Material performance of porous asphalt, including when laid over concrete

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Executive Summary

Porous asphalt as a road surfacing material has been under test by TRL since 1967. This report examines the extensive results from five trial sites carrying moderately heavy traffic, one of which included sections 12 years old. Two of these trials were on the A38 at Burton, which compared the use of different binder contents and the suitability of certain binder modifiers to retain the binder without drainage. The third trial was on the M1 at Wakefield, which compared different European gradings and investigating the possibility of using pre-coated chippings in porous asphalt. The fourth trial was on the M40 at Stokenchurch, which examined the initial performance of porous asphalt overlaying jointed concrete. In addition, a site where it was laid under standard contract conditions on the M4 at Cardiff was monitored for the Welsh Office. The average traffic flows on each lane at the sites studied (other than the M40) were:

- 3,600 cv/l/d and 475 cv/l/d on the inside and outside lanes, respectively, on the A38;
- 4,565 cv/l/d, 1,320 cv/l/d and 40 cv/l/d on the three lanes of the M1; and
- 3,300 cv/l/d and 920 cv/l/d for lanes 1 and 2 (not recorded on lane 3) of the M4.

This report reviews the latest results for skid-resistance, texture depth, hydraulic conductivity, deformation and visual condition obtained from the various sites. Details of the laying of the M1 and M40 sites are given as background to the subsequent results; the details of the two Burton trials have been reported elsewhere.

The trial on the M1 indicates that porous asphalt made using the UK grading with 20 mm nominal maximum size provides superior performance to finer-graded porous asphalts, in terms of relative hydraulic conductivity and surface texture. Further, a trial section with porous asphalt using the UK 10 mm grading yielded unacceptable performance, in terms of relative hydraulic conductivity and texture depth, and demonstrated that this material should not be used at thicknesses of 40 mm or greater. The mixtures to European gradings performed at a level between that of the mixtures with the UK 20 mm and 10 mm gradings. The trial in which pre-coated chippings were inserted into porous asphalt showed that this can be laid successfully and that the chippings will be retained.

It is reputed that porous asphalt has a lack of skid-resistance in its very early life due to the thick binder film covering the aggregate at the surface. Evidence from the M1 and M40 sites indicates that the skidding performance expected from traditional surfacings, as measured by Sideway-force Coefficient Routine Investigation Machine (SCRIM), was attained after less than three weeks of trafficking. Furthermore, the skid-resistance on the M40 was comparable to that of an existing brushed concrete surfacing within 3 days of trafficking. Traditional surfacings, such as hot rolled asphalt, also require trafficking to fully expose the aggregate.

The M40 trial has shown that porous asphalt can be laid over jointed concrete with an asphalt roadbase. However, the joints have to be sufficiently ‘hard’ (as opposed to ‘rubbery’, which is an important property for the normal operation of a joint sealant) to minimise the possibility of material being forced into the joints during compaction only to be expelled afterwards. The emergence of reflective cracks only occurred in relatively limited locations in the first two years of trafficking and has not spread extensively after five years in service. The extent of reflective cracking over the full lifetime of the porous asphalt has still to be fully evaluated.

Overall, these trials have shown that it is feasible to lay porous asphalt under normal contractual conditions on moderately heavily trafficked motorways. Porous asphalt can remain structurally viable for up to twelve years under traffic loads of up to 4,000 cv/l/d, although the condition at the end of that time may no longer offer significant advantages when compared with non-porous surfaces.

1 Introduction

The Highways Agency permits the use of porous asphalt as the surface course where it can be justified by:

- the inclusion of porous asphalt in the *Specification of Highway Works* (MCHW 1) under Clause 938;
- the associated *Notes for Guidance on the Specification for Highway Works* (MCHW 2); and
- the advice on porous asphalt in HD 37 (previously HD 27) of the *Design Manual for Roads and Bridges* (DMRB 7.5.2 and DMRB 7.2.4).

However, the advice limits its use on roads with traffic up to 6,000 commercial vehicles per lane per day (initially 4,000 cv/l/d), above which value specific approval is required, because the trials on which the advice was based only carried traffic up to about 4,000 cv/l/d (Nicholls, 1997a). However, it has become harder to justify the use of porous asphalt because of the advent of proprietary thin surfacings that have similar advantageous properties.

TRL Limited, on behalf of the Highways Agency, has been monitoring trial sites with moderately heavy traffic on the A38 at Burton (Daines, 1986 & 1987a) (which carried 3,600 cv/l/d in lane 1) and on the M1 near Wakefield (Nicholls, 1997a) (which carries 4,565 cv/l/d in lane 1). Much of the early data was used to assist the Highways Agency in the development of the specification and associated advice. The main objective of this report is to update the basis for that advice using recent data from those trials in order to help establish the durability of the material for different types of road, including motorways. As part of a separate study for the Welsh Office, TRL also monitored the M4 near Cardiff (which carried 3,300 cv/l/d in lane 1).

An omission in previous research into porous asphalt is its use over jointed concrete, with a particular need to study the emergence of reflective cracks associated with the joints in the underlying concrete. Therefore, the overlay of a section of jointed concrete with porous asphalt on the M40 near Stokenchurch was monitored for evidence of reflection cracking.

This report reviews the latest results for skid-resistance, texture depth, hydraulic conductivity, deformation and visual condition obtained from the Burton and Wakefield trial sites together with observations from the Cardiff and Stokenchurch sites.

2 Porous asphalt sites

2.1 A38, Burton

In the summer of 1984, fifteen sections of porous asphalt containing both proprietary and non-proprietary binders with a total length of about 1.5 km were laid on both lanes of the southbound carriageway of the A38 Burton bypass. The objective of the trial was to allow comparison of different binders and binder contents on the effectiveness and durability of the material. In 1987, a length of carriageway immediately north of the 1984 trial sections was reconstructed and the opportunity taken to extend the work by laying a further c.800 m of porous asphalt in seven trial sections together with ten sections of hot rolled asphalt during November/December 1987.

Details of the materials used and the laying of each section are reported in RR 57 (Daines, 1986) for the 1984 trial and in RR 323 (Daines, 1992a) for the 1987 trial; the latter includes a location plan of the site showing the layout of the sections for both trials. The materials used in both trials are described in Tables A.1 (1984), A.2 (1987) and A.3 (hot rolled asphalt sections laid in 1987) of Appendix A. The grading for Section 2A of the 1984 trial was out of specification such that the interconnecting voids within the material closed up early; results from that section have not been included in the assessments.

By 1992, the 1984 trial had deteriorated to the extent that Staffordshire County Council had to start replacing certain sections, with the last of the sections being replaced in 1996 when some of the 1987 trial sections were also replaced. The timetable of replacement is shown in Table 1. None of the hot rolled asphalt has required replacement.

The traffic flows on the A38 in 1984 and 1990, together with those on the M1 and M4, are given in Table 2. From 1984 to 1990, the commercial traffic had increased by 8 per cent whereas the increase in cars had been 42 per cent. A speed survey carried out on 27 September 1990 showed the average speed of commercial vehicles was 90.6 km/h (56.3 mile/h) in the nearside lane and 97.8 km/h (60.8 mile/h) in the offside lane.

2.2 M1, Wakefield

2.2.1 Site

The location and layout of the trial sections are shown in Figure 1. The trial commences near the end of the slip road exit from the Woolley Edge Service Area on the southbound carriageway of the M1 motorway, approximately 7 km south of Wakefield, and covers the three lanes and hard shoulder of the carriageway. Part of the site is an embankment and the site curves gently to the nearside along the trial sections to the end, adjacent to Junction 38. There is a downhill gradient along the site of 3 per cent. The relative performance of the sections is unlikely to have been affected by these factors, except possibly where traffic enters Section 1 from the service area and leaves Section 7 at Junction 38.

A manual traffic count carried out on Tuesday 22 October 1991 yielded the results given in Table 2.

2.2.2 Materials

The trial was designed to compare the performance of porous asphalt with aggregate of nominal maximum aggregate size 20 mm, as developed in the United Kingdom, with examples of the smaller sized materials generally used in other countries. Three sections were laid to the UK specifications in BS 4987: Part 1 (BSI, 1988) but with slightly tighter tolerances, using both the standard 20 mm and the 10 mm size, together with sections using the aggregate gradings and binder grades taken from Belgium (Ministere des Travaux Publics, 1986), the Netherlands (Rijkswaterstaat, 1985) and Sweden (Vag-Och

Table 1 Replacement of sections in Burton trials

	Lane 1		*Lane 2*	
	Partial	*Full*	*Partial*	*Full*
1984 trial				
1992	–	1, 2B, 6, 9, 13	6, 13	1
1993	3	2A, 5, 7, 8, 10, 11, 15	3, 15	2A, 2B, 5 to 10, 13
1996	–	3, 4, 12, 14	–	3, 4, 11, 12, 14, 15
1987 trial				
1996	–	1, 2, 3, 5, 7, 7A	–	2, 5, 7, 7A

Table 2 Daily traffic flows *

Site	*Survey date*	*Lane*	*Commercial vehicles (>1.5 tonne)*		*Cars and light vans*	*Total vehicles*
A38 Burton	1984	Nearside	3,370		4,297	7,667
		Offside	416		3,180	3,596
	1990	Nearside	3,615		5,668	9,283
		Offside	477		4,948	5,425
M1 Wakefield	1991	Nearside	4,565		5,391	9,956
		Centre	1,322		12,341	13,663
		Offside	42		6,876	6,918
			Eastbound	*Westbound*		
M4 Cardiff	1992	Nearside	3,156	3,456	–	–
		Centre	782	1,058	–	–
		Offside	–	–	–	–

** Value recorded between 06.00 and 22.00 hours multiplied by 1.06, the factor relating traffic flow over 16 hours to a 24 hour count (DOT, 1981).*

Trafikinstitutet, 1990). Unmodified bitumen was used as the binder except in one of the UK 20 mm gradings that included bitumen modified by natural rubber, the material having performed well at Burton. The UK 20 mm porous asphalts allow results from this trial to be related to those from the Burton trials.

In addition, a section of UK 10 mm grading porous asphalt of lower polished-stone value (PSV) was laid with high PSV 14 mm pre-coated chippings rolled in. This section was laid to assess the viability of producing porous asphalt with relatively high skid-resistance but without having to use aggregate of high PSV throughout the full depth of the material. Details of the various sections are given in Table A.4 of Appendix A whilst the gradings are given in TRL Report 264 (Nicholls, 1997a).

Coarse aggregates known to be prone to stripping of the binder were excluded, although no specific tests were used to measure this property for the aggregates selected. The fine aggregate for the porous asphalts was specified to be crushed rock fines or sand fines or a blend of both. For Sections 4, 5 and 6, the continental gradings specify sieve sizes that do not correspond to the sizes then used in the UK asphalt industry and as used for the mixtures in BS 4987: Part 1 (BSI, 1988). For these materials, the equivalent proportions passing BS sieve sizes were obtained from the grading curve. This transformation is liable to have caused minor differences between the intended and trial gradings.

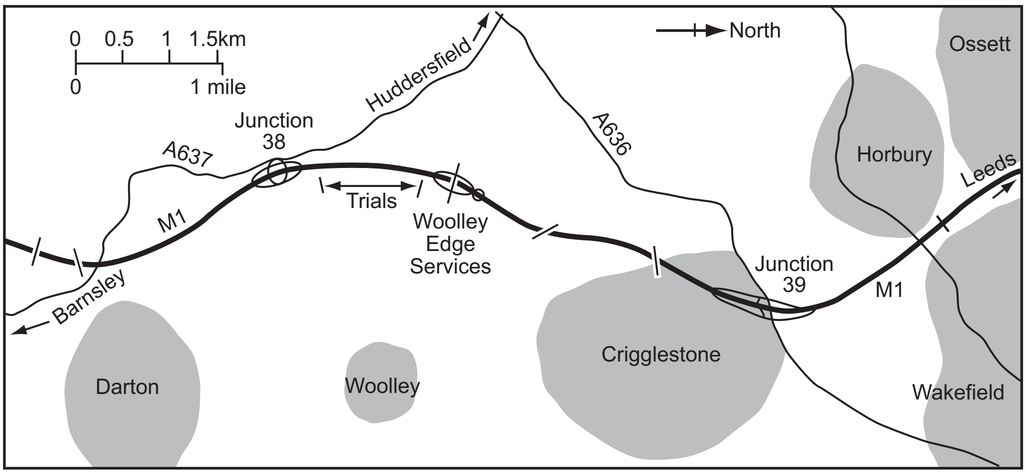
The specified binder contents were generally as given in the relevant standards. Nevertheless, binder drainage tests (Daines, 1992a; BSI, 1996) were carried out to determine the maximum binder content value at which not more than 0.3 per cent binder (as a proportion of the mixture) drained. A reduced tolerance of ± 0.3 per cent was applied to the target binder content for any mixture for which the test indicated that binder drainage could occur within the target range.

2.2.3 Construction

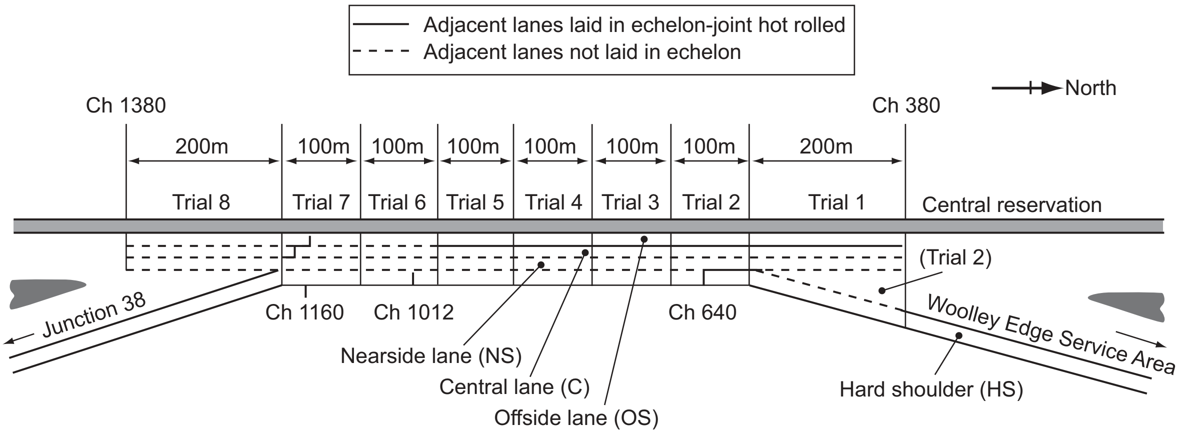
A 55 per cent stone content hot rolled asphalt binder course was laid prior to the experimental surface courses. The average wheel-tracking rate from cores extracted from this new binder course was 1.2 mm/h at 45 °C. A tack coat of K1-40 bitumen emulsion was then sprayed by tanker onto the new binder course at a heavy rate of 0.4 l/m² to act both as a seal on the binder course and an adhesive. The application was generally carried out on the day prior to laying the porous asphalt.

The porous asphalts were mixed at Tarmac Eastern's East Ardsley Plant, which is 14 km from the M1 site. The mixing plant is a 2.5 t batch mixer with computerised control. Transport of the mixed materials to the site was by double sheeted 20 t insulated lorries. The surfacings were laid between 29 July and 3 August 1991 when the weather remained generally fine, sunny, windless and with high air temperatures. Thus, laying conditions for all the sections were suitable.

Section 8, hot rolled asphalt, was laid first at the southern end of the site (Figure 1). The pre-coated Bayston Hill chippings were applied at a rate of spread of 14 to



Location of trial sections M1 near Wakefield, southbound carriageway



Layout of trial sections, southbound carriageway

Figure 1 Location and layout of M1 trial site, Wakefield

15 kg/m², about 75 per cent cover rate. The start locations of the lanes were staggered by about 5 m (Figure 1) in the general direction of the crossfall. This was to minimise rainwater flowing through the abutting porous asphalt of Section 7 from welling over onto the impermeable hot rolled asphalt.

Prior to laying the porous asphalt sections, the contractor carried out plant trial mixtures and laid them at the plant to gain experience. Laying in echelon was carried out on site for Sections 1 to 5, using two pavers with a maximum stagger of 20 m. The offside and centre lanes were laid first, followed by the nearside lane and hard shoulder. The longitudinal joints between the echelon laid strips were rolled hot, whereas other strips were laid against cold (or still warm) edges. Only one paver was used for the nearside lane and hard shoulder of Section 5, and for all lanes of Sections 6 and 7. All the hot rolled longitudinal joints are shown as continuous lines in Figure 1.

Analysis of the materials and binder recovery tests were carried out on samples taken at the mixing plant and from the tops of lorry loads at the site. In general, compliance was good overall; in particular, there was no evidence of significant binder drainage within the porous asphalt mixes. The exception was Section 6 (Sweden), where there was an average reduction of 0.7 per cent in binder content between plant and site samples. The binder drainage test for this mixture had shown that it was necessary to reduce the target binder content from 5.0 to 4.3 per cent. Some of the plant samples showed that the binder content was at the high end of the specified range and this may have been a contributory factor. This mixture did not use hydrated lime, which would have assisted in enabling a higher binder content to be retained.

2.3 M40, Stokenchurch

2.3.1 Site

The carriageway of the M40 motorway between junctions 5 and 7 was constructed in 1973 using un-reinforced concrete in 5 m bays. In 1984 and 1991, major joint maintenance was carried out resulting in the contraction joints being widened to about 35 mm. However, with the additional traffic using the motorway following its extension to join the M42 at Birmingham, it was decided to overlay the concrete with an asphalt surface course and roadbase, the work to be carried out in two phases in 1994 and 1995. For most of the length, the surface course selected was hot rolled asphalt, but for a length of both carriageways from junction 6 northwards in the 1994 phase, a trial length of porous asphalt was included. The planned 1995 phase was subsequently deferred.

Sections of the 1994 phase were given different treatments, using both dense bitumen macadam and hot rolled asphalt roadbase, and both hot rolled asphalt and porous asphalt surface course (Figure 2). Generally, the roadbase layer was laid 180 mm to 200 mm thick except over bridges, were it was reduced to 50 mm in order to limit the load on the structures. On two bridges within the porous asphalt trial, the roadbase layer had to be omitted entirely and it was decided to revert to hot rolled asphalt rather than lay porous asphalt directly onto jointed concrete.

2.3.2 Initial cracking of roadbase

Prior to the pavement being overlaid, a deflection survey was carried out by Oxfordshire County Council in order to identify any joints that required treatment. Those joints were then pressure grouted and the sealant in all the joints were topped-up to a level near that of the surface using a proprietary joint sealant.

However, on the northbound carriageway with porous asphalt surface course, the first section that was laid, the roadbase rose up in some places immediately after the vibrating roller had passed the contraction joints in the concrete, then cracked along the top of the ridge. Although these ridges dropped back to close giving a reasonably level profile, the cracks remained. The cracking seemed to be exacerbated by the use of vibrating rollers. The cracking only appeared where dense bitumen macadam roadbase had been laid at 50 mm depth, and then not universally and there was little evidence of cracking in dense bitumen macadam at full depth (that is, 150 mm). The ridges occurred almost immediately after laying, so diurnal and other longer term temperature effects were not the cause. Also, the cracks were in the thinner asphalt layers, so that thermal expansion effects in the concrete slabs (due to heat transfer from the asphalt) were unlikely to have caused this effect because there would be less heat available from the asphalt than where thicker layers were applied. The cracks occurred over under-bridges, which could be considered areas of lower structural rigidity and which, therefore, could allow more deflection of the pavement under the roller. However, there was no indication of movement in the pavement (which had been pressure grouted) with vibration, so that structural strength was not considered to be the cause.

A section of 20 mm by 30 mm foamed-plastic ‘backer rod’ had been inserted in each joint sealing groove to support the sealant at the correct depth. This backer rod is easily compressible and could have allowed some of the roadbase mixture to be forced into the joints by the rollers. When the load from the roller was removed, the elastic nature of the sealant would then cause it to push some of the roadbase material out again, causing a ridge in the roadbase. This mechanism would be consistent with the ridges being more prevalent in thinner layers, because the thicker the layer the better the load spreading ability whilst the paver was operating and the greater the static load provided by the roadbase layer itself after the roller had gone. The local areas where cracks had not appeared could be explained by the presence of cork sealant, used in some earlier repairs. Therefore, it was concluded by all parties involved that this mechanism was the most likely explanation for the ridges and resulting cracking.

A possible remedy in future construction would be to use a less resilient joint filler compound (provided their use would not restrict the ability of joint to expand and contract sufficiently). Such joint sealants should help to prevent the asphalt being forced into the joints only to be expelled by the sealant after the roller has passed.

2.3.3 Construction

The main contractor was Amey with CAMAS Associated Asphalt as the laying sub-contractor and the porous asphalt being supplied by Redland Aggregates Limited. The binder was the proprietary Shell Cariphalte DM, a Styrene-Butadiene-Styrene block co-polymer modified bitumen.

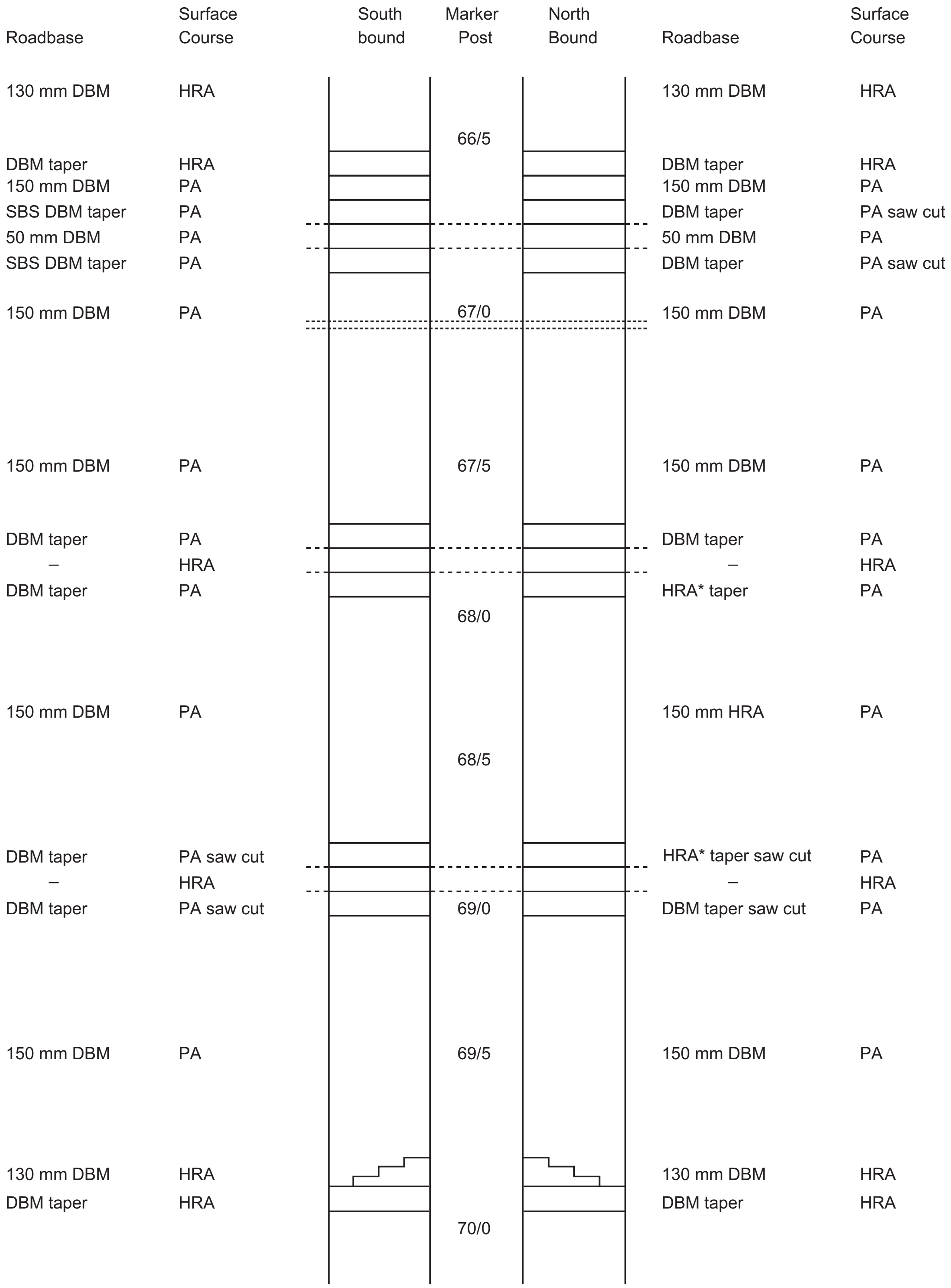
The porous asphalt was laid on the northbound carriageway between 26 August and 28 August 1994 when the weather was generally dry but cloudy. Laying started at the north end of the site in two passes: the inside lane and hard shoulder together and then the central and outside lanes together. Initially, a double-width paver was used, but this was found not to have sufficient traction and the contractor reverted to two pavers in echelon. The tack coat had been laid the previous day, but was still very sticky.

Samples of the porous asphalt for compositional analysis were taken and analysed both at the plant by the supplier and at the site by the Resident Engineer; the mean results are given in Table 3. The differences in composition found for samples taken from the plant and on

Table 3 Mean Compositional Analysis Results for M40

		Binder content		*Mass of aggregate passing BS sieve*				
Samples taken from	*Carriageway*	*Target (%)*	*Found (%)*	*20 mm (%)*	*14 mm (%)*	*6.3 mm (%)*	*3.35 mm (%)*	*75 μm (%)*
Plant	Northbound	4.5 ± 0.3	4.7	99	64	22	12	5.1
Site	Northbound	4.5 ± 0.3	4.2	99	65	21	12	5.1
Plant	Southbound	4.5 ± 0.3	4.6	99	65	23	12	5.0
Repeat plant*	Southbound	4.5 ± 0.3	4.6	99	66	25	13	5.7
Site	Southbound	4.5 ± 0.3	4.3	99	66	22	11	5.1

** Repeat plant samples analysed by the laying contractor as a check on the material supplier.*



Surface course taken as 50 mm thick; * On drawings as DBM, but constructed with HRA

Figure 2 Layout of sections on M40

site were significant in terms of the compliance of the mixture to the specification. However, the most probable causes of these differences, in assumed order of importance, are:

- segregation in the mixture during paving operations – site samples were taken from the mat edge, which will tend to be binder lean;
- loss of binder to the paper bags in which site samples were collected; and
- binder drainage, although this is not believed to have been a major factor because excess binder was not seen to be left in the wagons after delivery.

Therefore, it is concluded that there was not a significant loss of binder from the mixture during transport and laying. Consequently, it is reasonable to conclude that the expected life of the surfacing, which can be related to the binder content, would not have been significantly affected by binder losses during transport and construction.

The hydraulic conductivity of the surfacing was determined by the Resident Engineer in accordance with Clause 940 of the *Specification for Highway Works* (MCHW 1). The mean and range of results are given in Table 4, which show that the majority of the material was within specification but that the range for each lane was very wide. However, the readings taken on the first section of porous asphalt laid on the northbound carriageway were close to the limiting values in the specification, possibly due to the 'learning curve' needed with mixing and laying a 'new' material such as porous asphalt.

The porous asphalt on the southbound carriageway was laid between 30 September and 2 October 1994. Samples of the porous asphalt for compositional analysis were taken and analysed both at the plant by the Supplier and on site by the Resident Engineer. Plant samples were also tested in duplicate by the laying sub-contractor; the statistics from both sets of results, together with those from site, are also given in Table 3. The mean readings of hydraulic conductivity for lanes 2 and 3 are given in Table 4, although no data were provided to TRL on the results from the hard shoulder and lane 1. The results that were provided show considerably higher values than the corresponding results on the northbound carriageway. The compositional analysis results did not show any consistent difference between the southbound and northbound materials that could explain the approximate doubling of the average hydraulic conductivity value between the two carriageways.

2.4 M4, Cardiff

Although not a trial site in the series monitored for the Highways Agency, TRL has been monitoring a section of porous asphalt on the M4 near Cardiff on behalf of the Welsh Office. The site is described here because it is relevant to the objectives of this study. The commercial traffic figures for this section of road are included in Table 2.

The M4 between Junctions 33 and 34 (Capel Llanilltern and Miskin) consists of 3.4 km dual 3-lane with hard shoulder motorway. Travelling westbound from Junction 33, there is a downhill gradient of 2.5 per cent for about 1 km which reduces to 0.5 per cent for the remaining 2.4 km of the site, and the motorway curves gently to the left. A 3.07 km length of both carriageways was strengthened and regulated by the application of a thick bituminous overlay of heavy duty macadam prior to the application of the final 50 mm thick surfacing of porous asphalt with 20 mm nominal sized aggregate to a draft of the specification that subsequently went into the *Specification for Highway Works* (MCHW 1). The road was fully opened to traffic in May 1993.

The M4 between Junctions 32 to 33 (Coryton to Capel Llanilltern) consists of 4.7 km dual 3-lane with hard shoulder motorway. The carriageway is relatively straight and level. The section has concrete under-bridges across a river, a railway and a road, all in close proximity, together with two further bridges over roads. Prior to laying the porous asphalt, 800 m of both lanes 1 and 2 and the eastbound hard shoulder were reconstructed whilst the remainder of the section was strengthened by overlaying with 120 mm of dense bitumen macadam. Porous asphalt was laid on the whole length of both carriageways, including over the bridges, in 1994 to the standard specification (MCHW 1). The aggregate and binder were the same as used on the 1993 section. At under-bridge expansion joints, 300 mm wide mastic plug joints were installed after cutting transverse channels through the overlying porous asphalt; the edges of the plug joints were overbanded. The road was fully opened to traffic in August/September 1994.

3 Results and observations

3.1 Skidding resistance

3.1.1 Initial skid resistance

The weather changed from an extended dry spell to wet conditions shortly after some lanes on the northbound

Table 4 M40 Relative hydraulic conductivity results

Carriageway		*Target*	*Hard shoulder*	*Lane 1*	*Lane 2*	*Lane 3*
Northbound	Mean	>0.12*	0.26	0.23	0.26	0.32
	Range	>0.06†	0.04 – 0.50	0.03 – 0.71	0.09 – 0.71	0.06 – 0.85
Southbound	Mean	>0.12*	No data	No data	0.46	0.56
	Range	>0.06†	available	available	0.13 – 0.93	0.26 – 1.14

** Limit on running mean of 6 results*
† Lower limit, being the limit on any individual result

carriageway of the M40 had been re-opened with the new porous asphalt surface course. Several minor accidents were reported on the porous asphalt with vehicles shunting into each other whilst over the same period a similar spate of accidents did not occur on the southbound carriageway of brushed concrete. This type of observation suggests that newly laid porous asphalt may be more slippery than newly laid traditional surfacings (such as hot rolled asphalt with pre-coated chippings) due to the relatively thick layer of binder coating the coarse aggregate. Therefore, a Sideway-force Coefficient Routine Investigation Machine (SCRIM) survey was carried out on the southbound carriageway on 5 October 1994 following the porous asphalt surface course having been laid between 30 September and 2 October, 3 to 5 days earlier. The results are given in Table 5.

The results show that SCRIM coefficient for the recently opened porous asphalt on the southbound carriageway was similar to that for the adjacent existing concrete surface. The SCRIM result for the porous asphalt that had been trafficked for nearly two months (the northbound carriageway results) was equivalent to the concrete on the hard shoulder (still to be overlaid at that time) that had had limited trafficking. Therefore, these results indicate that the skid-resistance of porous asphalt, as measured by SCRIM, was broadly equivalent to the existing concrete surfacing which did not give rise to a similar spate of accidents over that period. Furthermore, the results are above the 0.35 investigatory level suggested in HD 28/94 (DMRB 7.3.1) for such sites. Consequently, either:

- the apparently higher rate of accidents on the porous asphalt was not related to the level of skidding resistance (other possible factors include the porous asphalt being at the bottom of a relatively long, steep slope and the presence of construction work to distract some drivers); and/or
- any period when friction of the porous asphalt offers a higher risk of skidding accidents is shorter than the three days between opening and the SCRIM survey.

Similarly, the initial SCRIM results, taken three weeks after opening, from the nearside lane on the M1 at Wakefield averaged 0.50 (range 0.43 to 0.58) for the porous asphalt sections, the same as the value for the hot rolled asphalt section. After three months trafficking, the values were still similar, with those for porous asphalt having increased to a mean of 0.57 (range 0.53 to 0.62) and those for hot rolled asphalt to 0.55. The overall change in that time could be due to the normal seasonal variations. The similar values on both occasions indicate a similar initial performance for both types of material, at least following three weeks of exposure to traffic. The limited effect of the binder masking the micro-texture of the aggregate is further supported by the observation that the lowest SCRIM results were from Section 2. Section 2 had the lowest binder content at a target of 3.7 per cent and hence should be the least effected by the binder covering the aggregate. Therefore, it might be expected that this surface would give the highest SCRIM value rather than the lowest.

3.1.2 Retention of skidding resistance

Skidding resistance has been measured on the A38 Burton and M1 Wakefield sites using SCRIM at 50 km/h, generally three times each year, and the Mean Summer SCRIM Coefficient (MSSC) and the Equilibrium SCRIM Coefficient (ESC) determined. The ESC is the average MSSC value over a number of years once conditions have reached equilibrium. The MSSC values for each lane obtained on these trial sites between 1990 and 1996 are shown in Figure 3 as the mean values for all sections. The values from Burton prior to 1990 and those for individual sections (both pre- and post-1990) are given elsewhere (Daines, 1992b; Nicholls, 1997b).

For the 1984 Burton trial, the skidding resistance on lane 1 had stabilised by 1987 (not shown in Figure 3) while stable conditions appear to have been reached by 1991 for the 1987 Burton trial. The mean MSSC values across the various sections in the 1987 Burton and the Wakefield trials after 5 years trafficking for both porous and hot rolled asphalt are shown in Figure 4.

In general porous asphalt provides skid resistance at least as good as that of hot rolled asphalt when the same PSV aggregate is used for the porous asphalt and the pre-coated chippings in hot rolled asphalt.

3.2 Surface texture

Surface texture has been determined on the Burton and Wakefield trial sites using three methods during a period of developing technology:

- *Sand-patch (SP)*: Texture depths were measured annually or biannually at ten locations along the wheel-path of each section. The test was generally performed to BS 598: Part 105 (BSI, 1990) or its predecessor, except that more recently a direct-reading cursor, calibrated in millimetres,

Table 5 SCRIM Readings on existing concrete and new Porous Asphalt from M40 on 5 October 1994

Carriageway	*Lane*	*Material*	*Length*	*Mean*	*Max.*	*Min.*
Northbound	Lane 1	Concrete	1.45 km	0.47	0.52	0.42
	Hard Shoulder	Concrete	1.00 km	0.55	0.62	0.49
	Lane 1	Porous asphalt	2.25 km	0.53	0.61	0.48
Southbound	Lane 1	Concrete	1.15 km	0.42	0.56	0.38
	Lane 1	Porous asphalt	2.95 km	0.44	0.62	0.37
Northbound (Contraflow)	Lane 3	Porous asphalt	0.30 km	0.53	0.60	0.41

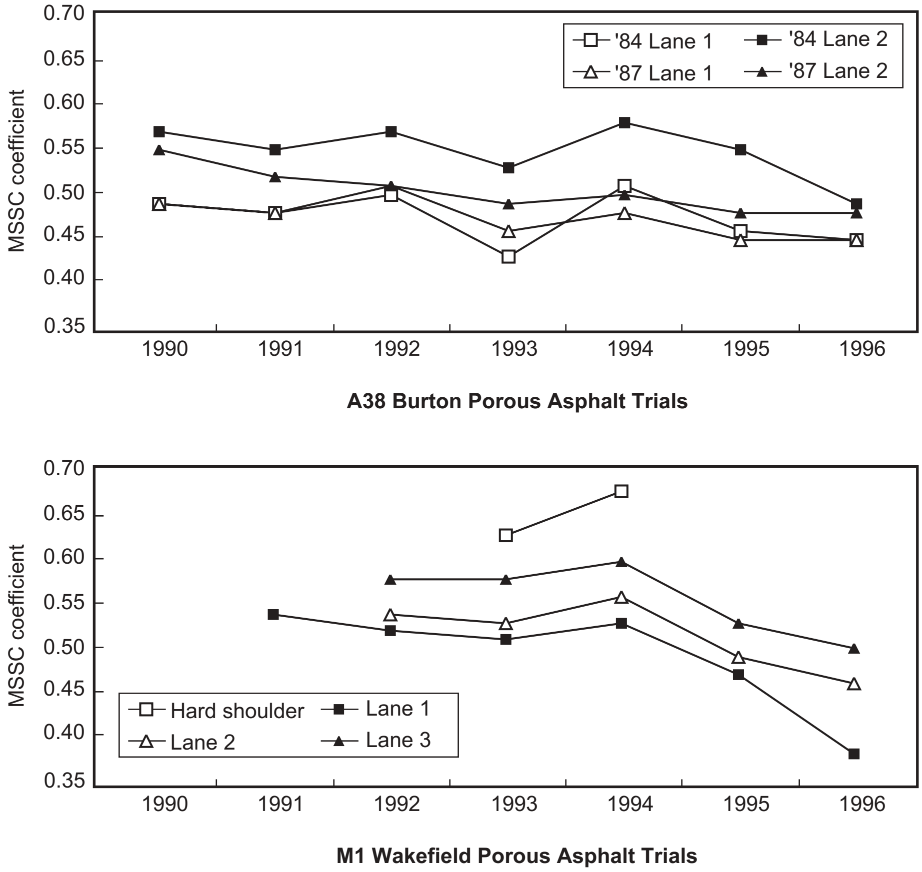


Figure 3 Mean MSSC values for each lane of the A38 and M1 trial sites

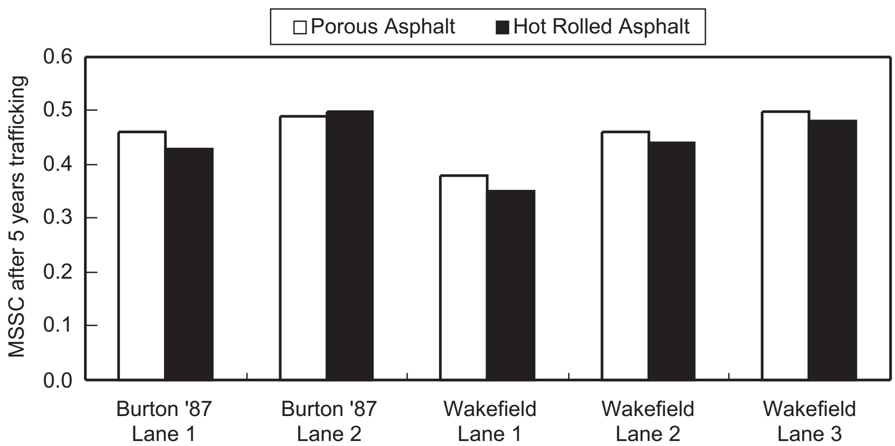


Figure 4 MSSC values after 5 years trafficking for Porous Asphalt and Hot Rolled Asphalt

has been used enabling results to be obtained more rapidly (analysis has demonstrated that the results obtained by the two methods are compatible).

- *Mini-Texture Meter (MTM)* (Hosking *et al.*, 1987): The MTM is a laser sensor-measured texture depth (SMTD) device which is mounted on a small, single-axled trolley and pushed over the surface. It measures the root-mean square (rms) of the variation in the surface height. The equipment was used to measure SMTD along the wheel-paths of each section, carried out on the same occasions as the sand-patch method.
- *High-Speed Texture Meter (HSTM)* (Cooper, 1985): The HSTM (or subsequent developments of vehicles capable of recording SMTD at normal traffic speeds) was generally used three times each year during spring, summer and autumn to measure the SMTD.

The mean sand-patch texture depth values for each lane obtained on these trial sites between 1990 and 1996 are shown in Figure 5 as the mean values for all sections. The values from Burton prior to 1990 and those for individual sections (both pre- and post-1990), together with those for MTM and HSTM SMTD, are given elsewhere (Daines, 1992b; Nicholls, 1997b).

All of the methods were developed for impervious materials and do not necessarily give an equivalent measure on porous asphalt. In particular, the loss of sand into the open pores could bias the result with the sand-patch method as well as contribute to the build up of detritus, whilst the effect of the different shape of the surfacing on the light beams from the laser devices is uncertain in sensor-measured methods. The techniques are, nevertheless, useful in comparing values of texture depth over the period of the trials.

The sand-patch and sensor-measured methods measure different properties, as illustrated by the mean of the porous asphalt section values for each lane from the 1987 Burton trial in Figure 6. Whilst the sand-patch values drop initially, possibly due to the pores clogging up and no longer able to receive as much sand, the two sensor-measured methods tend to give values which increase with time. Even between the two sensor-measured methods, there are differences in that the HSTM results increased in 1993 with the change from HSTM itself to SCRIMtex, with the laser mounted on a SCRIM. Hence, any relationship between different methods of measurement (Nicholls, 1997a) should include time as a parameter.

Figure 7 compares the average sand-patch texture depth of porous asphalt and that of hot rolled asphalt for the 1987 Burton trial. The figure shows that the sand-patch texture depth of porous asphalt is reduced initially to a greater extent than that of hot rolled asphalt, but the values were still significantly greater for porous asphalt at the end of the period.

Overall, the data indicates that it is unlikely that any 20 mm grading porous asphalt will have an unacceptably low value of texture depth, even after many years of exposure to traffic and irrespective of binder type and content. This appears to be equally true for all the methods of measurement examined.

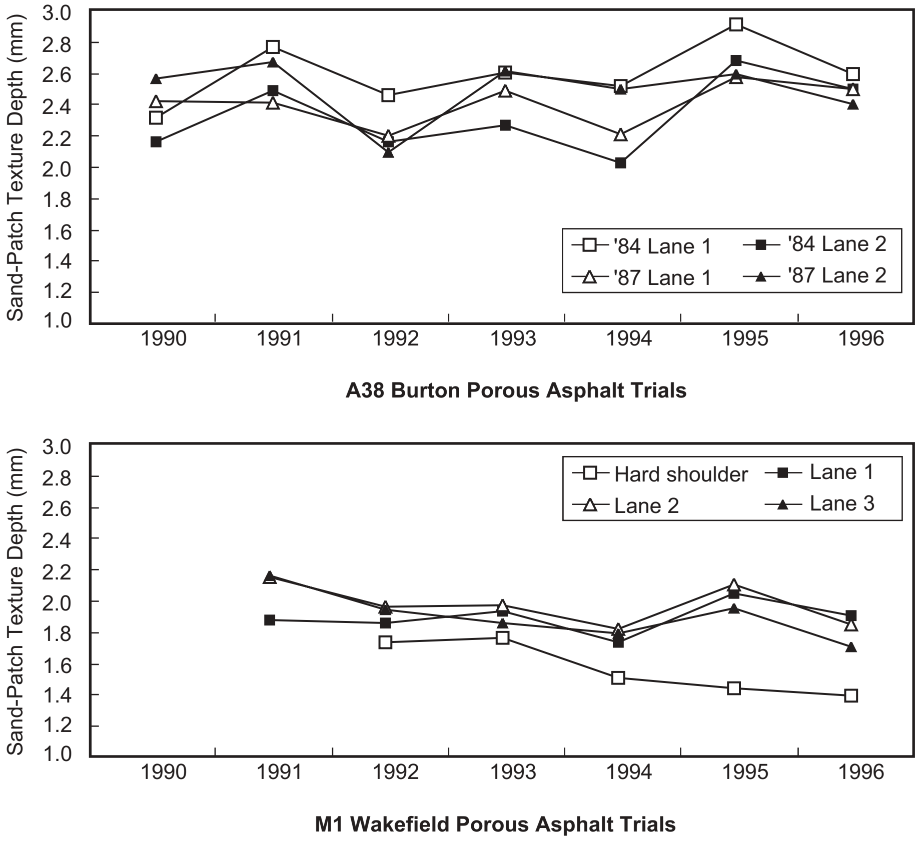


Figure 5 Mean sand-patch texture depth values for each lane of the A38 and M1 trial sites

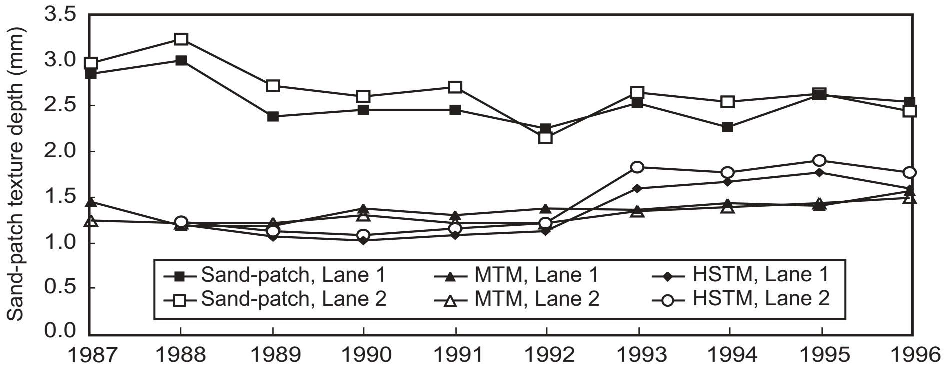


Figure 6 Texture measurements of Porous Asphalt on 1987 Burton trial

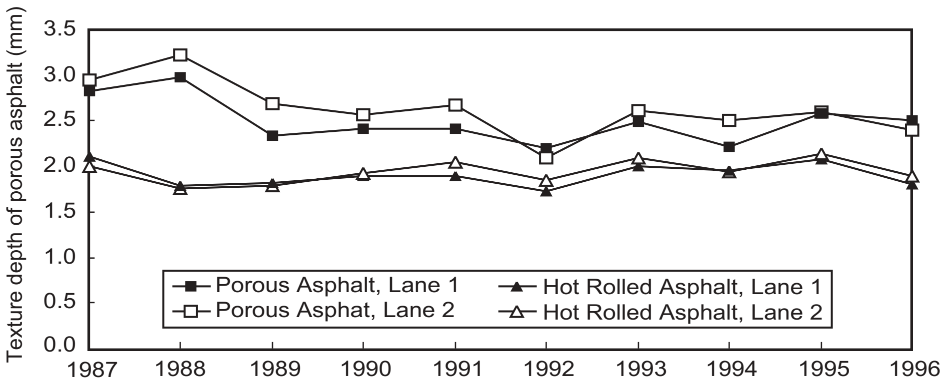


Figure 7 Sand patch texture of Porous and Hot Rolled Asphalt on 1987 Burton trial

3.3 Relative hydraulic conductivity

Relative hydraulic conductivity has been determined annually at the Burton and Wakefield sites using a falling-head permeameter (Daines, 1992a). However, prior to 1992, the permeameter used at Burton had a square base and was of slightly different dimensions to that currently specified. Therefore, the relative hydraulic conductivity results obtained by the square-based permeameter (and as quoted in some previous reports) should be multiplied by 0.6 to be equivalent to the standard permeameter defined in Clause 940 of the *Specification for Highway Works* (MCHW 1) and used in the 1992 and subsequent surveys. All measurements obtained with the square-based permeameter have been converted for use in this report.

Measurements were made at five locations in the wheel-paths of each section at Burton and in ten locations at Wakefield. When the measured outflow time exceeded 1 minute 40 seconds (hence the relative hydraulic conductivity is less than 0.010 s^{-1}), it can be assumed that the surfacing was locally effectively closed up. The mean hydraulic conductivity values for each lane obtained on these trial sites between 1990 and 1996 are shown in Figure 8 as the mean values for all sections. The values from Burton prior to 1990 and those for individual sections (both pre- and post-1990) are given elsewhere (Daines, 1992b; Nicholls, 1997b).

On all the sites, the relative hydraulic conductivity fell substantially from the initial, or ‘as laid’, values, particularly in the first year (which is not shown for the Burton trials in Figure 8). The average proportions of the as-laid values for the A38, M1 and M4 trials are given in Table 6. The results from the Wakefield trial and Cardiff sites show that the reduction on the hard shoulder is much more dramatic than on the running lanes. This increased rate of clogging up is probably due to there being no cleaning action from tyres travelling over the surfacing.

The Wakefield trial also demonstrated that the UK 20 mm grading produces relative hydraulic conductivity values up to an order of magnitude better than those employing smaller sized aggregate. The results are shown in Figure 9. This difference was particularly noticeable when comparing the value achieved by 20 mm porous asphalt (Sections 1 and 2) to that achieved with the UK 10 mm porous asphalt. Section 3, using the UK 10 mm grading at a thickness of 50 mm, proved unsuitable with the hydraulic conductivity and sand-patch texture results being significantly less than other sections. 10 mm porous asphalt has been used successfully elsewhere at lesser thicknesses, and it is assumed that the problem resulted from the greater thickness used here, making the aggregate to aggregate interlock unstable. The section was replaced by the standard 20 mm graded material in 1993.

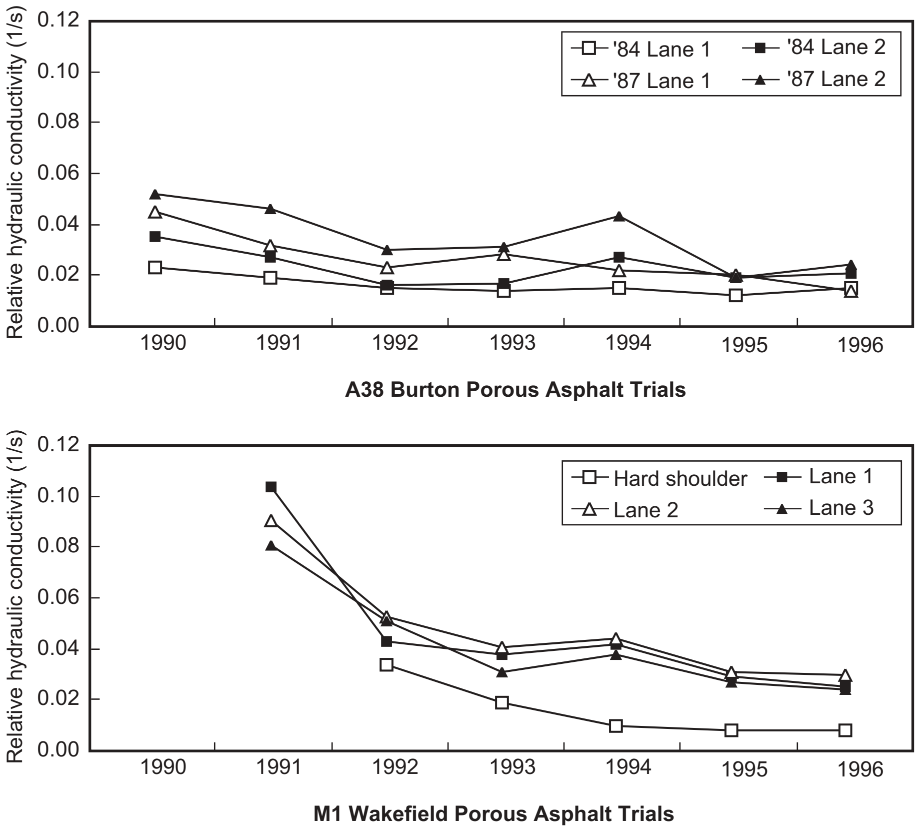


Figure 8 Wakefield Porous Asphalt trials

Table 6 Mean retained relative hydraulic conductivity after trafficking

	Period since opening							
Lane	*1 yr*	*2 yrs*	*3 yrs*	*4 yrs*	*5 yrs*	*6 yrs*	*7 yrs*	*8 yrs*
1984 Burton								
Lane 1	32%	23%	16%	15%	13%	11%	9%	7%
Lane 2	39%	27%	23%	20%	16%	16%	12%	7½%
1987 Burton								
Lane 1	38%	25%	17%	14%	10%	12%	10%	9%
Lane 2	41%	35%	21%	24%	16%	16%	23%	10%
Wakefield								
Hard shoulder	37%	21%	11%	8½%	*			
Lane 1	41%	37%	40%	28%	24%			
Lane 2	58%	45%	48%	34%	32%			
Lane 3	63%	38%	47%	33%	30%			
1993 Cardiff Eastbound								
Hard shoulder	61%	15%	*					
Lane 1	60%	46%	26%					
1993 Cardiff Westbound								
Hard shoulder	30%	6%	*					
Lane 1	55%	55%	40%					
1994 Cardiff Eastbound								
Hard shoulder	59%	37%						
Lane 1	76%	41%						
1994 Cardiff Westbound								
Hard shoulder	29%	17%						
Lane 1	52%	38%						

* = *closed up with relative hydraulic conductivity < 0.010 s^{-1}*
(Initial value for Wakefield hard shoulder taken as average for lanes 1, 2 and 3)

3.4 Deformation

Deformation has been measured on the trials annually, using a 2.0 m straightedge beam and calibrated wedge, bridging the nearside wheel-path in lane 1 and the offside path in other lanes. Measurements were taken at six equidistant points along the beam at ten locations in each section. From these data, the mean and standard deviation peak-to-valley height for each section was calculated (Daines, 1992a). The mean value from the first set of measurements carried out on a section provides a baseline for subsequent determinations of the deformation. A difference of more than 0.6 mm in the means determined from two sets of measurements was generally found to be statistically significant. From the records on individual sections (Daines, 1992b; Nicholls, 1997b), it was seen that those few mixtures whose measurements in the first year showed significant deformation, also tended to be those which deformed excessively in the longer term.

The mean total deformation from the baseline measurements for both lanes of the 1987 A38 Burton trial and Lanes 1 and 2 of the M1 Wakefield trial are shown in Figure 10 as the mean values for all sections between 1990 and 1996. There was no further significant deformation on the 1984 A38 Burton trial beyond 1990, so the measurements are not reported. Deformation was not measured on the hard shoulder and Lane 3 of the M1 Wakefield trial (because they should not carry any commercial traffic). The values from Burton prior to 1990 and those for individual sections (both pre- and post-1990) are given elsewhere (Daines, 1992b; Nicholls, 1997b).

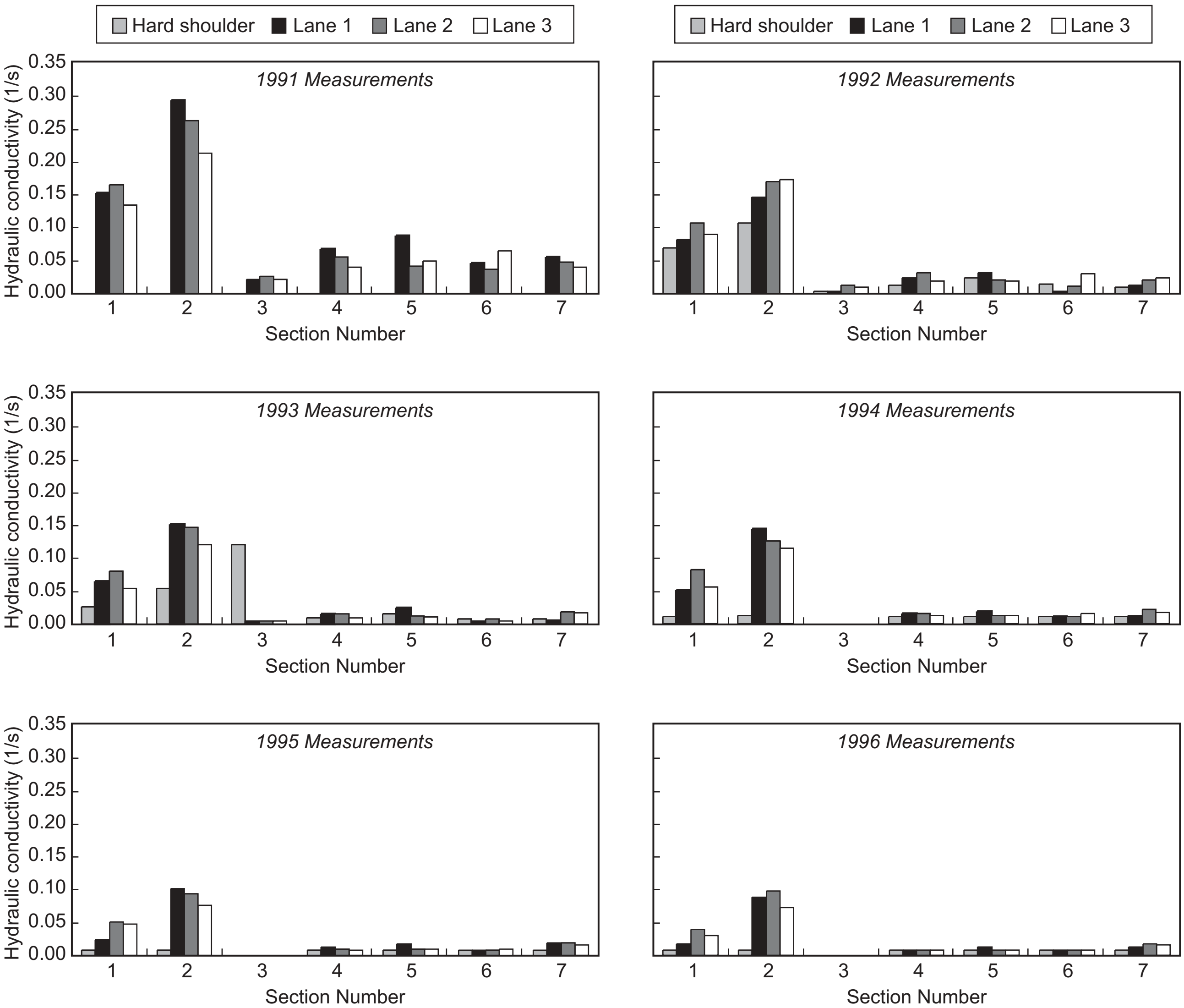


Figure 9 Change in relative hydraulic conductivity with time on M1 at Wakefield *(Hard shoulder, Lane 1, Lane 2 and Lane 3 for each section)*

The rate of deformation (total deformation divided by the number of summers since the baseline measurements) fell from their initial values in successive years. Two mechanisms are likely:

- initially, some secondary compaction occurs which helps to lock the aggregate skeleton; and
- subsequently, the binder hardens which stiffens the porous asphalt.

Porous asphalt is not expected to deform excessively, and the total deformation values confirm this. All the surfacings deformed at overall rates of less than 0.5 mm/year (the nominal acceptable upper limit to deformation rates to avoid 10 mm ruts after 20 years (Szatkowski, 1979)) and many did not deform significantly in the offside lane during this period. Those sections with the highest binder contents tended to show the greatest deformation, but these rates of deformation are still acceptable. The measurements on both the 1987 Burton and the Wakefield sites showed similar behaviour.

3.5 Visual inspections

Visual inspections were carried out annually by a Panel drawn from the Industry (including the Highways Agency, contractors, materials suppliers and TRL) to assess the state of the surfacing and to act as a quantified measure of their durability up to that time (Nicholls, 1997c). In an inspection, each section is rated on a scale running from '*Excellent*' (E) through '*Good*' (G), '*Moderate*' (M), '*Acceptable*' (A), '*Suspect*' (S) and '*Poor*' (P) to '*Bad*' (B). Although individual assessments from different members do vary, as might be expected, the markings obtaining by averaging across the Panel have been found to be reasonably consistent with performance. Nevertheless, the ratings allocated to specific sections sometimes improve slightly on successive inspections for no obvious reason. The mean Panel markings for each trial site between 1990 and 1996 are shown in Figure 11 as the mean values for all sections. The values from Burton prior to 1990 and those for individual sections (both pre- and post-1990) are given elsewhere (Daines, 1992b; Nicholls, 1997b).

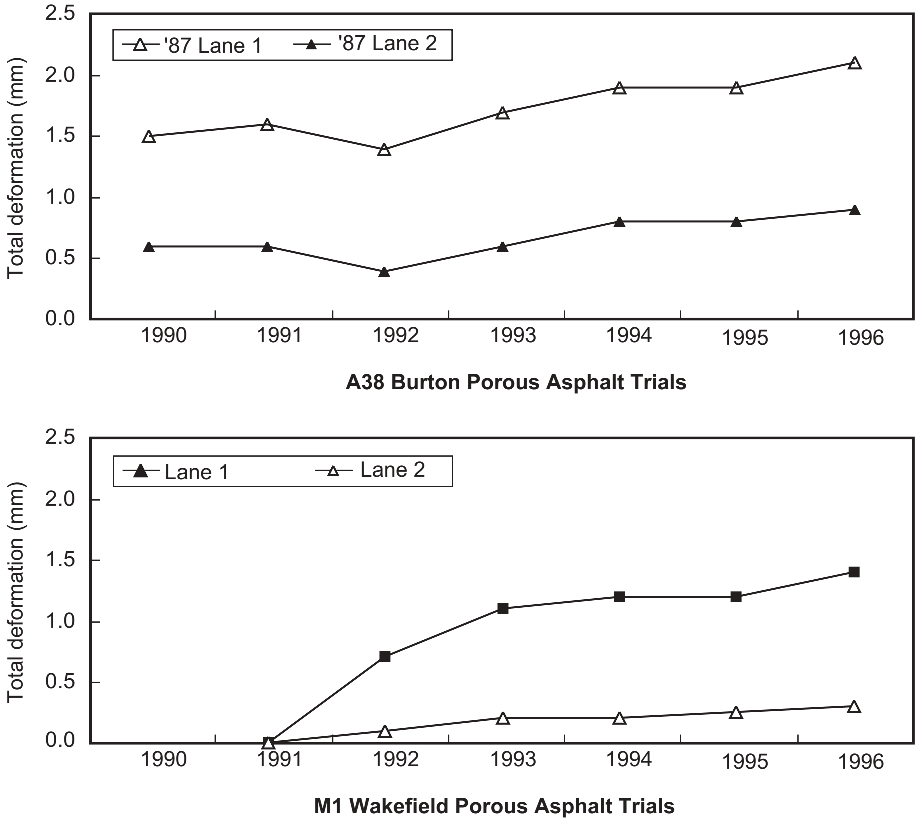


Figure 10 Mean total deformation values for some lanes of the A38 and M1 trial sites

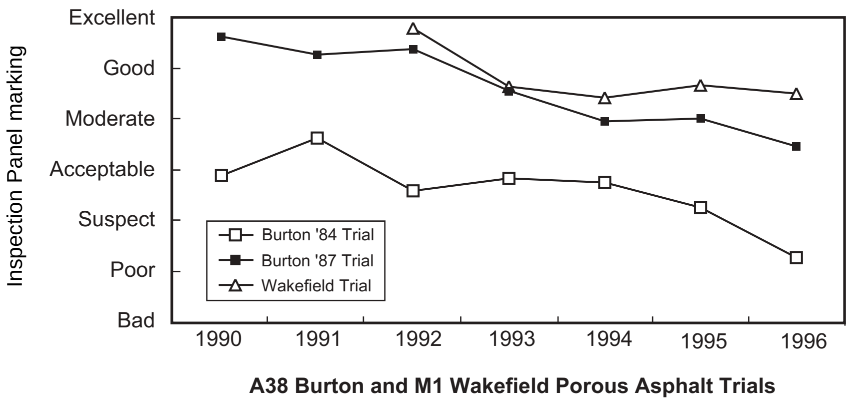


Figure 11 Mean inspection panel markings for each trial site

The Wakefield sections were generally rated '*Excellent*' after just one year but, by 1993, most sections were found to be equal to those of the 1987 Burton trial, despite the later being 4 years older. At this time on the Wakefield trial, only Sections 1 (20 mm nominal size) and 3 (10 mm nominal size, but with unacceptably low hydraulic conductivity) were rated as visually '*Good*'. This comparison indicates:

- the UK 20 mm aggregate grading for porous asphalt on the A38 trial is more robust than the smaller aggregate sizes used at Wakefield and generally specified in other countries; and
- improved performance of porous asphalt is achieved by using higher binder contents, which can often only be achieved, without binder drainage occurring, by the use of modifiers.

3.6 Cracks over transverse joints

A limited inspection of the M40 was carried out on 1 September 1994. Work on the central reserve was under way with two-lane traffic on the hard shoulder and inside lane of each carriageway. Therefore, the inspection was primarily of the centre and outside lanes. The weather was wet, as it had been the previous day, after a long hot and dry spell. A few areas were noted as being more open (i.e. less mortar between the coarse aggregate particles) than the norm and others as being more closed (i.e. more mortar), indicating some binder drainage despite previous assumptions (Section 2.3.3), but these areas were not very frequent. The cracks in the roadbase that were found during construction (Section 2.3.2) had been repaired. No cracks were found in un-sawn porous asphalt other than two possible cracks, both of which occurred over the hot rolled asphalt roadbase. At other places, possible cracks were discounted after further examination; even in the prevailing damp conditions, hairline cracks through porous asphalt are difficult to distinguish from connected gaps between the aggregate particles. The saw cuts through porous asphalt above joints over some of the tapered sections were not full depth and were not very straight, although they did appear to line up reasonably well with the joints at the ends. There was no indication of any fretting, which could have developed at these locations, but the surfacing had only been lightly trafficked at the time of the inspection.

A visual inspection of the porous asphalt on the northbound carriageway was made from the hard shoulder using a rolling closure in July 1995, approximately 11 months after the road was opened to traffic. Despite walking relatively slowly, it proved very difficult to identify any cracks with certainty other than those deliberately sawn. At one saw cut near marker post 66/5+80, minor fretting was beginning to take place in the nearside lane. The observed features that were considered to be possible cracks are listed under Year 1 in Table 7. With the limited number of possible cracks observed, the inspection was not repeated on the southbound carriageway.

The visual inspection of the porous asphalt on the northbound carriageway was repeated in 1996, approximately two years after the surfacing was opened to

Table 7 Cracks in Porous Asphalt on M40, northbound carriageway

				Severity rating after				
Marker post	*Roadbase material*	*Thickness*	*Saw cut*	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year 5*
66/7+44	DBM	150→50 mm taper	Surface c/se				A	A
66/7+49	DBM	150→50 mm taper	Surface c/se				A	A
66/7+55	DBM	150→50 mm taper	Surface c/se					A
66/7+59	DBM	150→50 mm taper	Surface c/se			A	A	A
66/7+65	DBM	150→50 mm taper	Surface c/se					A
66/7+79	DBM	150→50 mm taper	Surface c/se				A	A
66/7+89	DBM	150 mm	None			4	4	4
66/8+05	DBM	150 mm	None				1	3
66/8+30	DBM	50→150 mm taper	Surface c/se					A
67/4+22	DBM	150 mm	None			2	2	2
67/4+49	DBM	150 mm	None	1				
67/5+67	DBM	150 mm	None	1				
67/5+76	DBM	150 mm	None	1				
67/8+11	DBM	150→0 mm taper	None					3
67/8+31	DBM	150→0 mm taper	None					3
67/8+51	DBM	150→0 mm taper	None		3	4	2	4
67/9+50	HRA	0→150 mm taper	None					1
67/9+54	HRA	0→150 mm taper	None			2	3	3
67/9+75	HRA	0→150 mm taper	None	1				
67/9+85	HRA	150 mm	None		2	2	3	3
68/0+40	HRA	150 mm	None					2
68/0+65	HRA	150 mm	None					2
68/1+00	HRA	150 mm	None			2	3	2
68/1+57	HRA	150 mm	None					3
68/2+11	HRA	150 mm	None					3
68/3+80	HRA	150 mm	None		1	2	4	3
68/4+10	HRA	150 mm	None			2	3	3
68/4+12	HRA	150 mm	None				2	3
68/6+48	HRA	150 mm	None	1				
68/8+22	HRA	150→0 mm taper	Roadbase			2	3	3
68/8+40	HRA	150→0 mm taper	Roadbase		1	1	3	3
68/8+57	HRA	150→0 mm taper	Roadbase			4	4	4
68/8+70	HRA	150→0 mm taper	Roadbase				4	3
68/8+72	HRA	150→0 mm taper	Roadbase		2	2	3	
68/9+47	DBM	0→150 mm taper	Roadbase		2	4	3	4
68/9+54	DBM	0→150 mm taper	Roadbase		1	2	4	3
68/9+84	DBM	0→150 mm taper	Roadbase					1
69/1+76	DBM	150 mm	None	1				

Severity ratings:

1 = { Possible crack developing / Very fine crack

2 = Fine crack

3 = Crack

4 = { Multiple cracks / Crack with aggregate loss

A = Saw cut with noticeable aggregate loss traffic. Despite again walking relatively slowly, it proved difficult to identify many cracks with certainty other than those deliberately sawn, but some were observed (as listed under Year 2 in Table 7) in areas where the underlying asphalt was relatively thin. Nevertheless, because some definite cracks had been observed, the inspection was also carried out on the southbound carriageway shortly afterwards with the results listed in Table 8 (Year 2).

The inspections were repeated again in 1997, 1998 and 1999 along both carriageways and the observed cracks are listed in Table 7 for the northbound carriageway and Table 8 for the southbound carriageway. The inspection in 1998 took place in wet conditions, when the general condition of the porous asphalt was still generally good and seen to be effective at reducing the spray once a reasonable distance beyond the hot rolled asphalt. There were several large repair patches on the northbound carriageway near the bridge over the B4009. The patches were necessary to repair damage caused by a trailing jockey-wheel or similar, and there were signs of similar, if lesser, damage elsewhere. The damage, although obvious, had not resulted in an extended loss of aggregate, although these areas will probably be where such failure first occurs after the binder stiffness has dropped to the critical penetration (Nicholls, 1997a).

None of the possible cracks observed after one year were noted again the following year, so it can be assumed that no cracks emerged in the first year. After three years, the results show that more cracking had become apparent, particularly in the thinner sections at the tapers, with about half the observed cracks occurring in this small proportion of the total length. Nevertheless, the cracking was limited in extent and no extensive ravelling was observed. However, the cracks observed in previous surveys, where ravelling might be expected to be initiated, had not always been found subsequently, possibly due to the difficulty in observing cracks in a material with extensive voids and discontinuities.

The results after four and five years were very similar to those after three years, with very few new cracks being found and the previously observed cracks not getting significantly worse. Some cracks were even categorised as being less severe than previously, presumably due to their appearance changing under different weather conditions. Therefore, the presence of a crack in porous asphalt does not indicate incipient failure by ravelling, as might be anticipated, at least in the early life.

The ratio of observed cracks over the two roadbase materials varied with time, with more over dense bitumen macadam after two years, more observed over hot rolled asphalt after three years and back to marginally more over dense bitumen macadam after five years. Therefore, there appears to be little advantage in either material. With regard to the use of surface course saw cuts, most of them appeared to have closed up in the hard shoulder but were more open in the trafficked lanes; only a few had a noticeable aggregate loss.

Overall, the results from this trial appear to indicate that porous asphalt can be applied as the surface course over jointed concrete with an asphalt binder course or roadbase.

Table 8 Cracks in Porous Asphalt on M40, southbound carriageway

Marker post	*Roadbase material*	*Thickness*	*Saw cut*	*Severity rating after* Year 1	*Year 2*	*Year 3*	*Year 4*	*Year 5*
66/6+12	DBM	150 mm	None	–	2			
66/6+96	DBM	150→50 mm taper	None	–			3	3
66/7+47	DBM	150→50 mm taper	None	–	2			
66/8+48	DBM	50→150 mm taper	None	–	1			
67/2+26	DBM	150 mm	None	–	1			
67/2+59	DBM	150 mm	None	–		4		4
67/4+94	DBM	150 mm	None	–				1
67/8+46	DBM	150→0 mm taper	None	–		1		
67/8+51	DBM	150→0 mm taper	None	–		4		4
67/9+55	DBM	150 mm	None	–				1
68/0+28	DBM	150 mm	None	–	1			
68/2+61	DBM	150 mm	None	–			3	
68/7+02	DBM	150 mm	None	–	1			
68/8+34	DBM	150→0 mm taper	Surface c/se	–	1		3	A
68/8+55	DBM	150→0 mm taper	Surface c/se	–		A	4	A
68/9+13	DBM	0→150 mm taper	Surface c/se	–	1			
68/9+77	DBM	0→150 mm taper	Surface c/se	–				A
68/9+92	DBM	0→150 mm taper	Surface c/se	–				A
69/1+35	DBM	150 mm	None	–	2			
69/3+81	DBM	150 mm	None	–	1			
69/5+84	DBM	150 mm	None	–		1		
69/6+25	DBM	150 mm	None	–	2			1
69/6+47	DBM	150 mm	None	–		3		1
69/6+80	DBM	150 mm	None	–	1			

Severity ratings:
1 = { Possible crack developing / Very fine crack
2 = Fine crack
3 = Crack
4 = { Multiple cracks / Crack with aggregate loss
A = Saw cut with noticeable aggregate loss

However, by 2001 (after the monitoring by TRL had been completed and when the surfacing had been in service for seven years), significant repairs were scheduled because of aggregate loss in places. From the results of the surveys, there is little difference between a hot rolled asphalt roadbase and a dense bitumen macadam roadbase when laying porous asphalt over jointed concrete. Where the roadbase needs to be thinned, the porous asphalt can be saw cut over joints in the underlying concrete without inducing pre-mature fretting but saw cutting does not appear to be particularly beneficial in controlling subsequent reflective cracking.

3.7 Progressive ageing through the mat

One of the potential problems with a very open mixture such as porous asphalt is the potential for premature ageing of the binder because so much of it is exposed to the atmosphere. To check whether the binder has aged excessively, recovered binder from cores can be tested for penetration and softening to assess how much it changes with time.

In May 1996, cores were extracted from three sections of the 1984 Burton trial that were about to be replaced. The cores were taken in order to examine whether the binder aged more near the surface even in an open mixture such as porous asphalt. In July 1996, Staffordshire County Council cut each core into three horizontal slices and extracted the binder from each slice in accordance with BS 2000: Part 397 (BSI, 1995). They then measured the penetration, in accordance with BS 2000: Part 49 (BSI, 1993a), and the softening point, in accordance with BS 2000: Part 58 (BSI, 1993b), of the recovered binder, the results of which are given in Table 9.

Table 9 Binder tests from slices of 12-year old cores

Test / *Slice*	*100 pen + fibres* *Section 3*	*Shell Epoxy* *Section 4*	*Shell Cariphalte* *Section 12*
Penetration			
Upper	2 dmm	5 dmm	19 dmm
Middle	1 dmm	15 dmm	29 dmm
Lower	1 dmm	13 dmm	47 dmm
Softening point			
Upper	72.4 °C	69.6 °C	65.8 °C
Middle	73.0 °C	71.2 °C	59.6 °C
Lower	76.6 °C	68.2 °C	53.6 °C

The penetration results from Section 3 are inconclusive because the binder had hardened too much for the sensitivity of the test method. However, the softening point increased with depth, indicating increased hardening, the opposite of that expected. The results from Section 4 are also difficult to explain with the penetration test indicating the central portion had hardened least and the softening point test indicating the opposite; however, this section had an epoxy-resin modified binder which is likely to behave differently from other binders. Further, epoxy-resin modification makes binder recovery particularly difficult, and resulted in poorer repeatability of the procedure, which for this section is greater than the difference in softening point results. Section 12 produced the expected behaviour, with both penetration and softening point indicating reduced hardening with depth. Therefore, the results, whilst giving some support to the hypothesis of differential hardening with depth, are not conclusive and further analysis will be needed before any definite conclusions can be made in this respect.

4 Conclusions

The main conclusions that can be drawn from the observation of laying and monitoring porous asphalt on four major trunk roads are:

1 Porous asphalt can remain structurally viable for up to twelve years under traffic loads up to 4,000 cv/l/d, although the condition at the end of that time may no longer be satisfactory in terms of the desired properties. However, the typical life of porous asphalt is seven to ten years. It has not been possible to monitor any sites with greater traffic.

2 Trials with porous asphalt made using the UK 20 mm grading provided superior performance to finer-graded porous asphalts, in terms of relative hydraulic conductivity and surface texture.

3 A trial with porous asphalt using the UK 10 mm grading laid at a thickness of 50 mm yielded unacceptable performance, in terms of relative hydraulic conductivity and texture depth and, if used, should not be laid at thicknesses of 40 mm or greater.

4 A trial applying pre-coated chippings to porous asphalt showed that this can be laid successfully and that the chippings will be retained. However, the resulting material had the lowest relative hydraulic conductivity of the porous asphalts in that trial so that the principal objective of using porous asphalt rather than a traditional surfacing was not fully achieved.

5 Any lack of skid-resistance in the very early life of porous asphalt due to the use of a thick binder film appears to be limited in both extent and duration.

6 Porous asphalt can be laid over jointed concrete with an asphalt roadbase provided the joints are sufficiently ‘hard’ to minimise the possibility of material being forced into the joints during compaction, to be expelled afterwards.

7 After five years, there is little difference between a hot rolled asphalt roadbase and a dense bitumen macadam roadbase when laying porous asphalt over jointed concrete. Where the roadbase needs to be thinned, the porous asphalt can be saw cut over joints in the underlying concrete without inducing premature fretting but saw cutting does not appear to be particularly beneficial in reducing reflection cracking.

8 The period that porous asphalt laid over jointed concrete remains serviceable (i.e. before the surfacing nears the end of its useful life) still needs to be ascertained.

5 Acknowledgements

The work described in this paper was carried out in the Infrastructure Division of TRL Limited. The assistance of Dr P M Nelson and Dr A R Parry in reviewing the paper and of the Welsh Office (now the National Assembly for Wales) in granting permission to make use of data from the M4 are gratefully acknowledged

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Appendix A: Sections in road trials

Table A.1 Sections in A38 Burton 1984 Porous Asphalt trials

	Aggregate			*Binder*	
Section No.	*Source*	*PSV*	*Nominal size (mm)*	*Type*	*Specified content (per cent)*
1	Blodwel	61	20	70 pen	3.7 ± 0.3
2B	Blodwel	61	20	100 pen	3.7 ± 0.3
3	Blodwel	61	20	Shell epoxy bitumen	3.7 ± 0.3
4	Blodwel	61	20	100 pen + Inorphil mineral fibres	5.0 ± 0.3
5	Blodwel	61	20	100 pen + 5 % ICI EVA 18-150	4.2 ± 0.3
6	Blodwel	61	20	100 pen + 5 % ICI EVA 18-150	3.7 ± 0.3
7	Blodwel	61	20	Mobilplast C1	4.2 ± 0.3
8	Blodwel	61	20	200 pen + 5 % ICI EVA 18-150	3.7 ± 0.3
9	Blodwel	61	20	100 pen + 5 % 14-2400 ESSO EVA	4.2 ± 0.3
10	Blodwel	61	20	Philmac 200 + SBS	4.2 ± 0.3
11	Blodwel	61	20	Shell 200 pen + SBS	4.2 ± 0.3
12	Blodwel	61	20	BP 100 pen + SR	5.0 ± 0.3
13	Blodwel	61	20	100 pen	3.7 ± 0.3
14	Blodwel	61	20	100 pen + 5 % NR (7.4 % Pulvatex)	5.0 ± 0.3
15	Blodwel	61	20	100 pen	3.7 ± 0.3

Table A.2 Sections in A38 Burton 1987 porous asphalt trials

	Aggregate			*Binder*	
Section No.	*Source*	*PSV*	*Nominal size (mm)*	*Type*	*Specified content (per cent)*
1	Bayston Hill	65	20	200 pen + 5 % Esso 21/33 EVA	4.2 ± 0.3
2	Bayston Hill	65	20	Tarmac 70 pen + SR	4.7 ± 0.3
3	Bayston Hill	65	20	100 pen + Arbocel zz8/1 cellulose fibres	`4.7 ± 0.3
4	Bayston Hill	65	20	Shell epoxy bitumen	4.5 ± 0.3
5	Bayston Hill	65	20	BP SB2/100	5.0 ± 0.3
6	Bayston Hill	65	20	200 pen + 7.4 % Revertex LCS latex (5 % NR)	4.7 ± 0.3
7	Bayston Hill	65	20	100 pen	3.7 ± 0.3
7A	Bayston Hill	65	20	100 pen	3.4 ± 0.3

Table A.3 Sections in A38 Burton 1987 Hot Rolled Asphalt trials

	Aggregate			*Mixture*	*Binder*	
Section No.	*Source*	*PSV*	*Size (mm)*	*Stability (kN)*	*Type*	*Specified content (per cent)*
8	Rowley Basalt	-	14	6 ± 2	Tarmac 50 pen + SR	7.2 ± 0.6
9	Rowley Basalt	-	14	3.5 ± 2	100 pen + Chemcrete	8.1 ± 0.6
10	Rowley Basalt	-	14	6 ± 2	Shell Multiphalte	7.2 ± 0.6
11	Rowley Basalt	-	14	6 ± 2	50 pen	7.2 ± 0.6
12	Rowley Basalt	-	14	6 ± 2	Shell Cariphalte DM	7.2 ± 0.6
13	Rowley Basalt	-	14	8 ± 2	Shell Cariphalte DM	6.9 ± 0.6
14	Rowley Basalt	-	14	3.5 ± 2	70 pen + Chemcrete	8.1 ± 0.6
15	Rowley Basalt	-	14	3.5 ± 2	Exxon 70 pen + 5 % EVA	8.1 ± 0.6
16	Rowley Basalt	-	14	8 ± 2	50 pen	6.9 ± 0.6
17	Rowley Basalt	-	14	3.5 ± 2	70 pen	8.1 ± 0.6
Pre-coated chippings						
8 – 17	Bayston Hill	65	20			

Table A.4 Sections in M1 Wakefield porous asphalt trial

	Aggregate			*Binder*	
Section No.	*Source*	*PSV*	*Nominal size (mm)*	*Type*	*Specified content (per cent)*
1	Bayston Hill	65	20	100 pen + 7.4 % Revertex LCS latex (5 % NR)	4.5 ± 0.3
2	Bayston Hill	65	20	100 pen	3.4 ± 0.3
3	Bayston Hill	65	10	100 pen	5.2 ± 0.3
4	Bayston Hill	65	14	100 pen	4.3 ± 0.3
5	Bayston Hill	65	16	100 pen	4.3 ± 0.3
6	Bayston Hill	65	16	85 pen	4.3 ± 0.3
7	Barrasford	54	10	100 pen	5.2 ± 0.3
	Bayston Hill	65	14 (chippings)		
Hot Rolled Asphalt					
8	Barrasford	54	14	50 pen	7.5 ± 0.6
	Bayston Hill	65	20 (chippings)		

Abstract

Porous asphalt as a road surfacing material has been under test by TRL since 1967, but the use on more heavily trafficked pavements needs to be evaluated. Trial sites carrying moderately heavy traffic on the A38 and M1 have been monitored on behalf of the Highways Agency. On the A38 at Burton (traffic flows on two lanes of 3,600 cv/l/d and 475 cv/l/d), the trial compared the use of different binder contents and the suitability of certain binder modifiers to retain the binder without drainage. On the M1 at Wakefield (traffic flows on three lanes of 4,565 cv/l/d, 1,320 cv/l/d and 40 cv/l/d), the trial compared different European gradings and investigated the possibility of using pre-coated chippings in porous asphalt. On the M40 in Oxfordshire, the trial of porous asphalt overlaying jointed concrete was monitored. On the M4 at Cardiff (traffic flows on the three lanes of 3,300 cv/l/d, 920 cv/l/d and not recorded), the site has been monitored on behalf of the Welsh Office. The results are discussed and conclusions for the use of porous asphalt drawn.

Related publications

TRL497 *The design of porous asphalt mixtures to performance-related criteria* by J C Nicholls and I G Carswell. 2001 (price £25, code E)

TRL376 *Effectiveness of edge drainage details for use with porous asphalt* by J C Nicholls and I G Carswell. 2001 (price £25, code E)

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