DURABILITY OF THIN SURFACING SYSTEMS IN THE UK AFTER NINE YEARS MONITORING

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ABSTRACT

Thin surfacing systems, as the term is currently understood, were introduced into the UK in 1991. Many sites with thin surfacing systems have reached or are approaching the end of their assumed lives so that a review of the service that can be expected from such surfacings can now be made with some confidence. The information collected from a selection of sites with thin surfacing systems has been evaluated in order to establish their serviceable life. In this report, the results from visual condition, SCRIMtex and recovered binder properties are given for sites monitored over the last three years of this review together with analysis of these data together with the results from preceding years, a total of 137 sites. The findings, now extended by a further three years monitoring since the last published report, indicate that, if a thin surfacing system is in a good condition after its first year in service, it will be serviceable for at least 5 years and the typical life of a thin surfacing system is about ten years, depending on the type of thin surfacing system and the condition of the substrate. The average life of the most commonly used systems (10 mm and 14 mm BBTM and SMA systems) is over 13 years.

Keywords: Stone mastic asphalt, Ultra thin asphalt layers, Durability, Skid resistance, Macro texture

1 INTRODUCTION

Asphalt surface course layers for major roads in the UK typically used to be at least 40 mm thick. Thinner surface course materials were available before 1990, but they were considered to be technically inferior and were only used on roads carrying low traffic levels within the county road networks. However, during the 1990s, various types of thin surfacing that have beneficial properties (in particular speed of laying and reduced noise and spray) were introduced into the UK, mostly from the continent [1]. Thin surfacing systems (or thin surfacings for short) have gained a significant share of the surface course market in all parts of the network because of these improved properties.

Thin surfacing systems are not a single generic type of asphalt but are defined in the UK as any bituminous material laid at a thickness of 50 mm or less that has a Highway Authorities Products Approval Scheme (HAPAS) certificate. Currently, there are certified products in the following categories:

- UTLAC Ultra-thin surfacings developed in France
- BBTM Very thin surfacings, generally with polymer-modified binder
- SMA Stone mastic asphalt, generally unmodified bitumen with fibres
- MSD Multiple surface dressings, generally with polymer-modified binder and aggregate applied separately
- MS Micro-surfacing or thick slurry surfacing, generally with modified binder

These system types can be grouped into (a) asphalt systems (mixtures of aggregate and bituminous binder mixed hot, generally off site) and (b) surface treatment systems. For this purpose, the asphalt systems are UTLAC, BBTM and SMA and the surface treatment systems are MSD and MS.

The first of the thin surfacing systems currently used in the UK was imported from France in 1991. This ultra thin layer asphalt concrete (UTLAC) surfacing system had been modified slightly from the French design in order to achieve the texture depth required for high-speed trunk roads in the UK. A thin asphalt concrete (BBTM) surfacing system was introduced in 1992, with other systems following either directly from France or developed in the UK but based on similar concepts to those used in France (Nicholls et al, 1995). In 1994, stone mastic asphalt (SMA) was introduced into the UK from Germany and trialled in this country, from which a variety of thin stone mastic products were developed (Nunn, 1994). In 1995, a multiple surface dressing was introduced into the UK that had properties more akin to asphalt materials although produced on site (Nicholls, 1998). Micro-surfacing (MS) with polymer-modified binders have also been developed in thin surfacing systems. Further variants on the basic theme of a thin surfacing system may emerge in the future.

Thin surfacing systems laid in the UK in the early and mid 1990s have passed their initially expected serviceable lives of 8 to 10 years. Therefore, from the late 1990s it has become possible to compare their predicted and actual levels of performance. In addition, it is also now possible to examine how these materials deteriorate as they reach the end of their serviceable lives. In order to gain this knowledge, TRL have monitored some of the older UK sites in order to assess the durability of those systems for the Highways Agency [5, 6, 7, 8] over a total of nine years.

2 MONITORED SITES

The sites chosen to be monitored for the project were initially taken from those sites that had been used to gain Highways Agency (HA) approval under the scheme used prior to the HAPAS system. These sites tended to be the oldest thin surfacing sites in the UK at that time and provided readily available data for inclusion in the study. Subsequently, when further sites were required, they were selected from those already being studied for other projects or nominated by contractors and/or local authority engineers. The numbers of sites that were monitored for this work using the different monitoring techniques employed are tabulated in Table 1.

Table 1: Number of sites monitored and observations made

System type	UTLAC	BBTM	SMA	MSD	MS	Total
Visually inspected	17 (71)	52 (250)	58 (227)	6 (28)	4 (22)	137 (598)
SCRIMtex surveyed	18 (75)	21 (81)	23 (97)	4 (18)	1 (6)	67 (277)
Cored for binder properties	4 (21)	11 (47)	12 (51)	2 (13)	2 (9)	31 (141)

Values in brackets are the total number of observations from those sites

The sites that have been monitored form only a small sub-set of the sites that have been laid in the UK. Whilst every effort has been made to make these sites representative of the total population, it is appreciated that the selection has certain biases that, it is hoped, should approximately balance. These biases include:

Older sites

- More care was taken because thin surfacing systems were new, improving potential durability.
- Less experience then available, so workmanship may have been less robust.

Replacement sites

- Sites had no problems when identified, so does not include potential for premature failure.
- Sites taken from other research projects should have had the extra care taken with trial sites.
- Sites notified by contractors are likely to be taken from what they believe to be their better sites.
- Sites notified by highway authorities are likely to be unusual sites.

Furthermore, it was not practical to investigate the substrates of the sites when selecting them despite their condition being important for durability, and this may have induced a further bias.

The sites that were monitored varied from motorways to minor roads across England and Wales. Although the traffic flows for many sites are known or could be obtained, analysis has not included traffic in previous reports because it was considered that this additional variable would over-complicate the analysis. However, in this analysis it has been considered worthwhile categorising the sites by road category. The four categories of road that have been used are:

1.	Motorway	(13 sites)
2.	Other trunk road	(42 sites)
3.	Non-trunk A road	(70 sites)
4.	Minor (B, C or unclassified) road	(12 sites)

The number of sites listed is that for all sites for which any data has been collected, including some sites with very limited data and others where separate lanes have separate data requiring separate entries.

3 SKID RESISTANCE

The Sideway-force Coefficient Routine Investigation Machine (SCRIM) is the standard equipment used for measuring skid resistance in the UK [9]. It was neither practical nor economic to monitor all the sites for skid resistance; therefore, a representative subset was chosen to be monitored, with 17 sites over the last three years of the study.

Measurements to obtain SCRIM coefficients were taken three times on each of the sites during the summer measuring season to allow for seasonal variations during each year. The average of the three SCRIM coefficients measured during the summer months gives the Mean Summer SCRIM Coefficient (MSSC). Skid resistance has a general variation between years which are not accounted for in the MSSC calculations. Therefore, each value was factored by multiplying the average of all observations on all sites divided by the average of observations for the year in question on all sites. In deriving these factors, all initial and first year values were ignored because the sites were unlikely to have reached equilibrium. In the following analyses, it is the MSSC adjusted for between-year variation (referred to as adjusted MSSC) that has been used.

The in-service skid resistance of a surfacing is dependent on the polished stone value (PSV) of the aggregate, the volume of commercial traffic and the geometry of the site (junctions, slopes, bends, etc). It would need considerable data to be able to consider the variation of skid resistance with each of these factors. However, by assuming that the PSV of the aggregate was selected appropriately for the other two factors, the adjusted MSSC can be plotted for different values of PSV. The results were combined for each age by type of system and PSV range (<63, 63 – 67 and 68+) and are shown graphically in Figure 1.

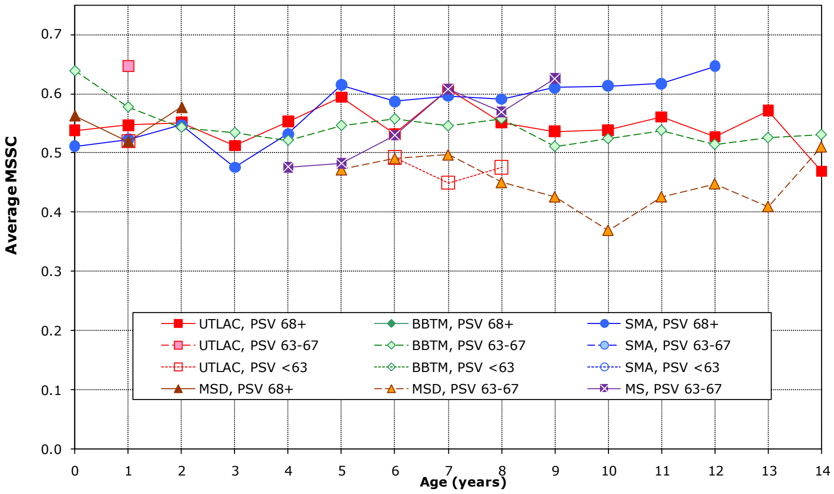

Figure 1: Average adjusted MSSC results

When linear trend lines were applied to Figure 1 for the four system/PSV combinations with data from at least 12 years, all the trend lines fall with age although there is considerable scatter. When repeated without data from the first two years (during which the sites reach equilibrium), the trend lines again fall except for BBTM with PSV 63-67.

The data set is, in terms of statistical analysis, incomplete because only one site has data up until 14 years; many sites have gaps in monitoring; several sites have only a few readings; and not all sites have initial readings.

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- Not all sites have initial readings.

In order to minimise the bias from the inconsistency of data points in Figure 1, the results for the twelve sites with data for at least seven years are shown in Figure 2. These plots show a general slow reduction with time, but with some contrary points.

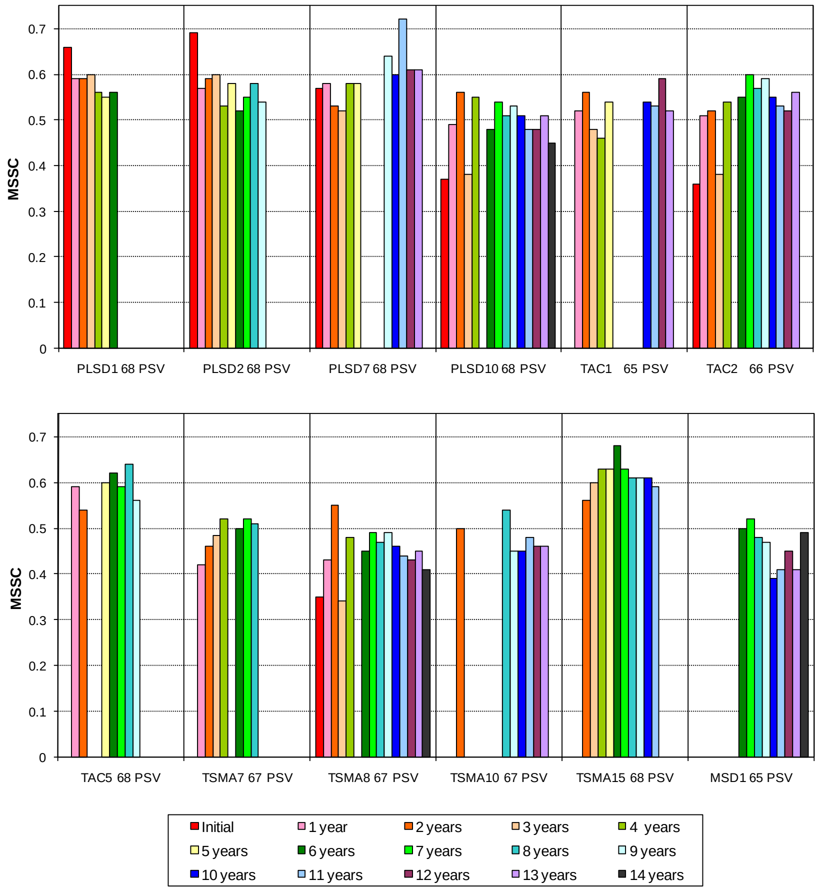

Figure 2: Adjusted MSSC results for sites with at least 7 years of data

A rigorous statistical analysis to determine which variables are important in defining differences between adjusted skid resistance results [8] indicated that, in general, there was no statistically significant decrease of MSSC as a uniform function with age of the surfacing. There is considerable fluctuation but no regular change in normalised MSSC values; some of the fluctuation in the data is possibly due to which of the sites that were included at each age. There is evidence that PSV does influence the MSSC measured, as would be expected, and that this influence appears to be quite consistent as the thin surfacing systems age.

Overall, skid resistance is considered not to be a significant cause for replacing the surfacing because the MSSC showed no significant decrease with the age of the surfacing.

4 TEXTURE DEPTH

4.1 Sand patch texture depth

In the UK, the texture depth of new surfacings on all trunk road sites has been measured by the patch method prior to the road being opened to traffic. Also, the patch texture depth after two years trafficking was required from trial sites in order to gain the original HA approval and is now required to obtain a HAPAS certificate. The results of these measurements have been combined for each age by type of system and nominal maximum aggregate size (10 mm and 14 mm) and are shown graphically in Figure 3.

Figure 3 shows that the texture depth drops over the first few years, although the amount of change and the time required to stabilise are unclear. However, the texture depth for all systems from an age of about four years appears to remain within a relatively controlled band between 0.75 mm and 1.5 mm. The two exceptions are 10 mm BBTM at 8 years with 2.1 mm and 14 mm MSD at 12 years with 0.5 mm.

4.2 Vehicle-mounted sensor-measured texture depth

For in-service monitoring of trial sites, it is not practical to close sites in order to measure the texture by the patch method. Therefore, the texture depth is often monitored by laser-based texture-measuring equipment mounted on a vehicle such as SCRIM (SCRIMtex) which can travel at normal traffic speeds. The annual SCRIMtex measurements were made on same subset for which SCRIM measurements were taken. The results have been combined for each age by type of system and nominal maximum aggregate size (10 mm and 14 mm) and are shown graphically in Figure 4.

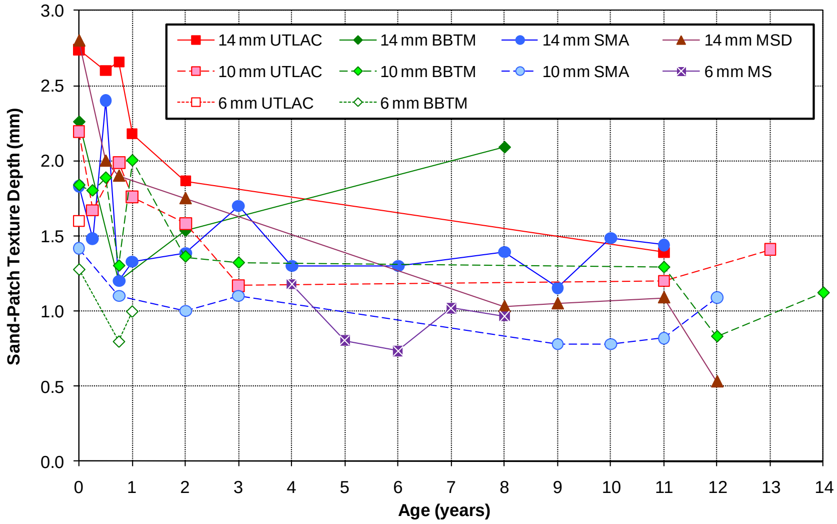

Figure 3: Average sand patch texture depths

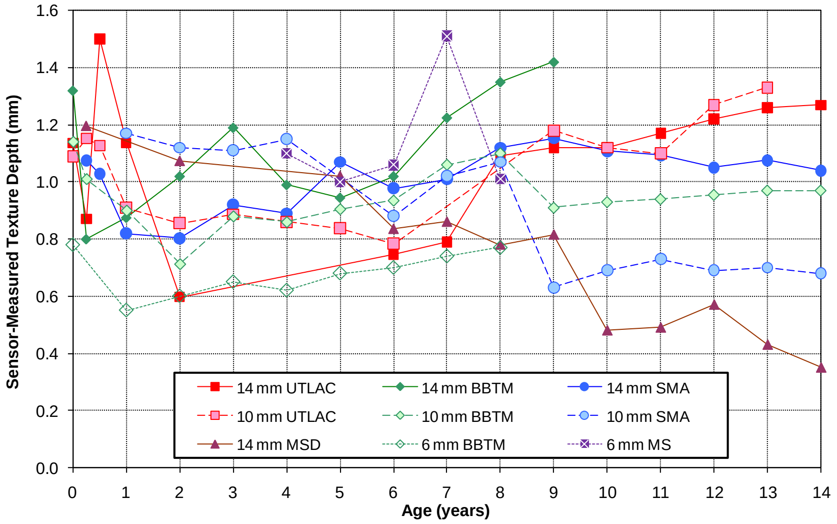

Figure 4: Average sensor-measured texture depths

Figure 4 shows SMTD to be generally constant or to steadily increase with age for asphalt thin surfacing systems. However, the more limited MSD data set from a single site suggests a steady decrease in texture with life, possibly due to the chipping embedment normally assumed in the early life of these systems as well as other surface dressings.

As for adjusted MSSC, the points in Figure 4 are from incomplete data because a different set of sites, if from the same population, was averaged for each year in service. Therefore, the results for the ten sites with data for at least seven years are shown in Figure 5. The results in Figure 5 show considerable variations in performance between the sites. The general trend is for an increase in texture depth with age, particularly towards the end of the life in service, except for the MSD type which shows a significant decrease as discussed earlier. The general increase is the consequence of particle loss, as indicated by the '–' suffix in the Inspection Panel visual condition mark (Section 5.1).

A rigorous statistical analysis to determine which variables are important in defining differences between texture depths [8] indicated that there are reductions in texture depth as the surface ages but generally only in the early years. Understandably, the texture measures are influenced by aggregate size and binder contents. Different road types tend to use different aggregate sizes and an analysis of road type/aggregate sub-sets found that texture measures still differ with age of the surface. This trend suggests that there is a reasonably consistent pattern of reduction (within sub-groups of sites) that is not influenced by other factors such as aggregate size, binder contents or particle loss.

Overall, texture depth is considered not to be a significant cause for replacing the surfacing because the values showed no significant decrease with the age of the surfacing. In fact, individual sites showed an increase in texture when nearing the end of their service life, but as the result rather than the cause of the failure.

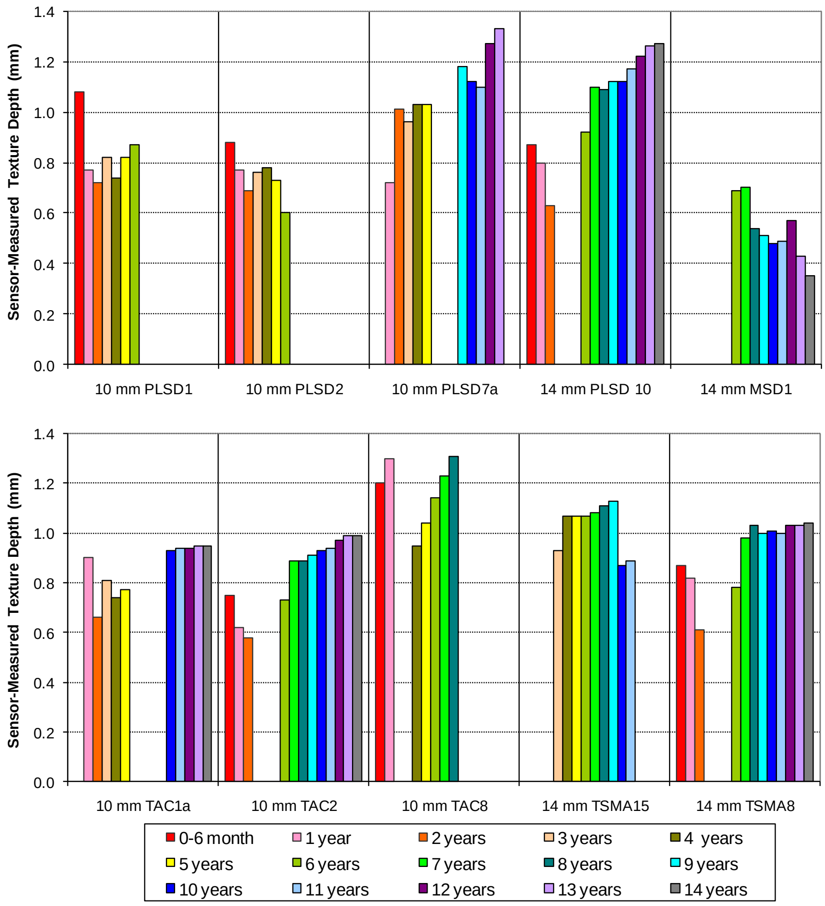

Figure 5: Sensor-measured texture depths of sites with at least 7 years of data

5 VISUAL CONDITION

5.1 All sections

The sites monitored were assessed visually by an Inspection Panel (comprising representatives from the HA, asphalt producers, bitumen suppliers, trade bodies and TRL) and ranked in accordance with the TRL Inspection Panel methodology [10]. The assessment attributes a mark (*Excellent*, *Good*, *Moderate*, *Acceptable*, *Suspect*, *Poor*, *Bad* or midway between two adjacent marks) plus, when appropriate, defect suffixes to each site.

The total number of sites and the observations made of them are given in Table 2. Of the 137 sites, 32 were only monitored once whilst 13 had nine or more visits.

Table 2: Number of sites and observations (obs.) of visual condition by system type and aggregate size

System Type	UTLAC		BBTM		SMA		MS /MSD	
	Sites	Obs.	Sites	Obs.	Sites	Obs.	Sites	Obs.
14 mm	9	32	21	82	49	197	6	28
10 mm	7	33	23	134	9	30	–	–
6 mm	1	6	8	34	–	–	4	22

The results have been combined as mean values for each age by type of thin surfacing system and are shown graphically in Figure 6 together with linear trend lines for each type.

As for adjusted MSSC and SMTD, the data points in Figure 6 are not strictly comparable from year to year because a different set of sites, if from the same population, was averaged for each year in service. The results for the thirteen sites with data for at least nine years are shown in Figure 7. The trend of these plots is generally a reduction with time but, for several sites, there is a strong plateau after an initial loss on several of the sites as there is for skid resistance and texture depth.

The visual condition data has been analysed in a number of ways [8]. The main findings are:

- The trends for sites grouped by system type using the mean values at each age showed that quadratic equations do not significantly improve the modelling of service life relative to linear equations which produced correlation coefficients (excluding MS) between 0.80 and 0.97.
- When the systems are split by aggregate size, the correlation coefficients (excluding MS) were between 0.98 and 0.50.

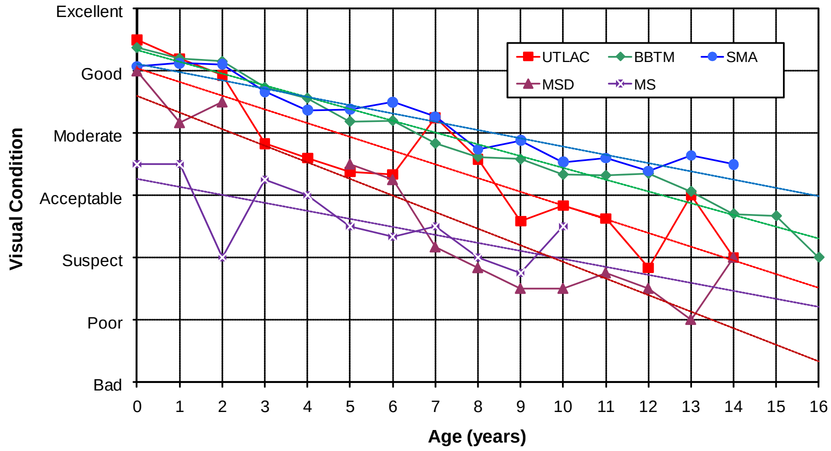

Figure 6: Average visual condition markings

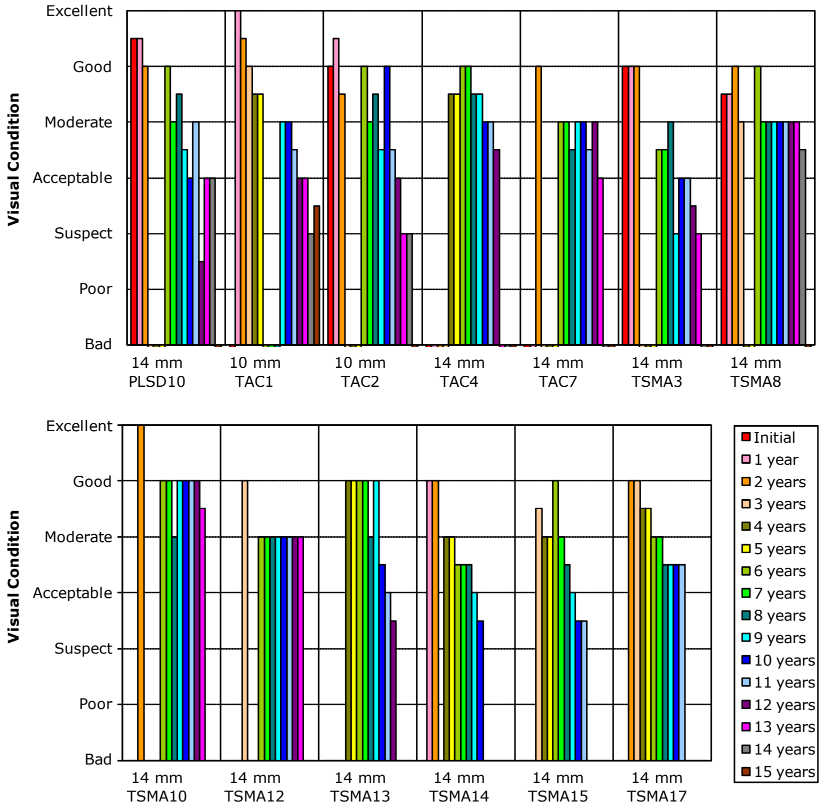

Figure 7: Visual condition markings of sites with at least 9 years of data

- When individual data points were used with the systems split by aggregate size, the correlation coefficients (excluding MS) were between 0.31 and 0.93.
- An analysis of median values implies that, if sites can be allowed to deteriorate to a Suspect condition, there would be no defects on BBTM and SMA systems until 8 years in service.
- Using multiple regression analysis on the asphalt systems shows that the binder content is the most significant factor after age. The system and, to a lesser extent, the binder type and the aggregate size also influence the rate of deterioration. The category of road, however, does not appear to affect the deterioration.

5.2 Multiple regression for asphalt systems

The data held on the various sites includes the following parameters:

- *Cond* Visual condition of the surfacing.
- *Type* The type of system, from the list given above, that was applied.
- *Syst* The proprietary thin surfacing system that was applied.
- *Road* The road type onto which the thin surfacing system was laid.
- *Agg* The nominal maximum aggregate size (in millimetres).
- *Bind* The binder content of the mixture (in percent)
- *Age* The age at which the site was monitored (in years)

Extracting the data on these parameters for the asphalt types of system (UTLAC, BBTM and SMA) produced 434 complete data sets plus another 112 sets for which the binder content is not available, giving a total of 546 data sets. The following transformations of the non-numeric variables were made:

- *Cond* The visual condition markings converted to Excellent = 7, Good = 6, Moderate = 5, Adequate = 4, Suspect = 3, Poor = 2 and Bad = 1.
- *Type* The type of system converted to TAC = 1, PLSD = 2 and TSMA = 3□.
- *Syst* The systems ranked in descending order of average visual condition, irrespective of age or other parameter.
- *Site* The sites categorised by the type of road with motorways = 1, other trunk roads = 2, other “A” roads = 3, and all other roads = 4.

Cond was the parameter which is monitored whilst *Age* was assumed to be the most important parameter because any site can be monitored through its decline from new until it becomes unserviceable, however long that takes. Multiple linear regression analyses were carried out using the SPSS 14.0 for Windows package with *Cond* as the dependant variable and *Age* plus one of the other parameters as the independent variables in order to identify the significant of those other parameters. The results are given in Table 3.

Table 3: Correlations with *Cond* against *Age* plus another parameter

Independent variables	Constant	Coefficient for *Age*	Coefficient for other variable	R^2_{adj}
Age and *Type*	6.126	-0.181	0.070	0.412
Age and *Syst*	6.672	-0.170	-0.037	0.462
Age and *Road*	6.199	-0.183	0.030	0.408
Age and *Agg*	5.660	-0.179	0.049	0.422
Age and *Bind*	5.085	-0.192	-0.217	0.499

The results show that *Bind* is the most significant parameter with *Syst* second and the others being having a secondary influence, although with analysis of a slightly larger data set.

A multiple linear regression analysis was then undertaken with *Cond* as the dependent variable and all the other parameters as independent variables in order to give the relationship in Equation 1.

$$\begin{aligned}Cond \;=\; & 4.852 - 0.231 \times Type - 0.022 \times Syst + 0.001 \times Road + \\ & 0.035 \times Agg + 0.307 \times Bind - 0.186 \times Age\end{aligned} \qquad (R^2_{adj} = 0.539) \qquad \ldots (1)$$

The independent variables were then extracted in turn to find the least significant as the one causing the least change to R²adj, then repeating this process to find the next least significant. The relationships at each removal are given in Equations 2 to 6.

Removing *Road* gives:

$$\begin{aligned}Cond \;=\; & 4.849 - 0.231 \times Type - 0.022 \times Syst + 0.035 \times Agg + \\ & 0.306 \times Bind - 0.186 \times Age\end{aligned} \qquad (R^2adj = 0.540) \qquad \ldots (2)$$

Removing *Agg* as well gives:

$$\begin{aligned}Cond \;=\; & 5.545 - 0.177 \times Type - 0.027 \times Syst + 0.251 \times Bind - \\ & 0.185 \times Age\end{aligned} \qquad (R^2adj = 0.538) \qquad \ldots (3)$$

Removing *Type* as well gives:

$$Cond \;=\; 6.435 - 0.030 \times Syst + 0.032 \times Bind - 0.182 \times Age \qquad (R^2adj = 0.526) \qquad \ldots (4)$$

Removing *Syst* as well gives:

$$Cond \;=\; 5.085 + 0.217 \times Bind - 0.192 \times Age \qquad (R^2adj = 0.499) \qquad \ldots (5)$$

Removing *Bind* as well gives:

$$Cond \;=\; 6.268 - 0.182 \times Age \qquad (R^2adj = 0.409) \qquad \ldots (6)$$

Starting with the last equation, the correlation increases with the addition of each parameter, as would be expected. The biggest differences occur with the addition of the first parameter, *Bind*, followed by the next parameter, *Syst*. The remaining improvements are very marginal, confirming that the parameters other than *Age*, *Bind* and possibly *Syst* are of relatively limited significance. In the case of *Road*, the correlation increased slightly with its removal, indicating that the extra degree of freedom reduced the certainty rather more than the extra parameter resolved part of the scatter.

The order of removing the independent variables implies a ranking in terms of their influence on the visual condition of surfacings as follows:

1. The age of the site, with surfacings deteriorating with increased age.
2. The amount of binder in the surfacing, with surfacings deteriorating faster with less binder.
3. The supplier of the proprietary system, with no guidance because the data has deliberately been made anonymous.
4. The type of system, with BBTM surfacings being most durable, then UTLAC and finally SMA surfacings.
5. The nominal maximum aggregate size of the mixture, with surfacings deteriorating faster with smaller aggregate sizes.
6. The type of road has no real influence.

These rankings are unsurprising other than that the road was not significant and that SMA appears to be the least durable of the three types of system whereas the reverse was found from the basic plots without consideration of the other parameters where the SMA lines were at the top. The probable reason for the anomaly is that the binder content, which is generally higher in SMA than UTLAC and BBTM systems, is already taken account of in *Bind* so that any difference is due to the binder type, polymer-modified bitumen being better than straight-run bitumen and fibres. The overall marginally better performance of SMA than BBTM and, more significantly, over UTLAC reflects the increased binder content being more important than the improved binder type.

The overall conclusions of this analysis were:

- The binder content is the most significant factor after age in the deterioration of thin surfacing systems.
- The system and, to a lesser extent, the binder type and the aggregate size also influence the rate of deterioration.
- The category of road does not appear to affect the deterioration, although this observation could just reflect the fact that less care is taken in construction and maintenance on minor roads which counters any extra stresses imposed on more major roads.
- After allowing for the different binder content and binder type involved, SMA surfacings are marginally less durable than BBTM or UTLAC surfacings.

5.3 Influence of jointed concrete substrate

Of the sites monitored, 15 had thin surfacing systems laid over a jointed concrete substrate (generally directly without a bituminous binder course). As expected, reflective cracks appeared over the joints which detracted from the visual condition assessments. Once that stage was reached on any site, two marks were given, one with and one without the reflection cracks and associated defects at the joints. The latter assessments have been included in the main data set on the basis that defects at the joints for such a thin layer would be independent of the material type.

Taking the difference between the two measures for each site, as shown in the vertical axis of Figure 8 (where one unit indicates a difference of one mark, say *Moderate* excluding joints and *Acceptable* including them), shows that reflective cracking did not make any significant difference for at least five years, and even then the three sites where a difference was seen showed no difference again until year 11 whilst another started showing a difference at year 9. The majority of observations showed no difference because the reflection cracking had not shown through (or at least the cracks had not spalled) and were, therefore, the same assessments.

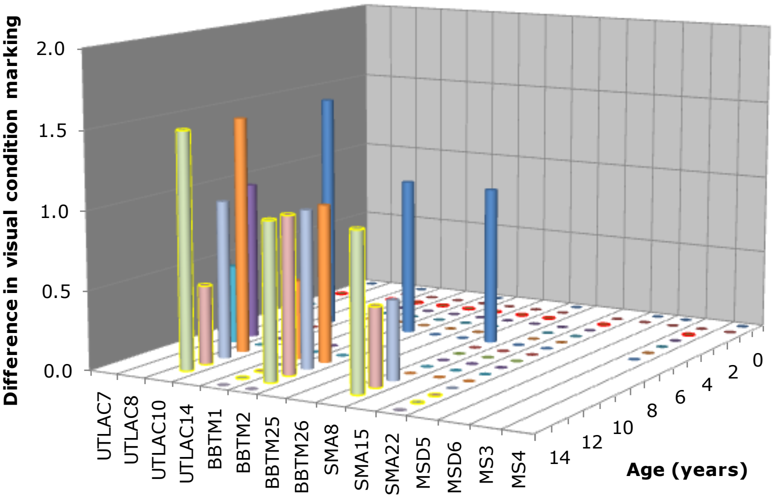

Figure 8: Difference in visual condition marks on sites with jointed concrete substrates when not excluding the reflection cracks

Although differences were not observed on all sites, the emergence of reflection cracks on some sites when they became older could impair the visual condition by up to one and a half marks, which in turn implies that the time before the surfacing will need to be replaced will be significantly reduced.

6 OVERALL DURABILITY

6.1 Sites with known lives

As has been shown in earlier sections, the serviceable life of a pavement can be estimated beyond available data by the use of trend lines. However, these estimates have a degree of uncertainty due both to the variability in performance of the same type of surfacing and, particularly, because projecting trend lines beyond available data will increase the uncertain. The nature of deterioration in pavements is that failure can occur suddenly and not necessarily in a smooth, predictable fashion. Therefore, another method of estimating serviceable lives is to consider known serviceable lives. These can be defined in two main ways:

- When the site has been resurfaced or overlaid (termed ‘life in service’ in this report), or
- When the visual condition of the site dropped to *Suspect*, as assessed by the Inspection Panel (termed the ‘serviceable life’ in this report).

The disadvantage of the first definition is that some of the sites being monitored have remained in service long after the Inspection Panel had deemed them unserviceable whilst others were removed when still in what was considered to be a serviceable condition. The reasons for the former could include shortage of funds to carry out the ideal maintenance treatment and for the latter could include the surfacing being replaced because it was located within a section for which a major maintenance scheme was being implemented and the surfacing being surface dressed whilst still in good enough condition to benefit from the treatment.

In addition it should be noted that estimates of known lives are not totally representative of the lives of total population because thin surfacing systems have not been used in the UK for long enough to include the durable tail of the population.

The known service lives for sites from which data has been collected but which have either subsequently been replaced/overlaid or dropped to a visual condition of *Suspect* or less have been tabulated. The life in service of a material at a site can be either greater (if replaced early) or less (if the material was allowed to remain in place after it had become unserviceable) than the serviceable life as assessed independently. The histograms of the lives in service achieved are shown in Figure 9. However, the data are biased to giving lower than typical lives in service because sites that are still serviceable are not included in the dataset. Nevertheless, the average life in service for all types is 9.9 years with a standard deviation of 3.0 years and the life in service for individual types are 10.5 years for UTLAC, 9.9 years for BBTM, 9.4 years for SMA and 9.0 years for MSD. No allowance is made for road category.

Estimates of serviceable life can also be derived directly from the visual observations of the inspection panel. A histogram of this data where the visual condition has dropped to *Suspect* is also seen in Figure 9. As for 'lives in service', the data are biased to giving lower than typical lives in service because sites that are still serviceable are not included in the dataset. The average for all types is 9.2 years with a standard deviation of 3.1 year whilst the lives for individual types are 9.4 years for UTLAC, 10.0 years for BBTM, 9.1 years for SMA, 6.8 years for MSD and 4.0 years for MS. Most of these values are similar to those of the lives in service, indicating the serviceable level broadly reflects current maintenance practice.

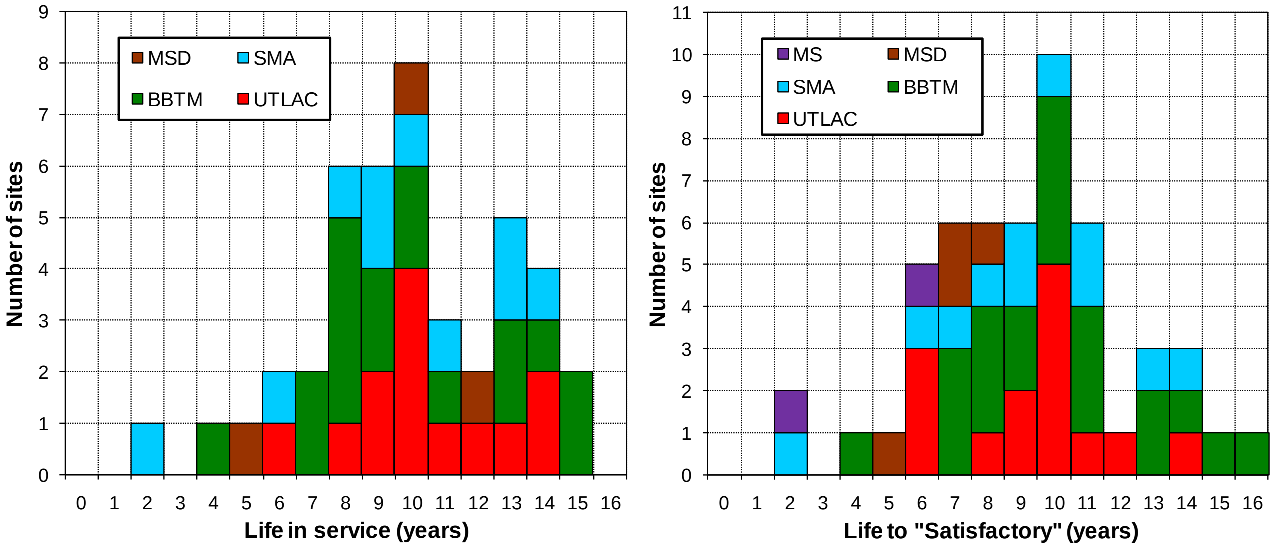

Figure 9 – Histograms of lives in service and of serviceable lives

6.2 Expected service life

Several analytical methods have been used to assess the service life [8]. Combining these values to give an estimate of the typical lives produces Table 4. There is limited confidence in any values that have been extrapolated beyond the available data; therefore, these values are not shown but are replaced with a greater than sign in front of the age at the last survey.

Table 4: Typical predicted serviceable lives from combined results from linear and quadratic statistical analysis of visual data

Panel Mark	Serviceable life (years) for system type									
	UTLAC			BBTM			SMA		MSD	MS
	14 mm	10 mm	6 mm	14 mm	10 mm	6 mm	14 mm	10 mm	14 mm	6 mm
Moderate	5	4½	3½	7½	7	5	8	11	2½	–
Acceptable	9	7½	5½	>12	13	10	14	>14	5½	3
Suspect	13	9½	6	>12	>16	>10	>14	>14	9	8½
Poor	>14	>14	>6	>12	>16	>10	>14	>14	13	>10

The dash for MS to reach Moderate condition indicates that those systems usually have some visual defects when constructed.

The more rigorous non-linear statistical analysis [8] provided estimated service lives and 95 % confidence limits on those estimates for the thin surfacing systems to reach the serviceable condition of a visual condition of *Suspect*. The values, together with the number of sites and observations on which they are based, are given in Table 5.

Table 5: Predicted serviceable lives from non-linear statistical analysis of visual data

Thin surfacing system	Nominal size (mm)	Sites (Number)	Observations (Number)	Estimated serviceable lives (years)	95 % confidence limits (years)
UTLAC	14	9	32	12	9.1 – 15*
	10	7	33	11	9.5 – 13
	6	1	6	5.5	4.7 – 6.5
BBTM	14	32	82	16*	14* – 19*
	10	33	134	17*	16 – 18*
	6	8	34	14*	10 – 20*
SMA	14	49	197	19*	16* – 21*
	10	4	30	26*	16* – 38*
MSD	14	6	28	7.4	6.3 – 8.5
MS	6	4	22	7.8	2.8 – 13*

Many of these values are extrapolations, being greater than the oldest site observation. These values are indicated with the addition of an asterisk.

The smaller size asphalt systems have generally been laid very thin and, hence, are more susceptible to laying conditions than thicker layers.

6.3 Mode of failure

Defects were monitored in terms of whether they were present rather than the extent to which they were present [8]. The time before the average of the number of categories of defects that were identified on each site reached one was only a few years, with 10 mm SMA taking the longest at nine years and 14 mm SMA next at seven years. After ten years, the upper age to which thin surfacing systems were hoped to reach when first introduced to the UK (eight to ten years), on average sites with SMA systems exhibited between one and two categories of defect, sites with UTLAC and BBTM systems exhibited between two and three categories of defect and the sites with surface treatment systems exhibited around four categories of defect. This relative performance is typical through the life of the surfacings.

With regard to the most common categories of defect, particle loss and cracking were first and second whilst, of the next two most common categories, delamination became more prevalent than fatting up after about four years when any excess binder had been worn off. However, because it is a transient defect for asphalt systems (the fatted up binder gets worn away by the traffic in time), fatting up is not likely to lead to failure for asphalt systems.

7 RECOVERED BINDER PROPERTIES

Data were also collected on the residual binder properties in an attempt to understand the influence of material properties on surfacing life which might be used in the development of a predictive tool for surfacing life. Therefore, a number of cores were taken from representative selection of the sites during the course of the study. 141 of these cores were taken from 31 of the sites with the distribution of cores taken from each type of surfacing was provided earlier in Table 1.

Sets of cores were cut from the selected sites and the binder recovered from the cores using the rotary evaporator method in accordance with EN 12697-3 [11] before being combined to produce sufficient sample for subsequent testing. These samples were then tested for penetration and softening point in accordance with EN 1426 [12] and EN 1427 [13], respectively.

A standard statistical computer program was used with the complete data set of penetration values to assess the null hypothesis that the recovered penetration results were not affected by the thin surfacing system type and/or the age at the time of measurement [8]. The analysis found that there was a zero probability of the null hypothesis for either parameter or their combination. Therefore, it is highly probable that the type of thin surfacing system and the age of the surfacing both have an effect on the recovered penetration.

Similarly, the program was used with the complete data set of softening point values to assess the null hypothesis that the recovered softening point results were not affected by the thin surfacing system type and/or the age at the time of measurement. The analysis found that there was a zero probability of the null hypothesis for either parameter but a 0.28 probability of their combination. Therefore, it is highly probable that the type of thin surfacing system and the age of the surfacing both have an effect on the recovered softening point, as would be expected.

The results were studied to identify if the binder properties were correlated with the age or visual condition of the surfacings [8]. It was expected that the type of thin surfacing system and the age of the surfacing would both have an effect on the penetration and softening point of the binder recovered from thin surfacing systems. However, no clear relationship could be found for either:

- the change of binder properties with time; or

- the visual condition of the surfacing with binder properties.

8 CONCLUSIONS

The principal conclusions of the study are:

- Skid resistance and texture depth are not considered to be a major durability issue. Therefore, durability has to be estimated from the visual condition.
- Estimates of the serviceable lives of thin surfacing systems have been generated by several different methods, although many of these values are extrapolations, being greater than the oldest site observation.
- Aggregate size and system were the most important influences on estimated lives in terms of visual condition, with binder content also important in some situations.
- For thin surfacing systems laid directly onto jointed concrete, the difference between the actual overall condition and that for the condition ignoring any reflection cracks is negligible for at least five years.
- The principal mode of failure or reason for reaching an unserviceable condition was the significant presence of one or more visual defects, of which the two most prevalent were particle loss and cracking.
- The penetration and softening point of the thin surfacing material is related to the age and type of the material but the relationships found were insufficiently clear to be used as a life predictor.

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