the surface falls below this level, the pavement should be investigated and, if necessary, remedial action taken to improve its skid resistance properties.

2.2 High speed friction

Low speed skid resistance is an excellent measure for characterising pavement skid resistance performance. When conducting detailed analysis of pavement skid resistance it is also important to consider high speed friction. High speed friction can provide detailed information of surface performance under similar conditions to those experienced by vehicles. In the USA high speed friction is the standard measure for the assessment of pavement skid resistance and the measurement device used is the Pavement Friction Tester (PFT).

The PFT (Figure 2-2) 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 50, 80 and 100 km/h.

Figure 2-2 Pavement friction tester

During testing, the test wheel 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 these data the peak[a] and locked-wheel[b] friction are determined.

[a] Peak friction is the maximum friction value reached as the test wheel begins to slip.

[b] Locked-wheel friction is the friction value experienced when the test wheel is locked.

2.3 Texture as a proxy for high speed friction

Research carried out in the 1990s (Roe, Parry, & Viner, 1998) showed that surface texture is related to locked-wheel friction at the higher speed ranges, for a large number of pavement surfaces. Figure 2-3 shows the relationship developed in the 1998 work between texture and high speed friction.

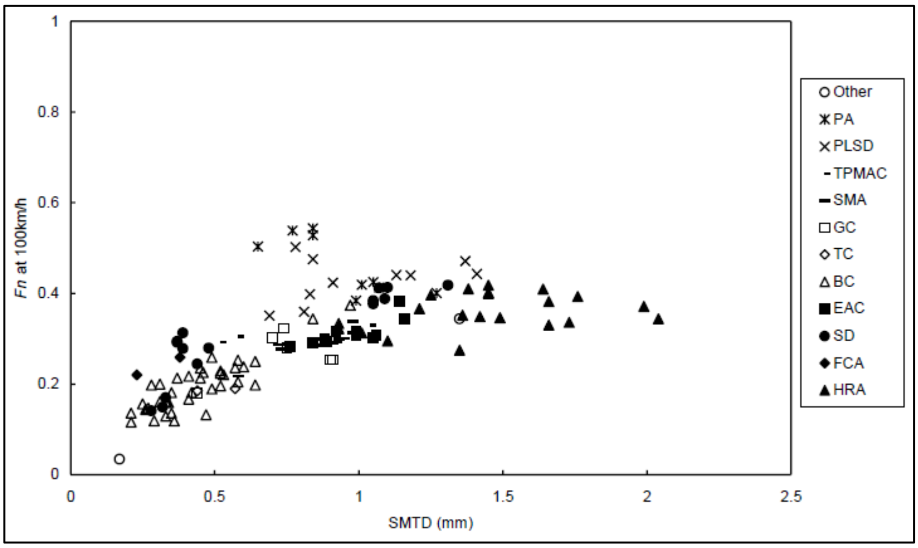

Figure 2-3 SMTD Vs high speed friction at 100 km/h (Roe, Parry, & Viner, 1998)

The PFT is not suitable for conducting network level high speed friction surveys in the UK. Consequently, the relationships developed in the 1998 work are the basis to allow the use of texture depth as a surrogate for high speed friction measurements. Whilst texture measurements are a useful tool in characterising the likely high speed friction performance of some surfaces, for more detailed investigations, measurements of high speed friction should made directly using the PFT.

Texture depth can be measured in a number of ways, summarised below:

- Mean Texture Depth (MTD), measured using the volumetric patch technique. A known volume of glass beads is spread over the pavement surface in a circle until the beads are level with the surface. The circle diameter is measured and a formula used to calculate the mean texture depth. This method requires multiple repetitions over a single surface and on in service carriageways requires a lane closure.
- Sensor Measured Texture Depth (SMTD). A single point displacement laser is mounted to a vehicle and driven over the pavement surface. The displacement between the laser and road surface is measured to build up a 2 dimensional texture plot of the pavement. SMTD is a route mean square measure of the texture above and below the mean pavement height within an assessment length (300 mm).
- Mean Profile Depth MPD. As for SMTD, a 2 dimensional texture plot is analysed and MPD is a measure of the average height above a mean level of the highest peaks within an assessment length (100 mm).

A policy, similar to that for skid resistance, is in operation for texture depth to ensure appropriate levels of texture on the network are maintained; these are discussed in detail in Chapter 4.

3 Condition of concrete on the HA network

The Highways Agency Pavement Management System (HAPMS) is a database containing information on the construction and condition of the HA road network. This chapter presents information extracted from HAPMS, used to assess the current state of the concrete carriageways on the HA network.

3.1 Lengths of concrete surface on the HA network

HAPMS was used to obtain details of the construction of the HA network over the last seven years. The lengths recorded in HAPMS as having concrete as the top layer are given in Table 3-1 and Figure 3-1.

Table 3-1 Length of HA network recorded as concrete surface

	Length (km)						
Material	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Cement bound material	28	25	11	6	6	8	6
Concrete block paving	-	1	1	1	1	1	1
PQ concrete	1587	1513	1432	1351	1285	1174	1079
Re-textured concrete	-	1	25	28	23	62	96
Total concrete top	1614	1540	1469	1386	1316	1245	1182

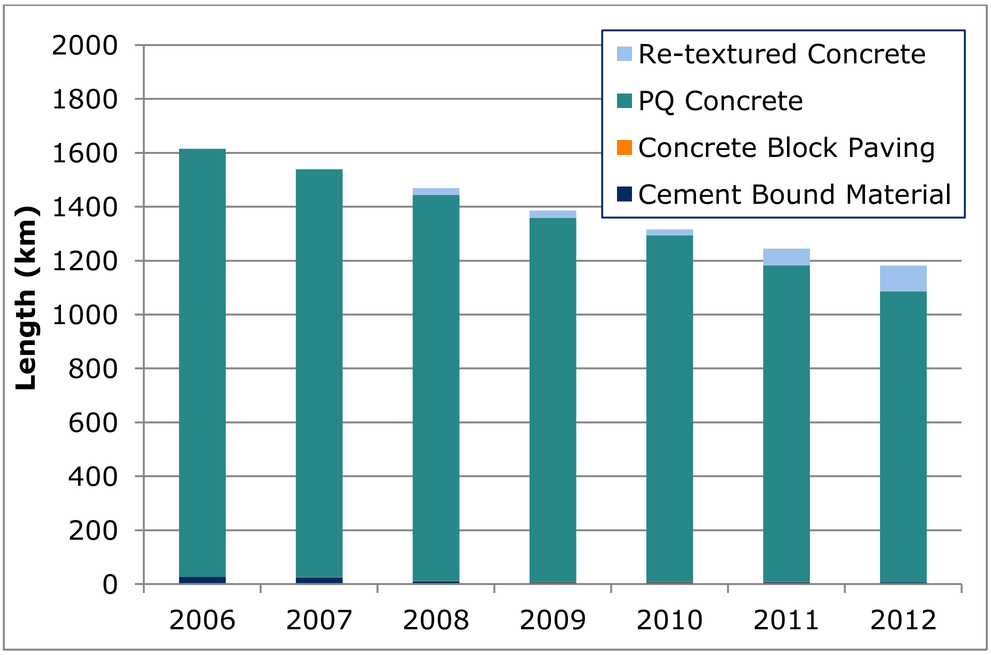

Figure 3-1 Length of HA network recorded as concrete surface

The information in Table 3-1 shows that the length of concrete surfaced carriageways on the English road network has reduced by approximately 200 km between 2006 and 2012. The length of carriageway on which re-texturing has been carried out has increased by approximately 100 km over the same period. It is possible that the reduction in the length of concrete surfaced carriageways could be a result of them being overlaid due to poor skid resistance. An analysis was carried out to ascertain the lengths of concrete carriageways with asphalt overlay between 2006 and 2012[c]. This analysis showed that the number of concrete carriageways with an asphalt surface has increased over this timeframe. However, the lengths identified may have concrete below the surface for a number of reasons that cannot be determined by the analysis:

- Overlay due to poor skid resistance or texture
- Overlay due to poor noise characteristics
- Thick overlay as part of a structural remedy such as crack and seat
- The surface is still as at its original construction, which used a concrete foundation layer and an asphalt surface.

There is a significant percentage of the network that does not have construction details in HAPMS. The majority of lengths with no construction details are lengths assigned to Design Build Finance and Operate projects (DBFOs). Unlike Maintaining Agent Contractors (MACs), who operate the majority of the HA network, DBFOs are not required to record condition and construction information in HAPMS.

Of the length for which construction details exist, approximately 1,182 km is concrete surface, and this equates to 3.5% of the network. Analysis[d] showed that, in 2012, no construction detail exists for 2,032 km of the carriageway. If the same proportion of concrete is expected on the network for which no construction details exist then it can be estimated that, in total, there are approximately 1,253 km of concrete surface on the HA network.

3.2 Low speed skid resistance

The sections identified as having a concrete surface construction were also used to investigate the change in skid resistance for concrete surfaces over time. Only lengths that were labelled as concrete over the complete analysis period (2005 to 2011)[e] and have SCRIM surveys in each year were used. This may have excluded some sections that were overlaid because of poor performance but this query was chosen to identify any systematic deterioration of the network as it was in 2011. This resulted in the analysis of 418.44 km with seven years of SCRIM results.

The average values (series markers) and 90th percentile range of values (error bars) are shown in Figure 3-2. The 0.35 investigatory level for non-event dual carriageways is also shown in Figure 3-2 for reference. This is the second lowest investigatory level value recommended in the UK skid policy and the majority of concrete carriageways have this investigatory level applied to them.

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[c] The results of this analysis are given in Table 7-2 in Appendix A

[d] Reporting of this analysis can be found in in Table 7 3 in Appendix A

[e] The June results contain the SCRIM survey from the previous year, therefore the 2006 to 2012 results used in section 3.1 correspond to the 2005 to 2011 SCRIM survey years.

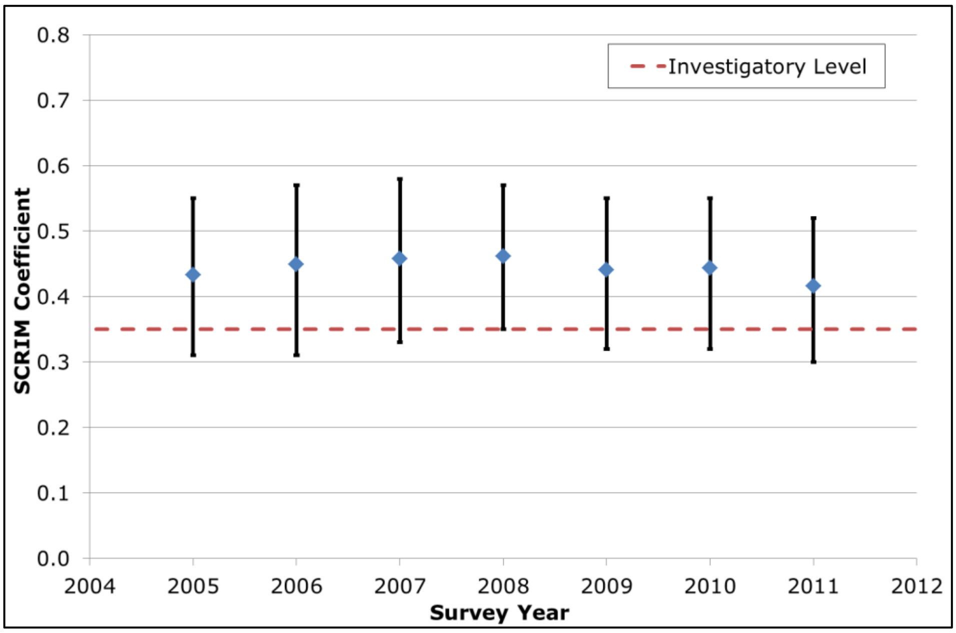

Figure 3-2 Average SCRIM coefficient values for concrete surface

It can be seen that there has been no substantial change in the overall level of low speed skid resistance since 2005. A small decrease is shown after 2008 demonstrating that the increase in the use of re-texturing over the same period has not had a substantial effect on the national average. Despite this, the average level remains above the investigatory level laid out in HD28/04 of the DMRB (Department for Transport, 2004) of 0.35 for non-event dual carriageways.

Table 3-2 shows the percentage of the concrete surface network that has different investigatory levels assigned. This table shows that the majority of surfaces are assigned an investigatory level of 0.35, implying that most concrete surfaces are in locations where little braking or manoeuvring occurs (i.e. motorways and dual carriageways).

Table 3-2 Percentage of concrete surfaces within investigatory level categories[f]

IL	2011
0.35	87.61%
0.40	8.68%
0.45	2.70%
0.50	0.92%
0.55	0.10%

[f] The investigatory level distribution between 2005 and 2011 can be found in Table 7-4 in Appendix A

3.3 Texture depth

A subset of the section lengths used in the previous two analyses were further utilised to investigate changes in texture depth. As with the SCRIM analysis, only lengths that were labelled as concrete over the complete analysis period and have TRAffic speed Condition Surveys (TRACS) information in each year were used. This resulted in the analysis of 309.33 km with seven years of TRACS results. The average texture depth values for these lengths are shown in Figure 3-3.

Categories used for assessing TRACS texture results are also indicated by coloured bands in Figure 3-3; full details of these categories are given in Table 4-5.

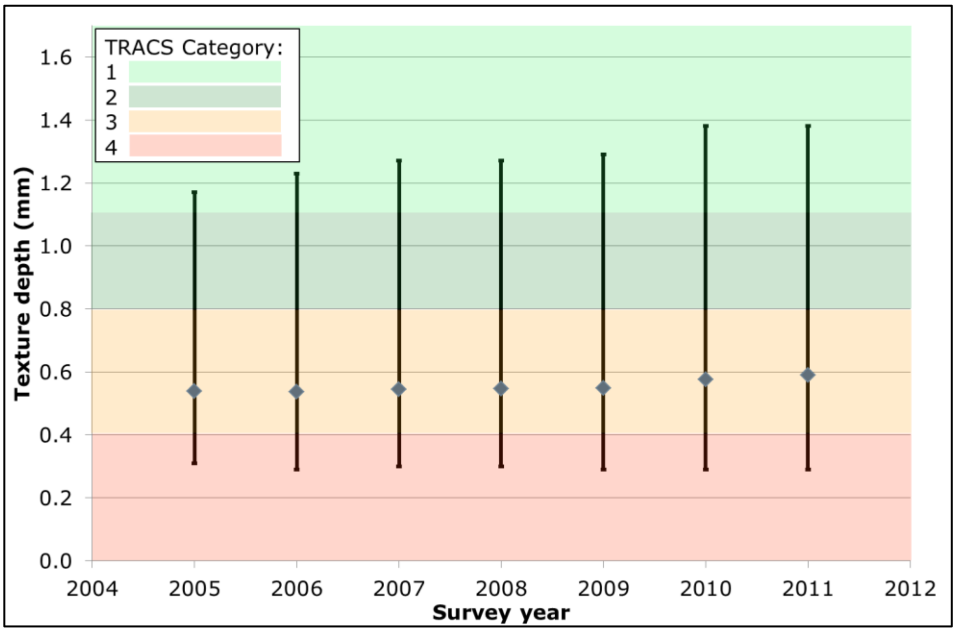

Figure 3-3 Average texture depth values for concrete surface on HA Network

It can be seen that all the values are within TRACS category 3 (moderate deterioration) and there appears to be a small increase in the average texture depth of concrete surface on the network between 2009 and 2011.

3.4 Traffic levels

In addition to the analysis of information from HAPMS, measurements of traffic flow obtained from the Highways Agency Traffic Information System (HATRIS) were also analysed. Combining information from the HATRIS and HAPMS databases it was possible to generate carriageway Annual Average Daily Traffic (AADT) values for a number of sections. The values were then grouped into different traffic bands and split into concrete and other surfacing types, depending on the construction of lane 1. This resulted in 366 km of results for concrete and 8,034 km of results for other surface types. Figure 3-4 shows the percentage of each type of surfacing within AADT category bands of 10,000 vehicles.

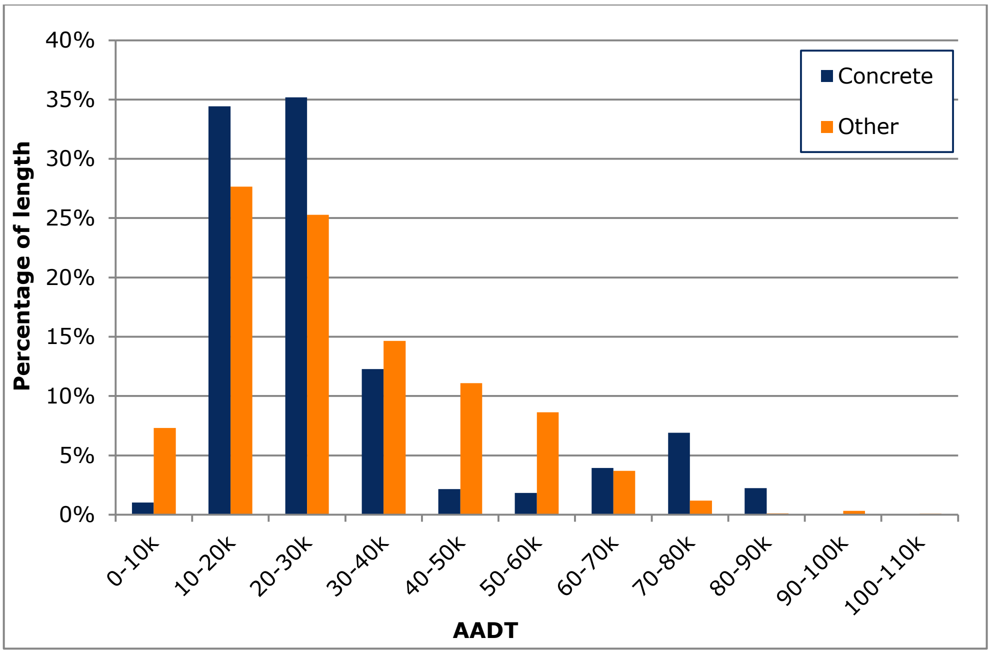

Figure 3-4 Traffic level distribution

This analysis shows that the distribution of traffic levels varies between concrete lengths and the rest of the network. In particular, there is a greater proportion of the concrete sites with an AADT between 10,000 and 30,000 vehicles. In addition a greater proportion of concrete sites have an AADT >70,000. This is probably due to the amount of concrete present on the M25: all but 1 km of the concrete sites with an AADT >70,000 vehicles occurring on the M25.

4 Review of texture depth requirements on concrete roads

A review of literature pertaining to pavement texture depth requirements, and the influence of texture depth and high speed friction on accident risk was carried out.

4.1 Current UK texture requirements

4.1.1 Newly laid concrete surfaces

Texture depth requirements for newly laid concrete surfaces are given in Clause 1026 of the Specification of Highway Works in the Manual for Contract documents for Highway Works (Department for Transport, 2006). Mean Texture Depth (MTD) is measured using the volumetric patch technique, described in BS EN ISO 13473-1:2004 (British Standards Institution, 2004).

Table 4-1 MCHW Clause 1026 newly laid concrete texture requirements (MTD)

Time of test	Required macrotexture depth (mm)		
		Specified value	Tolerance
Between 24 hours and 7 days after the construction of the slab or until the slab is first used by vehicles	An average of 10 measurements	1.00	±0.25
Not later than 6 weeks before the road is opened to the public	An average of 10 measurements	1.00	+0.25 -0.35

4.1.2 Newly laid bituminous surfaces

Interim advice note (IAN) 154/12 (Department for Transport, 2012) provides the most recent initial and retained texture depth requirements for newly laid bituminous materials. Table 4-2 shows the initial texture requirements for high speed roads, and Table 4-3 shows retained texture requirements for the English strategic road network. The values stated in IAN 154/12 are based on the volumetric patch technique for measuring MTD.

Table 4-2 Extract from IAN 154/12, initial texture requirements (MTD)

Road Type	Surfacing Type	Average per 1,000 m section, mm Minimum	Average per 1,000 m section, mm Maximum	Average for a set of 10 measurements (minimum)
High speed roads Posted speed limit ≥ 50 miles/hr (80 km/h)	Hot applied thin surface course systems to clause 942 with an upper (D) aggregate size of 14 mm	1.3	1.8	1.0
	Hot applied thin surface course systems to clause 942 with an upper (D) aggregate size of 10 mm	1.1	1.6	0.9
	Hot applied thin surface course systems to clause 942 with an upper (D) aggregate size of 6 mm	1.0	1.5	0.9
	Cold applied ultra thin surface course systems to clause 942	1.5	2.0	1.2
	Chipped hot rolled asphalt. Surface dressing and all other surfacings	1.5	2.0	1.2

Table 4-3 IAN 154/12 Retained texture requirements (MTD)

Surfacing Type	Average texture depth per 1,000 m section (mm)[1]
Hot applied thin surfacing course systems with an upper (D) aggregate size of 14 mm	0.9
Hot applied thin surfacing course systems with an upper (D) aggregate size of 10 mm	0.8
Hot applied thin surfacing course systems with an upper (D) aggregate size of 6 mm	0.7[2]
Cold applied ultra thin surface course systems produced using surface dressing techniques	1.0

[1] or the complete carriageway lane where this is less than 1,000 m.

[2] verification of high speed friction performance required.

4.1.3 In service requirements

The texture of the UK road network is measured annually using TRAffic speed Condition Surveys (TRACS); texture requirements for TRACS are set out in HD29/08 of the Design Manual for Roads and Bridges (DMRB) (Department for Transport, 2008). TRACS texture measurements are calculated from surface profiles measured by laser using the sensor measured texture depth (SMTD) algorithm as stated in the SCANNER user guide volume 5 (Department for Transport, 2009); texture condition thresholds and category descriptions are shown in Table 4-4 and Table 4-5, respectively.

Table 4-4 TRACS Texture (SMTD) thresholds

Category	Threshold value 1	2	3	4
Texture depth (mm)				
Anti-skid surfacing HFS	0.6	N/A	N/A	
All other surfaces	1.1	0.8	0.4	

Table 4-5 TRACS Category definitions

Category	Description
1	Sound – no visible deterioration.
2	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.
3	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.
4	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.

4.1.4 Comparison of texture requirements

It is not possible to directly compare values given in MCHW Clause 1026 and IAN 154/12 with those given in HD29/04 because the contract documents require measurement of texture depth by volumetric patch (MTD), whereas the design manual requires measurement by laser, reporting SMTD. It is not possible to directly convert MTD to SMTD (or vice versa) because the measurement methods employ quite different principles. However, relevant literature suggests that it may be possible to make estimates based on approximate comparisons.

Roe and Webster (1991) suggest that, for average uniformly textured surfaces, SMTD is approximately two thirds the MTD value. An estimated texture depth (ETD), can also be developed by combining equations found in PPR 148 (Viner, et al., 2006) and BS EN ISO 13473-1:2004 (British Standards Institution, 2004).

PPR 148 (Viner, et al., 2006) provides a relationship between SMTD and MPD:

$$MPD = 1.42 \times SMTD^{0.84}$$

Equation 4-1

BS EN ISO 13473-1:2004 (British Standards Institution, 2004) gives an equation for a value of ETD, based on MPD measures.

$$ETD = 0.2 + 0.8 \times MPD$$

Equation 4-2

Combining Equation 4-1 and Equation 4-2 gives the following relationship between SMTD and ETD:

$$ETD = 0.2 + 0.8 \times (1.42 \times SMTD^{0.84})$$

Equation 4-3

Equation 4-3 and the two thirds approximation made by Roe and Webster are in agreement for values of SMTD between approximately 0.5 mm and 1 mm but outside of this range the values diverge.

Using Equation 4-3, the values of SMTD quoted in HD29 have been converted into ETD values in the table below.

Table 4-6 TRACS Texture thresholds (ETD)

Category	Threshold value			
	1	2	3	4
Texture depth (mm)				
Anti-skid surfacing HFS	0.9	N/A	N/A	
All other surfaces	1.4	1.0	0.7	

The different requirements for texture depth are in general agreement that a retained texture depth of approximately 1 mm MTD is an acceptable limit for the Highways Agency network. IAN 154/12 expands on the requirements for asphalt roads providing more specific thresholds for different surfacing types and carriageway categories that had been found not to comply with the general trend observed in Figure 2-3. These values resulted from detailed high speed friction measurements on surfaces of these types. A similar approach may be sensible for concrete but the current understanding is that concrete surfaces obey the same texture / friction relationship as other surface types so it is likely that any change in texture threshold would be small.

4.2 Accidents and texture depth

A review of literature into accident risk and pavement texture depth was carried out. The aim of the review was to assess whether the current texture requirements could be amended overall or if different requirements could be applied to concrete surfacings.

The review showed that numerous attempts have been made to relate accident rates to road surface properties. All the attempts presented in this review show that, although relationships exist, there is a large amount of variability in the results. Road surface properties are rarely the main contributor to accidents and, while they are undoubtedly linked, surface characteristics generally play a minor part in accident occurrence.

4.2.1 UK Studies

Accident studies carried out in the UK have helped to build up a body of knowledge used in the preparation of pavement standards. One study of note is reported by Roe, Webster and West (1991), who made low speed skid resistance and texture measurements for a large percentage of the UK road network using a SCRIMtex device. Accident information was collected for the roads tested using the STATS 19 database. All the information was then combined using location references and a suitable texture requirement was calculated by determining the texture level below which the proportion of accidents exceeds that of the network. The study concluded that there is a trend for accident rate to increase as texture levels reduce and that a suitable level of texture is approximately 0.7 mm SMTD.

A second accident study conducted more recently is reported by Viner and Parry (2005). This report details work carried out to re-assess investigatory levels for skid resistance, specified in the design manual for roads and bridges, HD28/04 (Department for Transport, 2004). Road geometry, traffic flow, skid resistance, texture and accident information was gathered from several different databases and combined using location references. The primary aim of the work was to analyse the relationships between low speed skid resistance and accident occurrence, some analysis was also carried out to assess the relationship between low speed skid resistance, texture and accidents. The analysis concluded that both texture depth and skid resistance can influence accident rates on certain road categories. The relationship for non-event single carriageways is shown in Figure 4-1. This shows that the greatest accident risk occurs when the surface is subject to low texture and low skid resistance.

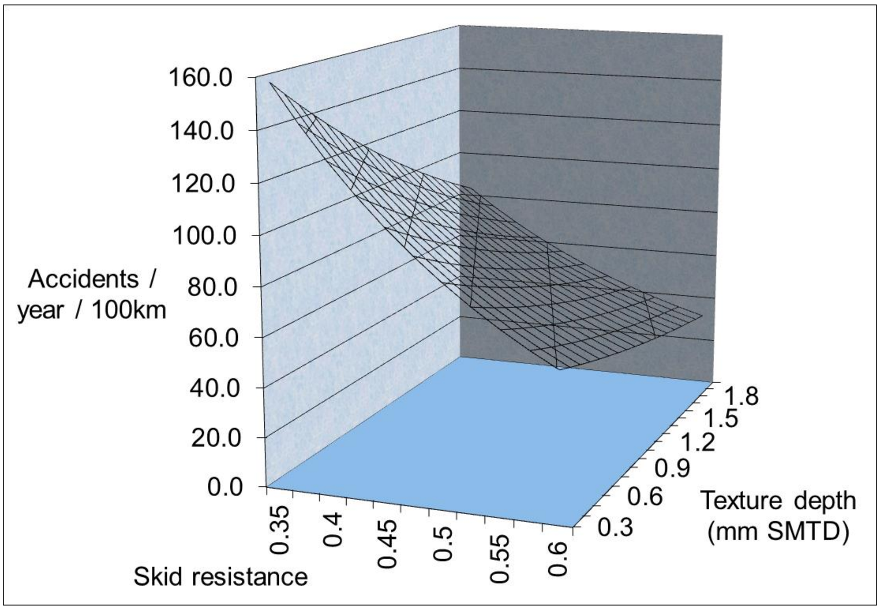

Figure 4-1 **Mean predicted all-accident rate by skid resistance and texture depth for single carriageways (Viner & Parry, 2005)**

4.2.2 Non-UK studies

Results from accident studies conducted in other countries should be viewed with caution because differences in legislation (speed limits, tyre tread limits, rules of the road etc.), driving characteristics (vehicles used, driver training, acceptable driving practices etc.) or environmental conditions, may influence the results.

Work carried out by Gothié (2000) and (2002) somewhat agrees with the research by Viner and Parry (2005). This work compared accident rates with skid resistance and texture values on approximately 200 km of roads. The results showed that accident rate tended to increase as either skid resistance or texture depth decreased. The increase in accident rate was particularly high for sections of road with very low skid resistance or texture.

Research conducted in Australia by VicRoads (2002) sought to calculate texture requirements for low traffic (<600 vehicles/lane/day) roads based on the relationships between texture levels and accident rates. For the roads studied the relationship between accident rate and texture showed that, as texture level reduced, accident rate increased. This research yielded texture limits for spray seal surfacings (similar to surface dressings) with aggregates of different sizes, as shown in Table 4-7. It is unfortunate that the method for measuring texture is not mentioned in the document.

Table 4-7 Spray seal surface texture limits (VicRoads, 2002)

Seal size	Minimum limit Early life (within 3 years)	Minimum limit Later life
7 mm seal	1.2 mm[1]	1.2 mm[1]
10 mm seal	1.4 mm	1.2 mm[1]
14 mm seal	1.6 mm	1.2 mm[1]

[1] Determined by an apparent increase in crash rate rather than a practically determined field texture.

A later Australian report (Cairney, 2005) describes two studies into the relationships between accidents and texture. For both studies, accident and texture measurements were made on a number of roads over 3 states. The first study was aimed at comparing the relationship between the number of accidents and texture directly. The second study had a larger scope and sought to compare rutting and other pavement characteristics, including texture, with accident rates.

The first study showed a strong relationship between decreasing texture and increasing accidents. This study showed that at textures below 0.3 mm SMTD the crash risk increased by 90%. The second study used crash rates (crashes/vehicle/km) whereas the first study simply used crash occurrences because sufficiently detailed traffic information was not available. Approaching the analysis using crash rates removes any skew that could occur in the results because of an over exposure to accident risk due to an increase in traffic flow. The second study showed that for sites with texture below 0.4 mm SMTD the crash rate was 80% greater than sites above that threshold.

A recent study carried out in Chongqing, China (Jianping, Boming, Haiying, Dong, & Ming, 2010) sought to develop a relationship between pavement texture levels and accident rate under wet pavement conditions. As with previous studies, accident and texture information was collected for lengths of carriageway and combined using location references. The results showed a relationship between wet weather accident rate and texture although it was statistically weak. The relationship showed that above a threshold the accident rate changed little and at low texture depths the accident rate rises sharply. The work concluded that pavements with texture levels below 0.4 mm MTD, or with a texture that changes by more than 0.3 mm per 100 m, negatively contribute to safety under wet conditions.

It appears as though little work has been carried out on this subject relating specifically to concrete carriageways. Work related to concrete carriageways identified as part of this review typically focussed on the more structural ailments associated with concrete carriageways such as cracking or stepping and so were outside the scope of the review.

4.3 High speed friction and accidents

In the USA, high speed friction is the standard measure for pavement skid resistance. No country wide assessment of high speed friction and accident risk was found, although state wide research papers from Virginia and Maryland were reviewed.

The relationship between accident and high speed friction in Virginia was assessed in 2004 (Kuttesch, 2004). The study found that there is a statistically significant relationship between high speed friction and accidents. As with the majority of studies comparing texture and accident risk this study also found a large amount of variability in the results. It was concluded that, for interstate highways, a target minimum friction value of 40, measured at 40 miles/hour (64 km/h), appears to have an effect on reducing wet weather accidents.

A paper submitted to the Transport Research Board in 2003 (Chelliah, Stephanos, Shah, & Smith, 2003) outlines a proposed design policy for the Maryland State Highway Administration aimed at minimising future wet surface accidents. As well as outlining the proposed design methodology the paper also gives some useful information regarding pavement design friction levels. Table 4-8 gives proposed design friction values for various site categories. This is a similar approach to that taken in the UK whereby higher demand sites (approaches to junctions for instance) are assigned a higher skid resistance requirement compared with lower risk sites such as motorways.

Friction and texture relationships are discussed in previous research (Roe, Parry, & Viner, 1998). From these relationships the texture required to generate a surface with the required design friction can be estimated. Because friction changes with speed, the relationship between friction and texture also changes with speed. Chelliah et al. (2003) do not state the measurement speed for the given design frictions so the standard test speed of 40 miles/hour (64 km/h) has been assumed (ASTM, 2011). Equation 4-4, derived from the earlier research by Roe, Parry and Viner, was used to estimate the SMTD required to generate the required high speed friction at 64 km/h, as stated in the Maryland study.

$$SMTD = 0.007{FN_{40}}^{1.267}$$

Equation 4-4

Table 4-8 shows the texture required to provide the design friction shown, having been estimated from a friction/texture relationship at 64 km/h.

Table 4-8 Site categories design friction (Chelliah, et al., 2003) and estimated texture depth requirements

Site category	Site description	Design Fn	*Estimated texture requirement SMTD (mm)*[g]
1	Approach to rail road crossings, traffic lights, pedestrian crossings, roundabouts, Stop and Give Way controlled intersections	55	*1.12*
2	Curves with radius ≤250 m, downhill gradients >10 % and 50 m long, Freeway/highway on/off ramp	50	*0.99*
3	Approach to intersections, downhill gradients 5 to 10 %	45	*0.87*
4	Undivided highways without any other geometrical constraints which influences frictional demand	40	*0.75*
5	Divided highways without any other geometrical constraints which influences frictional demand	35	*0.63*

[g] Values have been estimated using the relationship in Equation 4-4.

4.4 Conclusions from literature review

The literature review has shown that the requirements for road surface texture laid out in UK standards are in general agreement that a texture of 1 mm MTD is an acceptable level for the strategic road network. Interim advice note 154/12 (Department for Transport, 2012) expands the texture requirements to allow certain thin surfacing materials to retain a texture of 0.7 mm based on evidence that the high speed friction characteristics of the surface are not compromised.

A review of research to date on the relationship between texture and accident rates showed that, although there is a link between texture and accident rate, there is a large amount of variability in the results. A number of papers quoted texture thresholds, which are summarised in the Table 4-9, below. Texture thresholds that have been calculated from high speed friction values, and those reported as ETD should be viewed with caution. The texture- high speed friction and SMTD - ETD relationships will have margins of error associated with them and so values calculated using these relationships should be viewed as estimates.

Table 4-9 Recommended texture thresholds

Paper	Threshold definition	Threshold		
		FN_{40}	SMTD	ETD
(Roe, Webster, & West, 1991)	Below this threshold the percentage of accidents exceeds that for the network as a whole.	N/A	0.70	1.00
(Cairney, 2005)	Below this threshold crash rate was 80% greater than above the threshold.	N/A	0.40	0.70
(Jianping, Boming, Haiying, Dong, & Ming, 2010)	Textures below this threshold negatively contribute to safety and are to be re-surfaced.	N/A	0.40	0.70
(Kuttesch, 2004)	Textures below this threshold have the effect of reducing wet weather accidents.	40	0.75[h]	1.09
(Chelliah, Stephanos, Shah, & Smith, 2003)	Design threshold for newly constructed non-event highways.	35	0.63[i]	0.97

Compared with these thresholds the current UK TRACS thresholds, and in particular the threshold between category 3 (moderate deterioration) and category 4 (severe deterioration), of 0.4 mm SMTD, is well placed. The evidence collected for this review does not support a relaxing of the current texture threshold limit. A secondary aim of the review was to assess whether different texture requirements could be introduced for concrete surfacings. There was not enough evidence to support this.

[h] Estimated using the relationship in Equation 4-4

5 Current knowledge of concrete re-texturing techniques

This chapter will present the current state of knowledge for the following re-texturing options:

- Longitudinal diamond grinding (LDG)
- Bush hammering
- Shot blasting
- Shallow fine milling.

Recommendations as to what testing can be undertaken to best supplement this knowledge are also made. For each option the following properties will be presented:

- The associated hazards. For the purposes of this report a hazard is defined as any process issue that may preclude the routine application of the option.
- Expected failure mechanisms. The work detailed within this report is based on a pavement being found to be structurally sound and with skid resistance or texture characteristics that require addressing. To this end it is expected that the failure mechanism for the majority of re-texturing options will be a reduction in skid resistance or texture.
- Expected noise characteristics. The expected level of noise generated between the tyre and road surface is presented within this category.
- Effective service life. The estimation of effective service life requires some explanation and is described in the paragraphs below.

Given that the expected failure mechanism is a reduction in skid resistance or texture and that texture is used as a surrogate for high speed friction, effective service life is considered with regard to skid resistance and friction levels. In terms of road user safety, both low speed skid resistance and high speed friction are important factors and so service life shall be estimated based on these properties.

Standards for low speed skid resistance are presented in HD28/04 (Department for Transport, 2004). The effective service life of the options in terms of low speed skid resistance shall therefore be the point at which the skid resistance falls below the investigatory level appropriate for the site.

A type approval standard for high speed friction is currently being developed for inclusion within the HAPAS accreditation scheme for new road surfacings. The development of this standard is on-going, but proposed acceptable levels of high speed friction have been determined. Historic PFT results show that measurements taken on concrete roads greater than the proposed HAPAS level are within the upper 5th percentile of all measurements taken on concrete roads. This measure may therefore be unsuitable for assessing effective service life in this case. The effective service life in terms of high speed friction for the proposed options shall therefore be defined as the point at which a treatment is providing high speed friction consistent with pre-treatment levels.

In practice, the actual service life (i.e. the amount of time that any option shall be in place without alteration) is dependent upon a much broader range of factors such as surface condition and accident rate. Assessing the service life of each option in terms of its skid resistance and friction levels is used here as an analytical tool for comparing treatments against one another.

5.1 Longitudinal diamond grinding

5.1.1 Description of option

The longitudinal diamond grinding (LDG) process involves passing a rotating profiled drum over the pavement surface. The drum is composed of a number of circular, diamond coated, blades arranged to create the desired profile. During the grinding process the revolving drum is forced onto the pavement surface under a vertical load and pulled at a constant speed in the direction of traffic. The blades cut a macrotexture into the pavement surface whilst removing a thin layer (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, water is continually applied to the interface from an on-board tank. The resulting surface texture consists of longitudinal grooves approximately 2-3 mm wide, 3-4 mm apart and 0.5-1.5 mm deep.

5.1.2 Associated hazards

Environmental considerations must be made before carrying out LDG. Firstly, the process of grinding concrete pavements is a noisy one; exposure to residents should therefore be mitigated if possible. The arisings from the grinding technique can be hazardous to plant life and so should be properly recycled or disposed.

If this technique is to be applied to the whole pavement, all iron work (e.g. cats eyes) must be removed because they have the potential to damage the grinding head or eject sharp metals which could harm people in the vicinity.

5.1.3 Expected noise characteristics

Noise measurements for this option were made as part of a period of monitoring undertaken to assess the noise and frictional properties of this surface. Noise measurements show that a significant reduction in noise can be achieved with this process. The longevity of this reduction in noise has not been quantified and anecdotal evidence from the area maintaining agent and local residents suggests that the improvement has continued for a period of at least 3 years.

5.1.4 Effective life of treatment

Research into the longer term effects of LDG (Sanders, Wayman, Dunford, & Viner, 2012) assessed the frictional performance of this treatment over a 36 month period. The report concluded that, in terms of low speed skid resistance, the surface was producing values above the 0.35 investigatory level throughout the monitoring period. The report also stated:

"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."

This statement was based on declining high speed friction values over the 36 month period; it would be of benefit to re-assess these sites to ascertain whether the reduction has continued. Furthermore, this statement was based on the experience of a small number of sites and it is not known if it would hold true for surfaces with different constructions or constituents (e.g. coarse aggregates).

5.1.5 Recommended further investigation

It would be useful to re-visit the LDG sites reported by Sanders et al. (2012) and make high speed friction measurements to ascertain whether the trends shown throughout previous monitoring persist in the longer term.

Evidence for the acoustic performance of this option has been collected during the early life phase of service. Noise measurements made on some surfacings show that noise properties can change over time and it may therefore be of benefit to make further noise measurements from a longitudinally diamond ground surface that has been in service for at least 4 years.

5.2 Bush hammering

5.2.1 Description of option

The bush hammering process involves striking the road surface with a number of impact heads containing hardened tip chisel ended hammers. The effect of this process is to erode the cementitious matrix of the road surface to restore texture.

5.2.2 Associated hazards

As with longitudinal diamond grinding the bush hammering technique is a noisy one and strategies to mitigate the amount of disruption by noise when the process is being applied may have to be considered in some cases. Given that this option is impact based there is an inherent risk of damaging the surface or creating micro-cracks in the pavement surface.

5.2.3 Expected noise characteristics

Currently there is no information relating to the noise properties of this option.

5.2.4 Effective life of treatment

The on-going friction monitoring of a number of trial re-surfacing options on the M27 and M271 have provided skid resistance and friction results for a bush hammered surface over a 15 month period.

The high speed friction measurements show an immediate improvement in high speed friction as a result of the treatment. The majority of the improvement was lost after 5 months of service but remained stable for the remainder of the 15 month monitoring period. A service life therefore cannot be determined because it is not known whether this trend will continue, or if values will start to reduce at some point in the future.

5.2.5 Recommended further investigation

High speed friction monitoring of this site is to be continued under a different project sponsored by the Area 3 maintaining agent until the surface life reaches 29 months. The results from monitoring could be used to determine an expected service life.

Currently no noise performance information is available for this option, it is therefore important to make noise measurements.

5.3 Shot blasting

5.3.1 Description of option

Shot blasting uses a similar principle to bush hammering. During this process the road surface is impacted by steel shot propelled at the road by a rotating wheel. The shot erodes the cementitious matrix of the road to restore texture. During the blasting process the shot and arisings are collected and separated so the shot can be re-used.

5.3.2 Associated hazards

As with LDG, a considerable amount of dust can be created during shot blasting, it may therefore be necessary to wet the pavement to control the dust. Many shot blasting machines have an on-board capability to achieve this.

5.3.3 Expected noise characteristics

Currently there is no information relating to the noise properties of this option.

5.3.4 Effective life of treatment

The performance of this treatment is very similar to that of the bush hammering treatment and as with bush hammering it is not possible to determine a service life without further measurements being made.

5.3.5 Recommended further investigation

It would be beneficial to carry out the same measurements on this surface as have been suggested for the bush hammering treatment.

5.4 Fine milling

5.4.1 Description of option

The fine milling process used a rotating profiled drum to remove surface material. The fine milling drum is constructed from hundreds of point attack tools arranged in a grid pattern with spacings less than 8 mm. During milling, the head is forced into the pavement surface as it rapidly revolves and is pulled along the road at a constant speed.

The milling head cuts a fine texture into the road surface. When a texture of less than 1 mm is cut the process is referred to as shallow fine milling. The fine milling process can also be used to affect the surface profile and ride quality of a carriageway. This process requires the removal of more than 1 mm of material and is referred to as deep fine milling. Shallow fine milling is assessed in this document because there is little experience of the deep fine milling technique in the UK and so proper comment cannot be made.

5.4.2 Associated Hazards

The hazards associated with fine milling are similar to LDG: both are noisy, create arisings that are hazardous to plant life and require the removal of ironwork if the whole carriageway is to be treated. These issues should therefore be taken into consideration when using fine milling.

5.4.3 Expected noise characteristics

Currently there is no information relating to the noise properties of this option.

5.4.4 Effective life of treatment

To estimate the effective service life of the fine milling option, information can be used from the M271 and M27 monitoring. As with the other mechanical re-texturing techniques discussed here, an immediate improvement in low speed skid resistance is recorded after treatment. This improvement in low speed skid resistance remained at a similar level throughout the 15 month monitoring period.

An improvement in high speed locked-wheel friction has been maintained over the 15 month monitoring period. The peak friction has shown a reducing trend over the 15 month period but, despite this, the level is still significantly greater than the surface before treatment.

It is therefore not possible to determine a service life for this treatment without further measurements being made.

5.4.5 Recommended further investigation

It would be beneficial to carry out the same measurements on this surface as have been suggested for the bush hammering treatment.

5.5 Other re-texturing options

The following are recommended within HD38/97 of the DMRB (Department for Transport, 1999) as methods of re-texturing concrete roads. These techniques are not fully detailed in this report because they are either well established techniques or no longer widely used.

- Transverse grooving – diamond tipped blades are used to cut grooves into the surface at right angles to the direction of travel
- Longitudinal scabbling – a series of hardened tipped steel washers are loosely mounted side-by-side, hydraulically loaded and drawn across the road surface to remove worn ridges
- Hot compressed air – this process uses hot air to dehydrate and thermally shock the cement matrix of the pavement to remove a layer of the matrix material increasing pavement texture
- High pressure water jetting – this is essentially a cleaning process using high pressure water to remove detritus, oil and tyre material.

6 Site surveys to further existing knowledge

This chapter describes the noise and friction surveys that were carried out to expand the current pool of knowledge on the performance of concrete re-texturing techniques.

6.1 Noise

Due to financial and time constraints it was not possible to make additional noise measurements on all recommended surface types discussed in Chapter 5:

- Bush hammered
- Shot blasted
- Fine milled
- LDG surface over 4 years old.

Given their proximity and the lack of historical information, it was most beneficial to conduct measurements on the bush hammered, shot blasted and fine milled surfaces used as part of a trial on the M27. Measurements were made when each of these treatments had been in service for approximately 22 months.

Noise measurements were made according to the Statistical Pass-By (SPB) method prescribed in ISO 11819-1:2001 (ISO, 2001). This is the preferred method for comparing the noise emitted from road vehicles on different surfaces and classifying the acoustic performance of the surface. The results were analysed in accordance with the HAPAS noise certification guidelines (BBA, 2008) to enable comparison with noise levels with other road surfaces.

The acoustic performance of the different treatments was determined by calculating the Road Surface Influence (RSI) used in HAPAS assessments, which is the estimated difference in traffic noise levels expected from the measured road surface relative to a reference road surface assuming typical traffic conditions for the selected road category.

The reference surface is one for which no surface correction is required in the UK standard road traffic noise prediction model 'Calculation of Road Traffic Noise' (Department of Transport and Welsh Office, 1988). This is generally considered as a new HRA surface with 20 mm chippings.

The results of the measurements made on the M27 are summarised in Table 6-1. Also included for comparison in Table 5 1, are values from the measurements made on the newly treated LDG surface and an adjacent section of untreated carriageway on the A14.

Table 6-1 SPB measurements on concrete roads

Surface treatment	RSI value
Fine Milling	+2.1*
Shot Blasting	+1.7*
Bush Hammering	+1.7*
LDG	-4.0**
Typical aged brushed concrete	+2.7**

*From M27
**From A14

The results from SPB testing show that the fine milling treatment is providing the greatest RSI and LDG surface the lowest. Only broad comparisons between the surfacings on different sites can be made but noise generated after fine milling appears to be comparable to noise generated by a typical concrete surface. It is possible, therefore, that if the original surface is providing lower than average noise properties that the fine milling treatment could increase the amount of noise generated. The shot blasting and bush hammering treatments are generally producing lower RSIs than that of the typical concrete. Whilst it is possible that these surfaces may improve the acoustic performance of the surface, the RSI values are still high. It is clear that the LDG treatment has the effect of reducing the noise generated.

6.2 High speed friction

To supplement the current friction knowledge, further high speed friction testing was carried out. LDG surfaces on the A12 and A14 were measured during May 2013 and the results added to those collected as part of previous works. Surveys of the fine milled, shot blasted and bush hammered surfaces on the M27 and M271 were also undertaken as part of a separate monitoring programme during June and October 2013.

All high speed friction testing was carried out in accordance with ASTM standards (ASTM, 2011) and (ASTM, 2008) using the HA Pavement Friction Tester (PFT) (Figure 2-2).

The following sections present typical results from the PFT measurements made on LDG, fine milled, shot blasted and bush hammered concrete surfaces. The graphs in the following sections are intended to demonstrate the general behaviour of these surfaces only. Full reports on the frictional performance of the re-textured concrete surfaces on the A14/A12 (LDG) and M27/M271 (fine milling, shot blasting and bush hammering) can be found in TRL reports PPR 607 (Sanders, Wayman, Dunford, & Viner, 2012) and PPR 676 (Sanders, Dunford, & Viner, 2013) respectively.

Each graph shows the average peak or locked-wheel friction at 90 km/h[i] and, where applicable, control results (collected from adjacent un-treated concrete) have been included. Furthermore, using TRL's database of friction tests, the 90th percentile range of measurements made on HRA and concrete surfacings have been included as reference.

6.2.1 Longitudinal diamond grinding

The frictional performance of three sites treated with LDG has been monitored. The sites are located on the A12 Chelmsford bypass, A12 Kelvedon bypass and A14 Whitehouse to Copdock. The results for the A12 only have been presented for reference because the measurements made on the A14 are similar to those measured on the A12 Kelvedon site.

High speed friction results are variable for the LDG treatment; the Chelmsford and Kelvedon sites demonstrate different behaviours. The locked-wheel friction results from the Chelmsford site, shown in Figure 6-1, are similar for the 36 and 52 month measurements. The Kelvedon site (Figure 6-2), however, appears to show a continual

[i]Standard E274/E274M-11 (ASTM, 2011) states that the standard test speed shall be 40 mph (65 km/h). A 90 km/h test speed is used in this case because this better represents the speed of motorists on the UK road network. This gives the added advantage of a safer operating procedure during testing.

reduction in friction over the monitoring period but, since measurements have not been made over as long a period, a comparison is difficult. The treated sections on the Chelmsford site provided higher locked-wheel friction than untreated control sections until 52 months after treatment, but the treated sections on the Kelvedon site do not appear to have provided higher locked-wheel friction than the control sections at any time.

The peak friction behaviour is reversed with the measurements on Chelmsford site suggesting a continual reduction (Figure 6-3) and the Kelvedon site providing two similar measurements (Figure 6-4). Peak friction provided by the Chelmsford site remained above the untreated control until 52 months of service, when the values measured were comparable. Peak friction on the LDG sections of the Kelvedon site became comparable to untreated concrete after approximately 30 months of service.

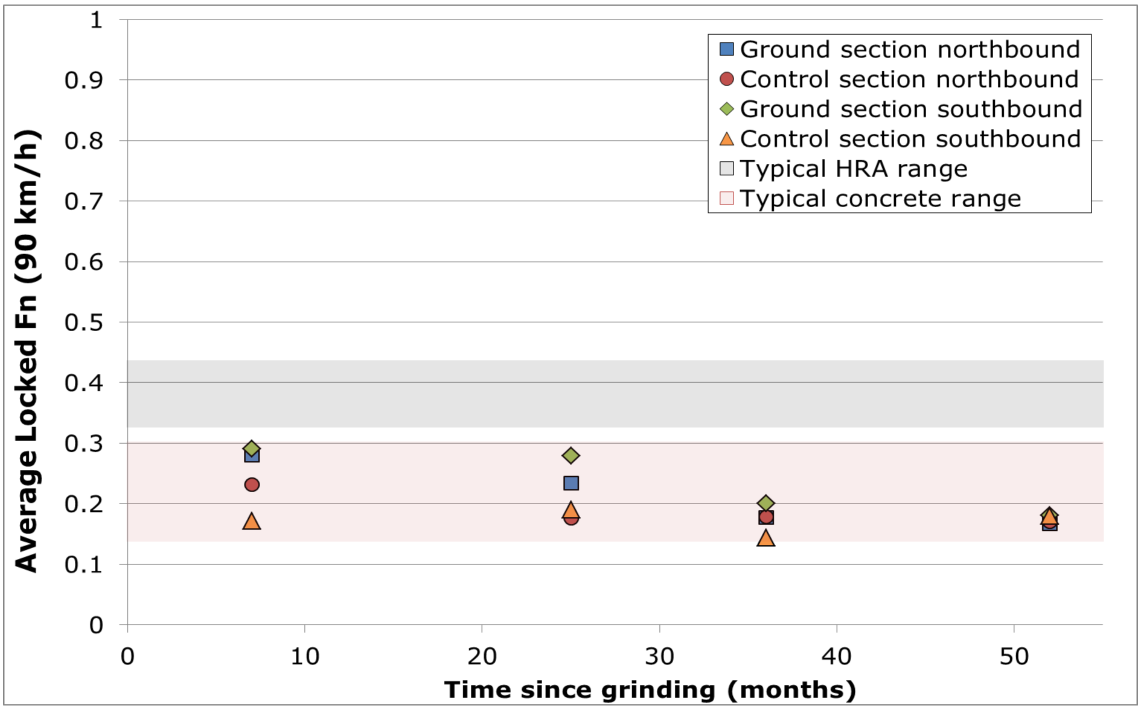

Figure 6-1 A12 Chelmsford locked-wheel friction

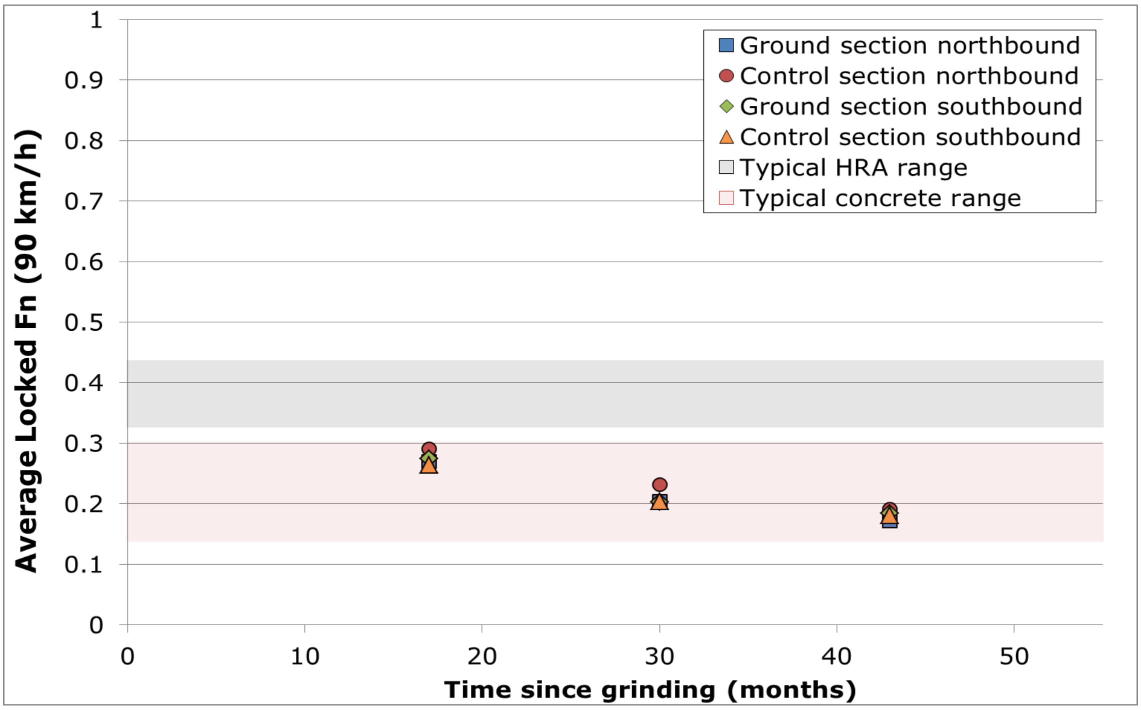

Figure 6-2 A12 Kelvedon locked-wheel friction

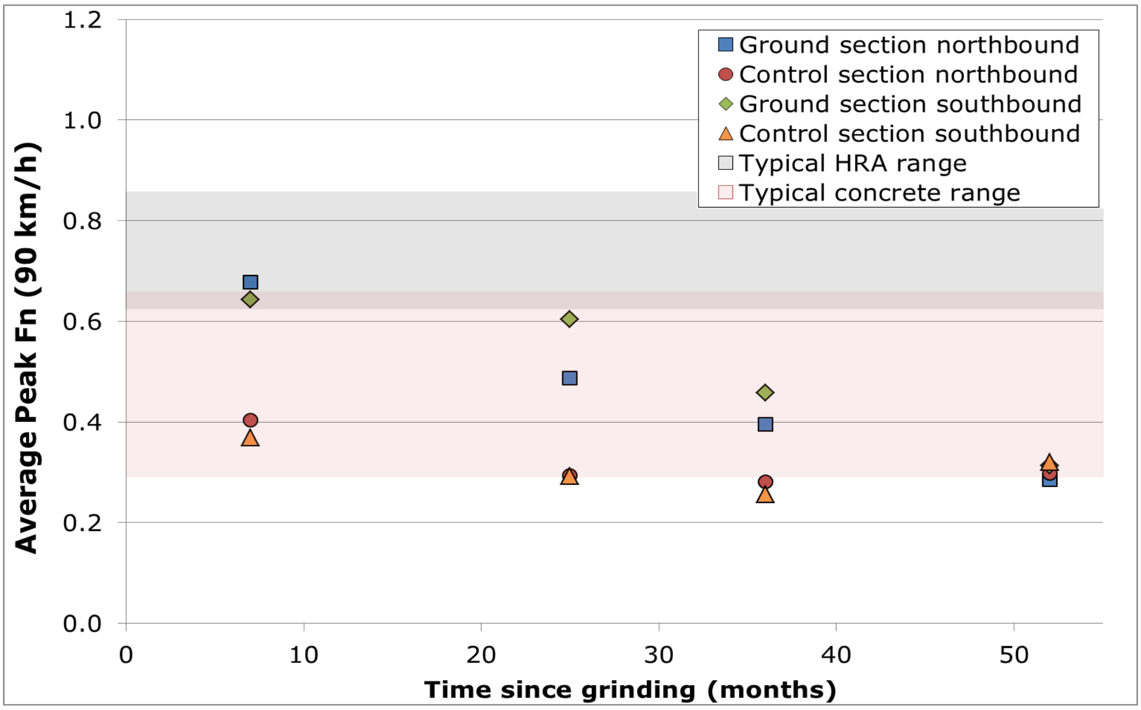

Figure 6-3 A12 Chelmsford peak friction

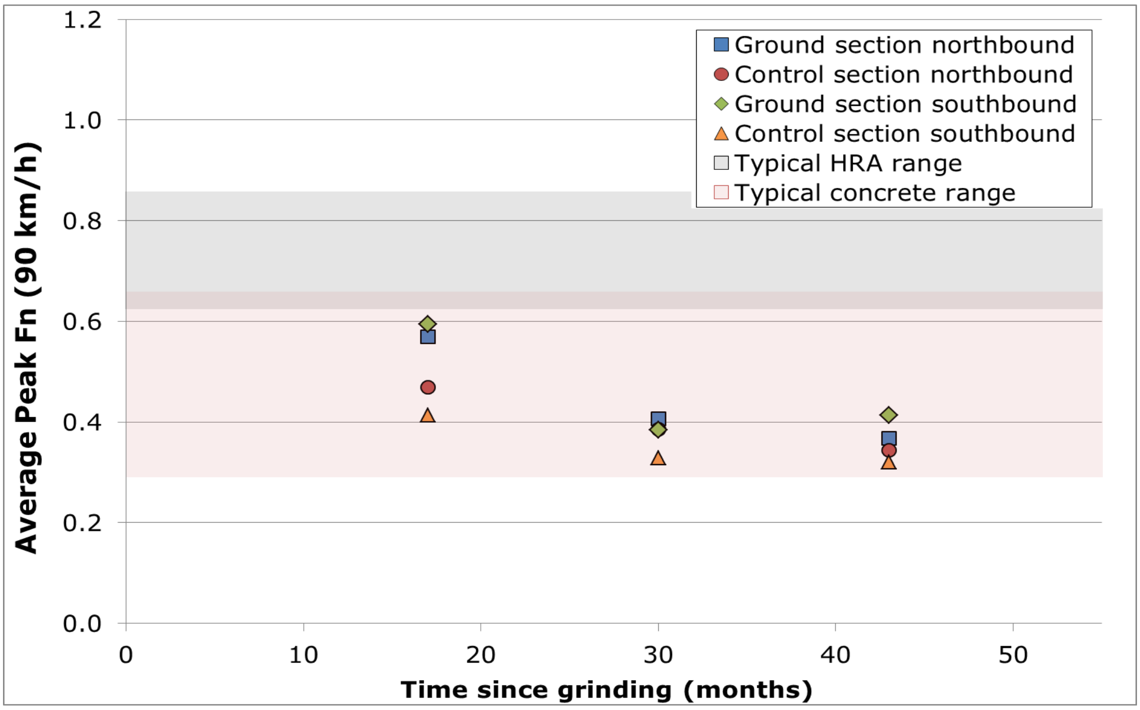

Figure 6-4 A12 Kelvedon peak friction

6.2.2 *Fine milling, shot blasting and bush hammering*

A trial of fine milling, shot blasting and bush hammering was conducted on the M27 at junction 7. Control sections that were tested at the start of the trial were subsequently treated with fine milling so further control measurements are not available.

Figure 6-5 and Figure 6-6 show that the high speed friction performance of all the re-texturing treatments starts to reduce after 15 months of service. If the trend in reducing high speed friction continues, the performance of the fine milled surface will fall below that of the untreated section after approximately 36 months. The shot blasting and bush hammering treatments were performing at a similar level to the control section at 15 months and reductions after this point, although small, place the performance of these treatments below that of the control.

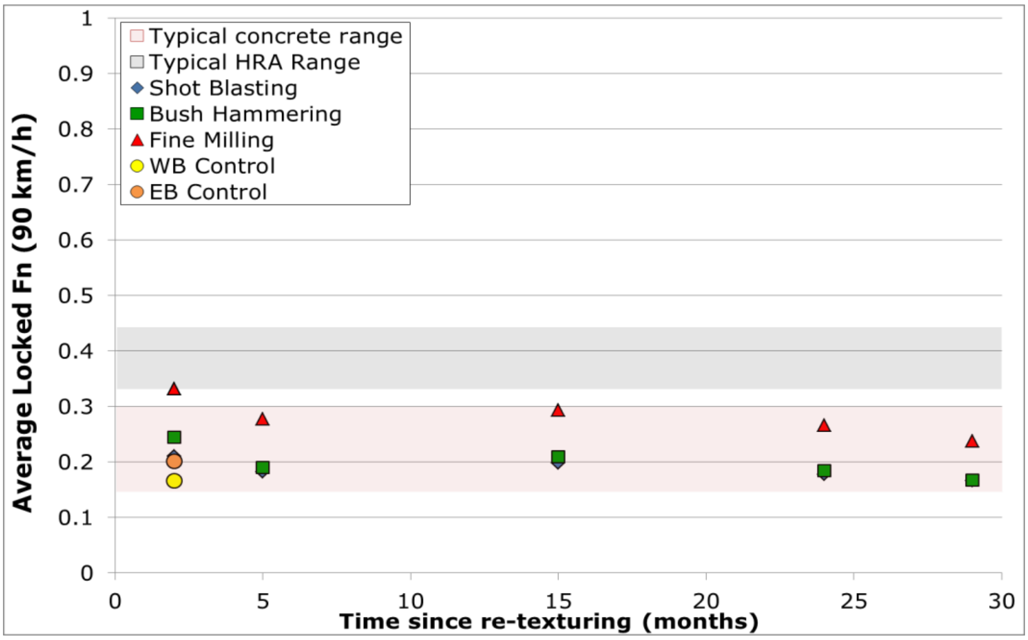

Figure 6-5 M27 locked-wheel friction

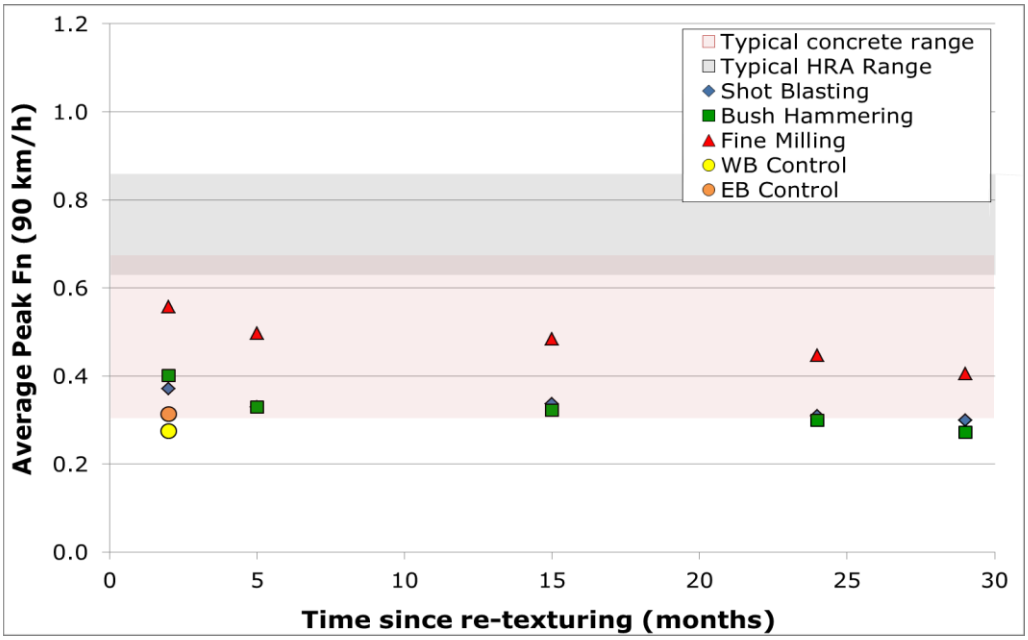

Figure 6-6 M27 peak friction

7 Summary and discussion

This chapter summarises the information gained through this study and discusses its practical implications for the more wide spread use of the re-texturing techniques.

7.1 Texture thresholds

A review of the current UK texture thresholds and relevant literature was carried out to ascertain whether thresholds could be reasonably adjusted.

Compared with texture thresholds given in other research, summarised in Table 4-9, the current UK TRACS thresholds and, in particular, the threshold between category 3 (moderate deterioration) and category 4 (severe deterioration), of 0.4 mm SMTD, is well placed. The evidence collected does not support any relaxation of the current in-service texture requirements.

A secondary aim of the review was to assess whether a specific threshold could be assigned to concrete surfaces. There was not enough evidence to support amending concrete texture thresholds one way or the other. However, it may be pertinent to extend the methodology of allowing surfaces within TRACS category 3 and 4 for texture to be used if they can provide suitable high speed friction performance. It is logical that, should a low textured carriageway with a low accident rate demonstrate no change in monitored high speed friction, then the accident risk ought to remain relatively low, despite low texture values.

7.2 Low speed skid resistance and high speed friction

Low speed skid resistance and high speed friction information was collected for each re-texturing technique.

It was found that, in general, the average values for low speed skid resistance are improved as a result of re-texturing. Some interesting variability was noticed on the surfaces treated with fine milling and LDG. In some local areas skid resistance fell significantly and, in some cases, below the assumed 0.35 investigatory level. Full details can be found in TRL reports PPR 607 (Sanders, Wayman, Dunford, & Viner, 2012) and PPR 676 (Sanders, Dunford, & Viner, 2013). Both the fine milling and LDG treatments use a profiled cylindrical drum. It has been speculated that the reductions in skid resistance are related to areas of pavement that fall below the re-texturing drum, due to local variations in surface megatexture, and so remain the original surface. It is not known whether this is a natural limitation of the techniques or if it could be due to limited operator experience.

An improvement in average high speed friction was also gained as a result of re-texturing. For the shot blasting and bush hammering treatments this improvement was minimal and for fine milling and LDG was more marked. High speed friction results varied from site to site but the general behaviour observed was that the high speed friction properties improved for a while and then appear to reduce with time. The extent of the reductions in high speed friction can affect the service life of the treatment, which is discussed in the next section.

7.3 Service life

Indications from measurements made on the LDG sites at the time of writing PPR 607 (Sanders, Wayman, Dunford, & Viner, 2012) showed that two sites were experiencing reductions in high speed peak friction. If these reductions had to continued, the friction level would fall below the control sections after 36 months of service. A service life of 36 months was therefore assigned in PPR 607.

Subsequent measurements have shown that one site is showing results consistent with those measured on the control sections after 52 months of service. The service life quoted in PPR 607 may therefore be cautious because it is becoming clear that the LDG technique results in different performance depending on the surface to which it is applied. Assessing all of the available information, a service life range of between 36 and 52 months can be assigned to the LDG technique.

The fine milling treatment may be appropriate for use in the short to medium term. Measurements made up to 2 years in service were promising but information after this time is not yet available. The point at which the high speed friction performance of the treatment should fall below that of the untreated surface has been calculated at approximately 36 months. However, it should be noted that this is based on the extrapolation of results from a single site and is therefore subject to change when new information becomes available. A cautious approach would be to assign a service life to the fine milling treatment of less than 36 months.

The performance of the shot blasted and bush hammered surfaces was comparable with that of the untreated section after 15 months of service. After this time the performance started to reduce, it is therefore necessary to assign an effective service life of 15 months to these surfaces.

7.4 Noise

Noise results in Table 6-1 show that, with an average RSI of -4.0, the LDG treatment produces a surface markedly quieter than the original surface. The fine milling treatment produced RSI values of +2.1, which were generally comparable with those measured on a typical grooved concrete surface. It may be possible that, depending on the original state of the surface, the fine milling treatment could increase the amount of noise generated. RSI values for the fine milling, shot blasting and bush hammering treatments were all of an order that would require their use in noise sensitive areas to be restricted.

7.5 Further monitoring

There is, as yet, little experience in the UK in using the concrete re-texturing techniques discussed in this document. The information used in this report was gathered from a small number of sources and it is likely that the use of these techniques on different surfaces will generate different results depending on pavement construction. Because the performance of the techniques on other surfaces is unknown it is necessary to monitor the skid resistance, friction and texture characteristics of new applications to ensure road user safety. Conditions of departures from standards have ensured that suitable monitoring is carried out.

As these techniques become more widely adopted and further information gathered, the understanding of the performance of the techniques will also develop, allowing techniques to be efficiently selected for different applications.

7.6 Comparison of re-texturing techniques

The re-texturing techniques discussed in this report are summarised and compared in Table 7-1. This table represents the best knowledge available at the time of writing, some of which is based on a small number of observations; values may be subject to change in light of new information.

Table 7-1 Summary of re-texturing options

Treatment option	Brief description	Service life of option (months)	Process issues	Road user benefits and issues	Departure required	Typical departure requirements
Longitudinal diamond grinding	A rotating profiled drum is passed over the surface to remove between 1 mm and 10 mm of the surface leaving a series of longitudinal grooves.	36 to 52	The process is noisy, considerations should be made to mitigate the exposure to local residents. Arisings should be disposed of in the proper manner, or recycled. Iron work to be removed prior to treatment and replaced afterward.	The finished surface is very smooth and quiet ride quality is improved and, stepping is reduced.	Yes	Monitoring of skid resistance, high speed friction and road geometry over at least a 5 year period.
Bush Hammering	The road surface is struck with a number hardened tip chisel ended hammers. The cementitious matrix of the road surface is eroded to restore texture.	15	The process is noisy, considerations should be made to mitigate the exposure to local residents. The repeated impacts received could damage the surface or create micro-cracks.	Little change from pre-treatment noise levels.	Yes	Monitoring of skid resistance, high speed friction and road geometry over at least a 2 year period.
Shot blasting	The road surface is impacted by steel shot propelled at the road by a rotating wheel. The cementitious matrix of the road is eroded to restore texture.	15	Dust production can be significant and should therefore be controlled. Shot particles to be collected during treatment for reuse and to remove from carriageway	Little change from pre-treatment noise levels.	Yes	Monitoring of skid resistance, high speed friction and road geometry over at least a 2 year period.
Fine milling (shallow)	A rotating profiled drum is rotated over the surface to remove material. The milling head cuts a fine texture into the road surface.	<36	The process is noisy, considerations should be made to mitigate the exposure to local residents. Arisings should be disposed of in the proper manner, or recycled. Iron work to be removed prior to treatment and replaced afterward.	Likely to be slightly more noisy than before treatment.	Yes	Monitoring of skid resistance, high speed friction and road geometry over at least a 3 year period.

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Appendix A Supporting information on concrete condition

The following tables are the results of analysis carried out on the HAPMS database for records between 2006 and 2011.

Table 7-2 shows lengths of the Highways Agency network for asphalt roads that have concrete below the surface. The asphalt thickness is the thickness of asphalt material between the road surface and concrete layer.

Table 7-2 Length of HA network with concrete below the surface layer

Asphalt thickness (mm)	Length (km)						
	2006	2007	2008	2009	2010	2011	2012
0<=50	1,977	1,938	1,903	1,809	1,745	1,746	1,724
50<=100	2,596	2,746	2,733	2,679	2,637	2,595	2,578
100<=200	6,795	7,080	7,175	7,152	7,102	7,253	7,257
>200	12,313	12,668	12,808	12,768	12,752	13,546	13,497

Table 7-3 shows lengths of the Highways Agency network for which construction details are available.

Table 7-3 Network definition and population of construction details in HAPMS

	Length (km)						
	2006	2007	2008	2009	2010	2011	2012
Network length	35,800	35,534	35,331	35,222	35,313	35,398	35,670
With construction details	32,769	33,166	33,049	32,739	32,772	33,149	33,638
No construction details	3,031	2,368	2,282	2,484	2,540	2,249	2,032

Table 7-4 shows the distribution of investigatory level thresholds for the concrete surface carriageways on the Highways Agency network.

Table 7-4 Percentage of concrete surfaces within investigatory level categories

IL	2005	2006	2007	2008	2009	2010	2011
0.35	85.80%	85.80%	85.86%	87.76%	87.65%	87.63%	87.61%
0.40	8.85%	8.85%	7.98%	8.65%	8.65%	8.65%	8.68%
0.45	4.22%	4.22%	5.03%	2.59%	2.70%	2.70%	2.70%
0.50	1.12%	1.12%	1.13%	0.90%	0.90%	0.92%	0.92%
0.55	0.00%	0.00%	0.00%	0.10%	0.10%	0.10%	0.10%

Surface Treatment Options for Concrete Roads

Many of the concrete road surfacings in the UK have been in service for over 30 years and are starting to suffer from reductions in skid resistance and texture. This report explores the state of the concrete network in the UK and the use of concrete re-texturing techniques as a method of restoring skid resistance and texture.

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