TRANSPORT RESEARCH LABORATORY

Road trials of high modulus base for heavily trafficked roads

Prepared for Highways Agency, British Aggregate Construction Materials Industries* and the Refined Bitumen Association

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M E Nunn and T Smith

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Executive Summary

The project described in this report was jointly sponsored by the Highways Agency, British Aggregate Construction Materials Industries and the Refined Bitumen Association.

Road trials have been carried out on High Modulus Base (HMB), a high stiffness roadbase macadam manufactured to the standard UK composition for dense bitumen macadam (DBM), using a penetration grade binder of less than 50. The terminology used for 15 pen HMB is HMB15, for 25 pen, HMB25, and for 35 pen, HMB35. Throughout this investigation HMB15 was compared with a control macadam that was made with a nominal 50 or 100 penetration grade binder. The properties of HMB25 and HMB35 were predicted by interpolation. Trials were carried out at five sites by five different contractors using different aggregate and bitumen sources and working in a range of weather conditions.

The overall objective was to compare HMB15 with control lengths of conventional DBM and heavy duty macadam (HDM) roadbase, which involved:

- Evaluation of the mixing, laying and compaction characteristics of the test material in relation to the control materials. In addition, the Contractor at each site was asked to report on his experience with HMB and to estimate the future cost of producing and laying the material.
- Measurement of the structural properties of samples taken from the test and the control pavements and the establishment of representative structural properties of HMB for pavement design purposes.

The trials demonstrated that, over the range of conditions experienced on the sites, HMB15 could be mixed, laid and compacted without difficulty using conventional UK plant. This allayed concerns that the material would be difficult to compact without the use of the very heavy, pneumatic-tyre rollers specified in France for the French variant of this material.

The trials established the structural properties of HMB relative to conventional roadbase that can be used for pavement design purposes. The superior load-spreading properties of HMB will allow either the same design life to be achieved by significantly reducing the thickness of the asphalt layers or a longer life to be obtained using current thicknesses. A reduction in pavement thickness offsets the increased cost of HMB15; considerable overall savings can be made, compared with DBM and HDM.

HMB has considerable potential for use in rut resistant asphalt pavements. HMB has a high resistance to deformation and, when used as a roadbase or basecourse in conjunction with a thin surfacing or a rut resistant wearing course, the resultant pavement would have excellent rutting resistance. However, further trials are recommended to evaluate the system fully.

1 Introduction

Experience in France, reported by Caroff and Corté (1994), has shown that roadbase materials with high stiffnesses can have considerable advantages over conventional roadbases. The standard UK roadbase materials, dense bitumen macadam (DBM) and heavy duty macadam (HDM), perform satisfactorily but improved materials would be advantageous in view of the requirement to produce more economic road designs by using thinner layers or by increasing the in-service life of the pavement. The work described in this report is a continuation of the investigation by Nunn and Smith (1994a) in which the engineering, manufacturing and laying characteristics of a French high modulus roadbase were compared with dense bitumen macadam incorporating a harder binder.

High modulus roadbase, known as enrobé à module élevé (EME), was introduced in France in the early 1980s as a measure to reduce the usage of oil-derived products. The high stiffness of this material enabled the roadbase thickness to be reduced by up to 40 percent compared with conventional French materials. EME is designed using a suite of laboratory tests. It has excellent load-spreading properties due to its high elastic stiffness, which is mainly achieved by using low penetration grade binders in the range 10 to 35. The designed material is considered to be very stable and consequently very heavy pneumatic-tyre rollers, weighing up to 45 tonnes, are regarded as essential for compaction.

The work by Nunn and Smith (1994a), indicated that high stiffness roadbase materials have considerable potential and demonstrated that, under pilot-scale conditions, difficulties encountered in mixing, laying and compacting high stiffness materials were no greater than those expected from standard macadams. They showed that roadbase macadams to the current UK specification, but using a 15 pen binder, had properties similar to EME and recommended that the modified macadam should be introduced on a trial basis to enable its properties to be confirmed over a range of site conditions likely to be encountered in normal contractual work.

This study, which was sponsored by the Highways Agency, British Aggregate Construction Materials Industries and the Refined Bitumen Association, describes full-scale trials of the improved macadam, now known as high modulus base (HMB), carried out on four reconstruction contracts and one new construction. These trial sites were selected to assess HMB15 manufactured using different aggregates, bitumen sources and mixing plants over a range of contractual and weather conditions. This range of conditions was essential because it is possible that large variations in the properties of nominally similar materials may occur at different sites. The quantity of material laid in each trial was sufficient to enable the Contractor to respond to any problems with the new material as though it was part of his normal construction practice. The overall objective of the trials was to identify the relative improvement in the structural properties of dense macadams that result from using very stiff binders, compared with control materials. In more detail, this involved the following:

- Comparison of the composition of the laid material with the specification.
- Evaluation of the mixing, laying and compaction characteristics of the test material in relation to those of the control material.
- Measurement of the structural properties of samples taken from the test pavements and establishing representative values for pavement design purposes.

In addition, the Contractor in each trial was asked to report on his experiences with the material and, to estimate costs of producing and laying the material, based on knowledge gained from the trial.

It should be noted that the term *asphalt*, used throughout this report, is generic and is intended to describe all bituminous materials.

2 Description of trials

The trial materials were laid in reconstruction contracts at Sites A, B, C and E and in a new construction at Site D. One trial took place in winter to establish whether concerns about laying HMB in adverse, cold weather conditions were justified; the other four trials took place during the summer months. Table 1 shows the nominal pavement construction and the materials investigated at each site.

Table 1 Nominal construction thicknesses and material type

				Thickness of asphalt layers		
Site	*Trial roadbase macadams*	*Wearing course (mm)*	*Base -course (mm)*	*Upper roadbase (mm)*	*Mid roadbase (mm)*	*Lower roadbase (mm)*
A	DBM HMB15	50	-	100	160	125 (HRA)
B	HDM HMB15	50	60	120	-	125
C	DBM HMB15	50	-	100	150	150
D	HDM HMB15	25	95	130	-	130
E	HDM HMB15	20	-	80	120	120

Each trial consisted of two sections; a control of either DBM or HDM and a test section of HMB15. The compositions of these materials are specified in Appendix A. The materials used at Sites A and D complied with the requirements of BS4987 Part 1, (1993), while those used at Sites B, C and E were designed in accordance with the requirements of Clause 929 of the Specification (MCHW 1). In each trial, approximately 1,300 tonnes of test material were laid. This quantity of material enabled the Contractor to use a complete binder storage tank of 15 pen bitumen thus avoiding operational problems arising from unused materials.

The lengths of test materials laid were considered sufficient to allow the contractor time to respond to any difficulties that might occur at the start of laying. However, difficulties with mixing, laying and compaction were not anticipated provided that the temperature of the HMB was such that the 15 pen binder was at the equi-viscous temperature of the control binder. At these temperatures both the control and the test materials were expected to behave in a similar manner. Within each section a smaller, representative length of 50 metres was selected for more detailed study. These areas were chosen using the results of a dynamic plate bearing test on the sub-base to identify areas of uniform and representative foundation strength. The general layout of each trial and

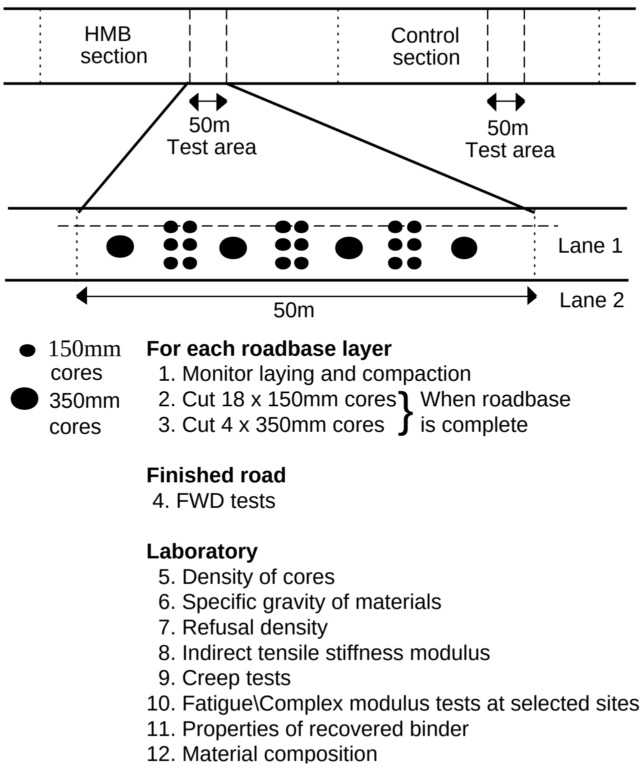

Figure 1 General trial layout

the small test area, used for more detailed testing, together with details of the sampling and testing carried out, are shown in Figure 1.

The mixing characteristics of each material were monitored by observing whether the material was adequately coated and whether any serious segregation had occurred. The temperature prior to compaction was recorded, together with the type of compaction plant used and the number of roller passes. Samples of material were taken from the paver screws for compositional analysis and specific gravity tests. When the roadbase had been completed, cores were removed for testing in the laboratory. Finally, at some sites, the structural quality of the pavement was assessed by measuring the pavement stiffness with the Falling Weight Deflectometer (FWD).

3 Manufacture, laying and compaction

Conventional batch mixer plants were used to produce materials for all of the sites apart from Site A where a continuous mixing plant was used. No problems were encountered by the operators, although the mixing temperature of the HMB, at up to 190°C, is substantially higher than that for conventional materials.

The trial material at Site A was laid in hot weather conditions on an HRA lower roadbase. Both the control and the test materials, which used a 40 mm nominal size crushed granite aggregate, were well coated and showed no signs of segregation. Compaction was initially carried out by a pair of 8 - 10 tonne vibratory tandem rollers, and then finished by a three point dead-weight roller. There were no difficulties in compacting either material. However, the HMB15 appeared to be more workable than the control material because the temperature of the mixture was substantially higher than the recommended minimum of 140°C. Consequently, in order to obtain good surface levels, rolling was delayed for a short time after the upper roadbase layer was placed to allow the mat to cool slightly in order to reduce workability. A 3-wheel, dead-weight roller was then used for the first few passes, before applying the vibratory roller. No other difficulties were experienced in compacting either material. A 50mm thick HRA wearing course was laid at a later date.

At Site B the materials were again laid in good weather conditions on a Type 1, crushed rock sub-base. Both the control material, HDM, and the HMB15, made with a 28mm crushed limestone aggregate, were well coated and showed no signs of segregation. The lower roadbase layer of HMB15 was mixed at the upper end of the specified temperature range. At this temperature, the HMB15 compacted easily and the mixing temperature was reduced by approximately 10°C for the next layer of roadbase material. Compaction was carried out by an 8 - 10 tonne vibratory tandem roller kept tight up against the paver, which applied 20 passes and then finished by a 10 tonne dead-weight roller. A 60mm thick layer of HDM basecourse was added later to both the test and the control sections; this is not considered in this report. The wearing course was a 50mm thick layer of HRA.

In contrast to the other trials, which were constructed under favourable summer conditions, the trial at Site C, shown in Figure 2, took place under much more adverse conditions with an ambient temperature of 2°C and a stiff breeze. The construction of both the test and the control pavements consisted of three layers of roadbase. In the first two layers a 40mm nominal size, crushed limestone aggregate was used, and a 28mm maximum aggregate size was used for the upper roadbase. Both the control material, DBM, and the HMB15 were well coated. However, the 40mm DBM roadbase showed some signs of localised segregation; no segregation was encountered in the HMB15. Compaction was carried out by a pair of 16 tonne vibratory tandem rollers. The Contractor had no difficulties in compacting either of the roadbase materials to the target percentage refusal density (PRD). Again, a 50mm thick HRA wearing course was used.

Figure 2 Laying and compaction in cold weather at Site C

The trial at Site D was carried out as part of a new construction in good weather conditions. The test material consisted of two layers of 28mm HMB15 roadbase and a 20mm HMB15 basecourse. The control material was HDM, using 28mm and 20mm maximum aggregate size for the roadbase and basecourse, respectively. Both the HMB15 and HDM were well coated and showed no signs of segregation. Initial compaction was carried out by a pair of three point dead-weight rollers and the final compaction by a vibratory tandem roller. The Contractor monitored material density during compaction using a nuclear density gauge and compaction was considered complete when the target PRD was achieved. Two types of proprietary stone mastic asphalt (SMA) mix were used as surfacing.

At Site E both materials were laid in fair weather conditions with an ambient temperature of 9°C and a light wind. Both the control material, DBM, and the test material, HMB15, were laid as three layers of 28mm maximum size aggregate roadbase; they were well coated with no signs of segregation. Compaction of the lower and mid-roadbase layers was carried out by a vibratory tandem roller. A three point dead-weight roller was used to compact the upper roadbase because the Contractor considered that better levels could be achieved by employing this type of compaction plant. A proprietary thin surfacing material was used to complete the construction.

The ambient air temperatures, paving temperatures and compaction details are summarised in Table 2, which shows that at all sites the temperatures of the HMB15 materials at the start of rolling were well above the recommended minimum of 140°C.

4 Experience of the contractors

The Contractors found no difficulties in mixing, laying and compacting HMB15. However it did appear that production rates were slightly lower with HMB15 than with conventional materials. At sites A and B there was slight difficulty in achieving an even surface on which to lay the wearing course. However, this was due to the Contractor raising the material temperatures towards the upper limit of the specified range because of his lack of experience with HMB15 and his concerns that the material may be difficult to compact. In the event it proved to be too workable at these higher temperatures. Even under the very low ambient temperature conditions encountered at Site C there were no problems. The main comment from the Contractors was that the behaviour of HMB15 was almost identical to that of conventional macadams and at more than one of the sites the following remark was made *".... if the paving gang had not been informed, they would not have known that the new material was being used."*

Table 2 Summary of paving, compaction and weather conditions

Site	*Material*	*Ambient temperature (°C)*	*Initial compaction temperature (°C)*	*Approximate No. of roller passes*
A	DBM	30	140 - 149	20
	HMB15	30	163 - 178	20
B	HDM	19	148 - 154	20
	HMB15	19	173 - 192	20
C	DBM	2	113 - 137	30
	HMB15	2	157 - 195	30
D	HDM	19	152 - 171	30
	HMB15	18	170 - 185	30
E	HDM	12	153 - 181	30
	HMB15	9	166 - 187	30

5 Laboratory and field measurements

5.1 Material composition

The material compositions and binder properties were determined by analysing cores cut from the test and control areas at each site, additional analysis was carried out on binder samples from the mixing plant in order to confirm the nominal binder properties and on recovered binder to determine the effect of mixing. The results of the analyses are shown in Appendix B.

Table 3 shows the Contractors Clause 929 measurements from job standard mix trials for Sites B, D and E. Sites A and C were not constructed using the 929 Specification Clause.

Most of the materials tested were within the target grading specification according to the analysis, except for a few examples of marginal non-compliance. The 28mm HDM used at Site B does not comply with the Clause 929 requirement of not less than 1% voids at refusal density.

Table 4 gives a summary of the results of measurements on the materials used in construction obtained by TRL.

This minimum voids requirement is a safeguard to prevent potentially unstable materials that are overfilled with binder being used, however there can be difficulties with voids measurement on specimens with relatively low voids content, which might explain the discrepancy between the TRL and Contractor's Clause 929 results in some cases. Nevertheless, the subsequent laboratory investigations showed that all the materials laid were likely to perform well.

Table 3 Summary of compaction data (Clause 929)

Site	Material	*In-situ voids content (%)*	*PRD (%)*	*Voids content at refusal (%)*
		Clause 929 measurements		
	Specified Clause 929	*<8*	*>93*	*>1*
B	28mm HDM	0.0	101.0	0.1
	28mm HMB15	1.2	99.8	1.0
D	28mm HDM	4.3	96.7	1.2
	20mm HDM	4.0	97.5	1.4
	28mm HMB15	2.7	98.9	1.6
	20mm HMB15	2.2	98.9	1.1
E	28mm HDM	4.3	96.7	1.0
	28mm HMB15	2.4	98.6	1.0

Table 4 Summary of compaction data (TRL measurements)

Site	Material	*In-situ voids content (%)*	*PRD (%)*	*Voids content at refusal (%)*
	TRL Measurements			
A	40mm DBM	6.6	95.0	1.6
	40mm HMB15	5.0	96.0	1.0
B	28mm HDM	0.0	98.7	0.0
	28mm HMB15	1.1	99.3	0.4
C	40mm DBM	4.1	97.3	1.4
	28mm DBM	3.1	97.0	0.1
	40mm HMB15	4.3	96.7	1.0
	28mm HMB15	5.9	94.9	0.7
D	28mm HDM	0.8	99.3	0.1
	20mm HDM	2.8	96.1	0.0
	28mm HMB15	3.0	97.7	0.8
	20mm HMB15	2.5	97.2	0.0

In some instances, it was recognised by all concerned in the contracts that some local materials performed well, even with voids contents close to zero at refusal. For example, experience has shown that the binder content for material laid at Site B has to be in the upper half of the range to obtain complete coating of the aggregate. However, although this produced a low voids content, there was no history of problems using this material. Therefore the Resident Engineer relaxed the Clause 929 requirements.

5.2 Compaction

Concern has been expressed by Contractors about the ability of the 8 - 10 tonne vibratory rollers, conventionally used in the UK, to effectively compact HMB. Similar materials in France require the use of very heavy pneumatic-tyre rollers of up to 45 tonnes that are not generally available in the UK. The effectiveness of 8 - 10 tonne vibratory rollers in compacting HMB is illustrated in Figure 3.

Figure 3 shows the density profile, measured by the TRL gamma-ray core scanner, described by Harland (1966), of cores of both control and test materials from

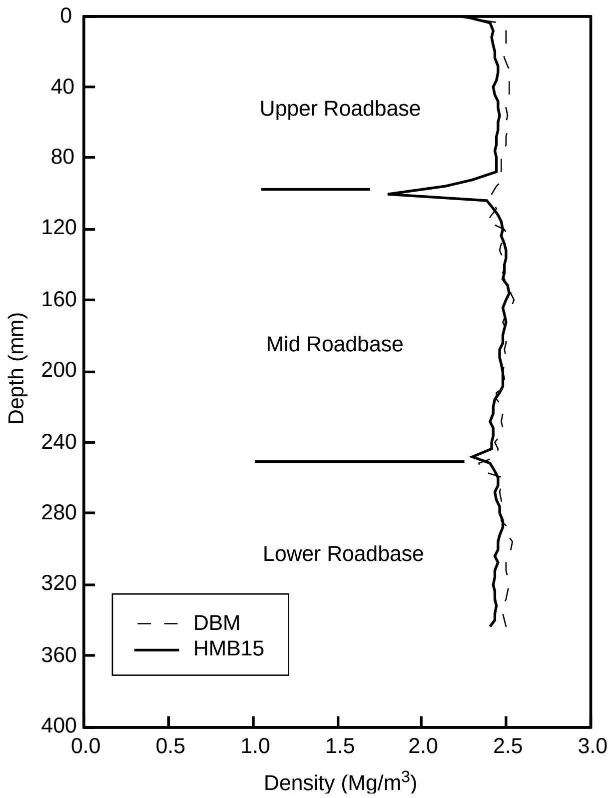

Figure 3 Density profile at Site C

Site C, which were laid in unfavourable cold winter conditions. The core scanner records the mean density of each 4 mm increment of a core through its full depth, which enables a profile of density with depth to be generated. In cases where insufficient compaction has been applied, the density will be poor, particularly in the lower part of the layer. The compaction of these materials was very uniform with depth and similar levels of compaction were achieved for the HMB15 and the control material at all the sites. These results demonstrate that compaction of dense graded macadams using very stiff binders is not a problem, provided that appropriate mixing and laying temperatures are used and that the rollers are kept close behind the paver.

In view of these findings it is not considered necessary to use the very heavy (up to 45 tonne) pneumatic-tyre rollers required for the compaction of EME in France.

5.3 Elastic stiffness modulus

The roadbase and basecourse are the main load spreading layers of the road. The elastic stiffness modulus of these layers is a measure of the ability of the pavement to reduce the stresses and strains developed in the sub-base and subgrade by traffic loading. It will also influence the level of tensile stress at the underside of the roadbase, which is considered to be an indicator of the risk of fatigue cracking.

Specimens were cut from each layer of the 150mm diameter cores and the indirect tensile stiffness modulus (ITSM) was measured at 20°C, using the method defined in British Standard Draft for Development BS DD 213 (1993). The test can be used to determine the increase in stiffness of HMB relative to the control materials (Brown et al, 1995). In addition, beams of material were cut from large diameter cores that were extracted from Site C to measure the complex modulus at loading frequencies in the range 0.1 to 35 Hz and temperatures from 10°C to 30°C using the TRL three-point bending test. The elastic stiffnesses of the four materials laid at Site C are plotted in Figure 4 against frequency at a reference temperature of 20°C. A shift factor, shown in the inset to this Figure, can be used to derive the elastic stiffness at other temperatures. The Figure clearly shows that both the HMB15 materials tested are considerably stiffer than the DBM materials and that HMB15 is much less frequency sensitive than DBM. Table 5 shows the stiffness of the four materials at 2.5Hz, the frequency associated with the ITSM test (Nunn and Bowskill, 1992), and at 5Hz, the UK reference conditions for design purposes.

Table 5 Elastic stiffness at 2.5Hz and 5Hz

	Material			
Frequency	*40mm DBM*	*28mm DBM*	*40mm HMB15*	*28mm HMB15*
2.5Hz	3.2	2.2	14.0	9.5
5.0Hz	4.1	2.9	15.0	10.3

A statistical analysis of the ITSM measurements (see Figure 5) shows that the standard deviation of HMB15, as a proportion of the mean value, is similar to that of the control materials. However, this will not produce more variable performance for the following reasons.

i A test sample is a very small quantity of material, in comparison with the slab of material under the wheel that is responsible for spreading the load. The majority of the variation measured in the test specimens is due to the small sample size and it will be *averaged out* in the larger volume of material supporting a wheel load.

ii The relationship between elastic stiffness, layer thickness and the load spreading ability of the pavement is non-linear. Figure 6 illustrates the relationship between the increase in stiffness relative to DBM, and thickness of the asphalt layer for a pavement with a design life of 80 million standard axles (msa). The Figure indicates that a proportional change in the stiffness of a high stiffness material will have less effect on thickness than for a low stiffness material.

Table 6 shows the mean ITSM for each material used at all the trial sites, together with the factors thought most likely to contribute to the variability in ITSM between trial sites. A multivariate regression analysis was carried out on

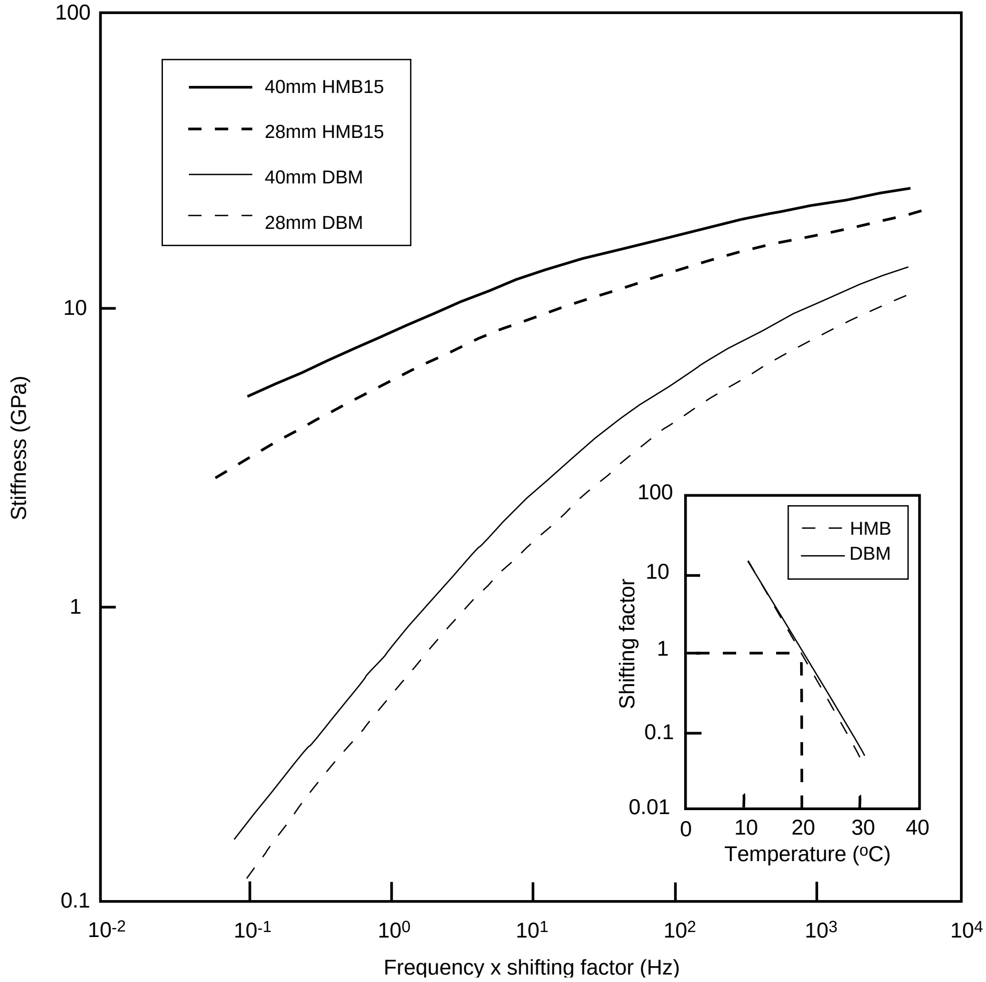

Figure 4 Elastic stiffness of materials at Site C

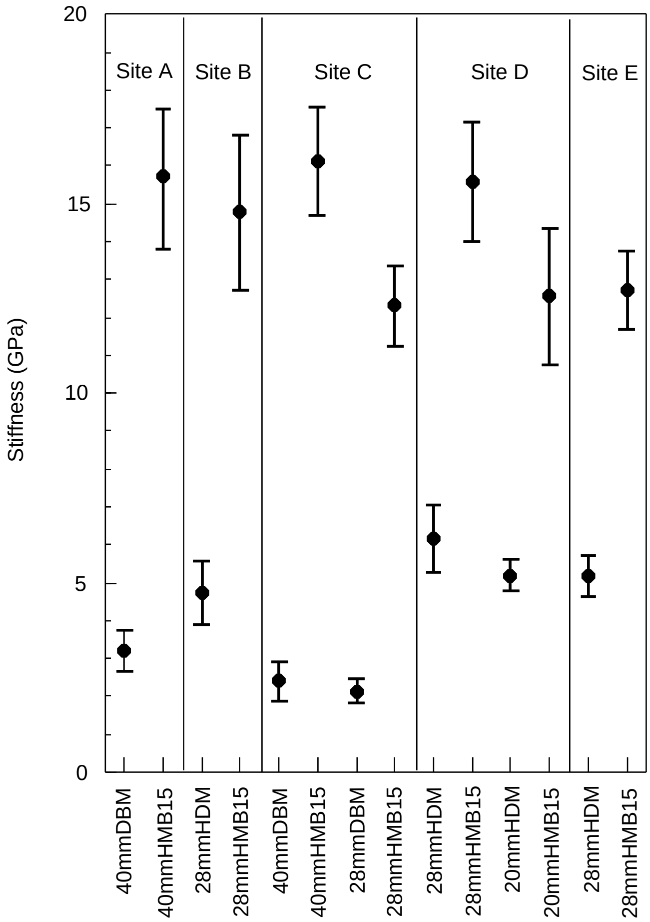

Figure 5 Mean ITSM and standard deviation

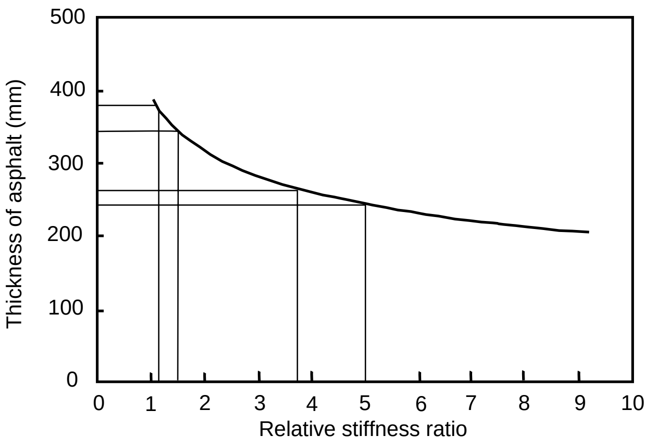

Figure 6 Relative stiffness ratio vs pavement thickness

Table 6 Indirect tensile stiffness modulus of trial materials

Site	*Material*	*Filler content (%)*	*Recovered pen of binder*	*Binder content (%M/M)*	*Voids content (%V/V)*	*Mean ITSM (GPa)*
A	40mm DBM	6.7	55	3.3	6.6	3.2
	40mm HMB15	6.9	12	3.6	5.5	15.7
B	28mm HDM	9.8	36	4.4	0.2	4.7
	28mm HMB15	10.0	13	4.6	0.7	14.8
C	40mm DBM	6.1	81	3.6	3.8	2.4
	28mm DBM	6.5	70	3.8	2.6	2.1
	40mm HMB15	6.4	12	3.3	4.3	16.1
	28mm HMB15	7.5	11	4.1	6.2	12.3
D	28mm HDM	8.0	34	4.2	0.8	6.2
	20mm HDM	8.4	34	4.4	2.3	5.2
	28mm HMB15	9.1	9	4.2	2.3	15.6
	20mm HMB15	8.4	10	4.9	2.5	12.6
E	28mm HDM	8.2	30	3.9	2.6	12.7
	28mm HMB15	8.8	16	4.1	2.4	5.2

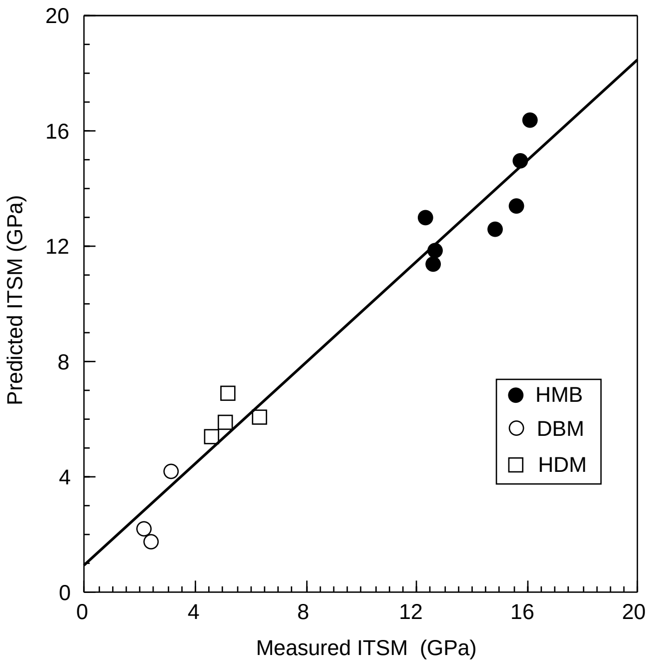

Figure 7 Regression of stiffness modulus against mix variables

the data to establish a relationship between ITSM and the mix variables. The analysis only identified penetration of the recovered binder and binder content as significant variables that influenced material stiffness. The results of this regression are shown in Figure 7.

$$\text{Log}_{10}(S_m) = 1.86 - 0.0138P - 0.144B \quad (1) \quad (R^2 = 0.93)$$

Where: S_m = ITSM
P = Penetration of recovered binder
B = Percentage by mass of binder

The results of the regression illustrate that 93 per cent of the variance of the values of the mean stiffness modulus is attributable to differences in the values of recovered penetration and binder content. Filler content, which was not varied independently in these trials, was not found to have a significant effect on stiffness modulus.

5.4 Resistance to deformation

Internal deformation of the asphalt layers can contribute significantly to the deformation measured at the surface of a road pavement. Therefore dynamic load uniaxial creep tests were carried out on the upper roadbase or basecourse layer at each trial site because, apart from the wearing course, these layers are considered to be at the greatest risk from internal deformation. The test, defined by the British Standard BS DD226 (1996), was carried out at 30°C over 1800 load cycles.

The dynamic load creep test has produced very variable results for nominally identical materials (Nunn and Smith, 1994b), which indicates that it is difficult to use the test to rank the deformation resistance of dense macadams. However, tests carried out as part of a pilot-scale trial of HMB (Nunn and Smith, 1994a) showed that the deformation resistance of HMB was so radically different to conventional materials that there was no problem using the test to discriminate between materials.

The mean creep stiffness of 6 specimens of each material and the relative creep stiffness are shown in Table 7. The results are similar to those obtained by Nunn and Smith (1994a) for EME and DBM15. It should also be noted that the low voids content of HMB15 and the control materials at some sites does not appear to have adversely effected the resistance to deformation. The greater creep stiffnesses of the test materials, compared with that of both the control materials, which are significant at the less than 0.1 per cent level, demonstrates their superior resistance to permanent deformation.

Table 7 Creep stiffness of trial materials

Site	*Material*	*Creep stiffness (MPa)*	*Relative creep stiffness*
A	DBM	14.8	1.0
	HMB	23.4	1.6
B	HDM	9.1	1.0
	HMB	35.0	3.8
C	DBM	6.9	1.0
	HMB	16.9	2.4
D	HDM	9.5	1.0
	HMB	58.5	6.1
E	HDM	6.3	1.0
	HMB	33.9	5.4

The superior deformation resistance was demonstrated in the laboratory wheel-tracking equipment used to test bridge plug joints. This machine uses a full-size commercial vehicle wheel with a realistic load. In this test, asphalt layers are placed on each side of the joint and the joint is repeatedly tracked to simulate in-service conditions. Excessive rutting occurred when standard asphalt materials were used for these layers, which necessitated stopping the test prematurely. When HMB15 was used the rutting was reduced to such a low level that the HMB15 layers could be retained for subsequent tests.

5.5 Resistance to cracking

It is important that asphalt used as a roadbase should not be unduly susceptible to cracking under the influence of traffic loading. Although laboratory fatigue tests grossly underestimate in-service performance, they can be used to determine whether changes in material composition lead to greater or lesser risk of fatigue cracking in the road. Concern has been expressed that, as HMB15 has a much stiffer binder than conventional roadbase materials, it might be more susceptible to fatigue cracking. Nunn and Smith (1994a) demonstrated that EME and HMB15 roadbase, laid in a pilot scale-trial, had a laboratory fatigue life similar to typical roadbase macadams. To confirm whether the HMB15 laid in these trials has similar fatigue characteristics to conventional macadams, uniaxial fatigue tests were carried out at a constant stress amplitude and temperature, using the method described by Goddard, Powell and Applegate (1978). Large diameter (350mm) cores of HMB15 and HDM were taken from Site B, cut into square section beams and tested. The results of fatigue testing are shown in Figure 8.

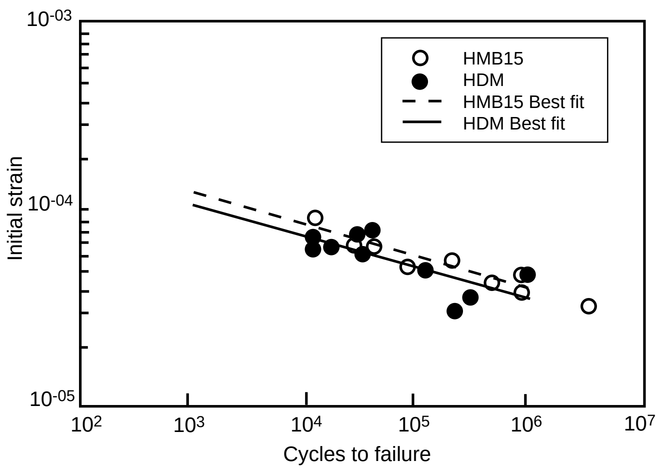

Figure 8 Fatigue resistance of HMB and HDM roadbase

The usual linear relationship between the logarithm of the repeated tensile strain at the start of the test and the logarithm of the number of cycles to failure was obtained. The results show that, at a given strain level, the fatigue life of HMB15 is not significantly different from that of the control HDM, which has been shown by Nunn, Rant and Schoepe (1987) to have a similar fatigue life to conventional DBM roadbase.

This result, and the results from the material laid in the earlier trial (Nunn and Smith, 1994a), indicate that the laboratory fatigue resistance of HMB15 is similar to that of conventional materials. Furthermore, in a fully flexible pavement, the effect of increased stiffness is to reduce the strain induced in the roadbase layer by traffic loading, thereby reducing the possibility of fatigue failure. It is estimated that the fatigue life of these materials would have to be reduced by a factor of four before it negated the benefits of increased stiffness.

5.6 In-service structural quality of pavements

The stiffness of the test pavements was compared directly with the control pavements at Sites A, C and D, using the Falling Weight Deflectometer (FWD). The survey at Site C took place on a very cold day in winter because of limited access to the site, when the pavement temperature was 6.5°C. Recent research by TRL suggests that this is outside the preferred temperature range as errors associated with temperature correction are large. In addition, both the control and the test pavement were very substantial constructions and the FWD testing on a cold day resulted in very small deflections so that it was not possible to discriminate between the two constructions. Therefore, the results of this survey were not included in the comparison.

Using a simple two layer model of the pavement and a back-analysis package, the stiffness of the asphalt layer and foundation on sites A and D were calculated. In both cases the stiffness of the asphalt has been corrected to that expected at 20°C. However the temperature sensitivity of HMB15 is different from that of conventional materials so a correction factor was derived from the results of three-point bending tests at a range of temperatures. Nevertheless, it should be noted that the stiffness calculated from FWD results will not be the same as that measured by the ITSM test as the test load is applied at different rates in the two methods.

Figure 9 shows that at Site A the stiffness of the foundation was constant throughout the trial length and that the calculated stiffness of the DBM was significantly less than that of the HMB15.

At Site D, the results shown in Figure 10, are less conclusive, however they do show a trend that indicates

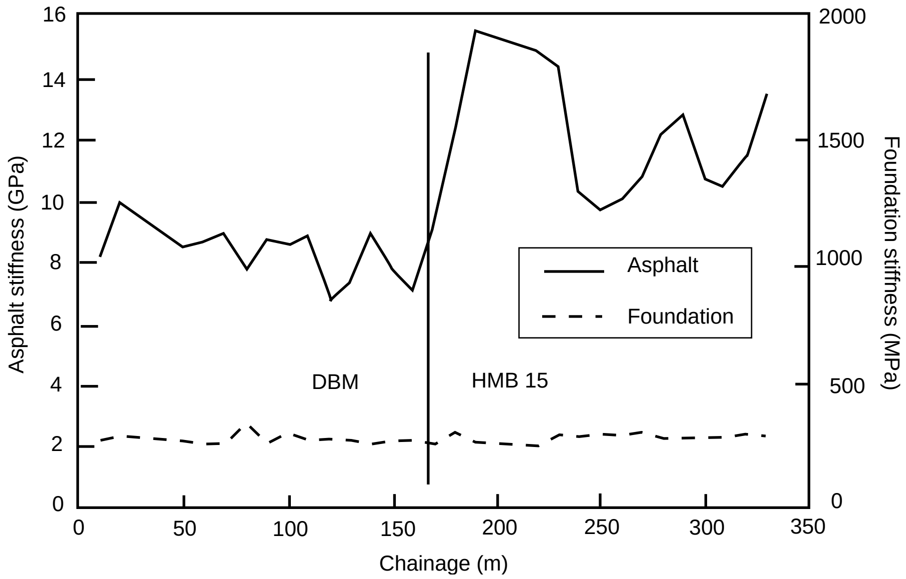

Figure 9 FWD Survey of Site A

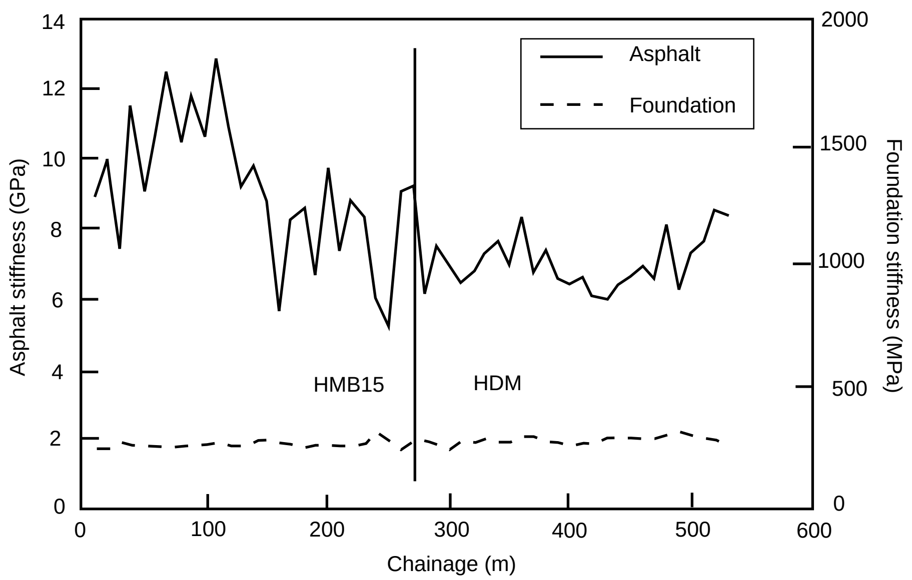

Figure 10 FWD Survey of Site D

that the HMB15 section of the trial is stiffer than the HDM section. There is more variability in the calculated stiffnesses of HMB15, however this may be due to the low deflections measured by the FWD.

6 Design considerations

The test material HMB15, produced under contractual conditions had mechanical properties superior to the control materials, DBM and HDM, at all the trial sites. HMB15 was stiffer and more deformation resistant and its resistance to fatigue was at least as good. These trials support the conclusions from the earlier pilot scale trial of high modulus roadbase (Nunn and Smith, 1994a) and confirm the potential of HMB15 for use in flexible pavement construction.

The trials using nominal 100, 50 and 15 penetration grade binders, enabled the structural properties of roadbase macadam to be related to the penetration of the recovered binder. The binder used in all the test sections was 15 penetration grade and therefore the improved properties of HMB15 relative to the control materials can be obtained relatively easily. However, by using Equation (1) derived in Section 5.3 the structural properties of HMB25 and HMB35 can also be determined.

Bitumen hardens during mixing and laying to typically 70 per cent of its initial level (Hunter, 1994). The average penetration of the 15 pen binder was 12, and if 35 penetration grade binder were used the penetration of the recovered binder would be expected to be about 25; likewise 25 pen binder would be expected to harden to about 17.5 pen. Table 8 gives the ITSM of macadams using different binder grades conforming to the middle of the specification (BS4987 Part 1), predicted using Equation (1). The difference in stiffness between mixtures using 28mm and 40mm maximum aggregate sizes is due to the higher binder content of the 28mm material.

Table 8 Predicted stiffness of roadbase macadam

Roadbase Macadam	*Nominal pen of binder*	*Pen of recovered binder*	*Target binder content (%M/M)*	*ITSM (GPa)*
DBM 28mm	100	70	4.0	2.1
DBM 40mm	100	70	3.5	2.4
HDM 28mm	50	35	4.0	6.3
HDM 40mm	50	35	3.5	7.4
HMB35 28mm	35	25	4.0	8.6
HMB35 40mm	35	25	3.5	10.2
HMB25 28mm	25	17.5	4.0	11.0
HMB25 40mm	25	17.5	3.5	13.0
HMB15 28mm	15	12	4.0	13.0
HMB15 40mm	15	12	3.5	15.4

Table 8 shows that HMB15 is about twice as stiff as HDM and about six times as stiff as DBM and that HDM is about three times stiffer than DBM. This can be contrasted with earlier trials reported by Nunn et al (1987) which indicated that typical HDM was twice as stiff as typical DBM. However in these earlier trials, the stiffnesses were compared at a test frequency of 5Hz and 20°C recommended for pavement design purposes, using the TRL three-point bending test. This is a higher frequency than the 2.5 Hz associated with the ITSM test (Nunn & Bowskill, 1992). Figure 4 shows that stiffer materials have a lower frequency sensitivity which will reduce slightly the relative stiffness of HMB at the design conditions (5Hz, 20°C).

In this series of five road trials, the range of ITSM values of the HMB15 macadams (12.3 -16.1GPa) were consistently higher than the range found in the initial pilot-scale trial (7.2 - 9.3GPa), reported by Nunn and Smith (1994a). Analysis by Nunn (1996), demonstrated that the stiffness of typical DBM is expected to be in the range 1.2 - 2.1GPa, which is lower than the values expressed in Table 7. These earlier results suggest that the stiffnesses measured in the five HMB road trials were at the upper end of the expected distribution.

In view of the uncertainties expressed above, the novelty of HMB and the lack of long-term experience of the material’s performance, Nunn et al (1997) considered it prudent to be conservative in selecting a design stiffness for HMB15, HMB25 and HMB35. For this reason a stiffness modulus for HMB15 of 12.4GPa at 5Hz and 20°C is recommended for pavement design calculations. The trials indicate that this stiffness should be exceeded 95 per cent of the time. The design stiffnesses for HMB15 and the corresponding values for HMB25 and HMB35 are given in Table 9.

Table 9 Design stiffnesses for roadbase macadams

Material	*Design stiffness (GPa)*	*Relative stiffness*
DBM	3.1	1.0
DBM50	4.7	1.5
HDM	6.2	2.0
HMB35	8.0	2.6
HMB25	10.3	3.3
HMB15	12.4	4.0

The stiffness of DBM in this Table is considerably higher than the stiffness of newly laid DBM. In LR1132 it was recognised that the stiffness of DBM can change considerably over its life and that the design stiffness given above should be considered to be an *effective in-service modulus*.

In their review of flexible pavement design, Nunn et al (1997) conclude that roads do not need to be built thicker than that required by the current standard for an 80msa design life in order to achieve a very long structural life of 40 years or more. They also consider that a thickness of less than 200mm for the asphalt layers is not recommended for even lightly trafficked roads that are required to last for 40 years. Thin roads will be at risk of structural deformation and the rapid propagation of any surface initiated cracks through the full thickness of asphalt (Schmorak and van Dommelen, 1995). The effect of the improved modulus of HMB15, HMB25 and HMB35 on thickness over a range of design lives is shown in Figure 11.

These design curves assume that the same type of material is used for the roadbase and basecourse and that the wearing course consists of 40mm of HRA. These designs are based on the design stiffnesses given in Table 9, and pavements designed using HMB are expected to perform as well as corresponding pavements constructed using conventional macadams.

Another area where HMB may have significant advantages over conventional roadbase and basecourse materials is in surfacing systems for pavements that are at excessive risk of rutting. The high resistance to permanent deformation of HMB makes the material very attractive for use as a substrate for thin wearing courses in areas of high risk of rutting. A combination of HMB basecourse or roadbase and a thin surfacing such as stone mastic asphalt would be expected to provide an extremely rut resistant surfacing system. However, this needs to be confirmed in practice.

7 Assessment of cost effectiveness

The benefit of using HMB as both roadbase and basecourse can be expressed as a reduction in thickness as shown in Table 10. The example is for a pavement with a design life of 80 million standard axles built on a foundation consisting of 5% CBR subgrade and 225mm of Type 1 sub-base. In cost terms, the benefits of reduced thickness have to be offset against the additional costs of using these materials.

Table 10 Thickness of bound layers using HMB

Surfacing thickness (mm)	*Material*	*Roadbase and basecourse thickness (mm)*	*Reduction (per cent)*
40	DBM	350	-
40	HDM	280	20
40	HMB35	250	29
40	HMB25	240	31
40	HMB15	220	37

Estimates of the extra cost of producing HMB15 were received from each Contractor and a typical breakdown is shown in Table 11. The main source of extra cost is associated with the higher cost of 15 penetration grade binder. Extra fuel is required to reach a higher mixing temperature and the aggregate takes longer to reach that temperature which reduces the output from the mixing

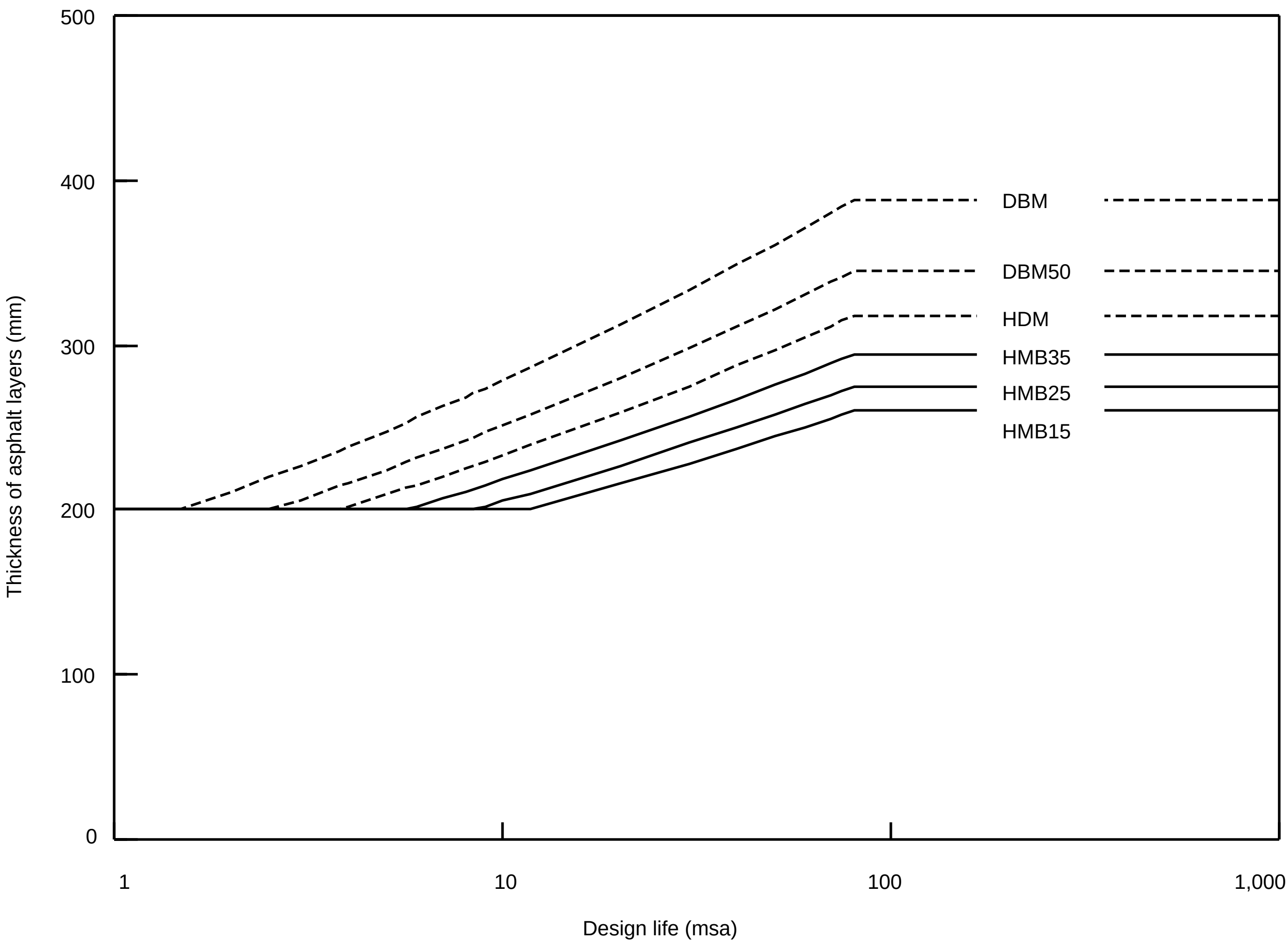

Figure 11 Design curves for improved macadams

Table 11 Relative breakdown of material production costs

Material	*Binder*	*Fuel*	*Aggre -gate*	*Plant*	*Extra filler*	*Reduced output*	*Other*	*Total*
DBM	50	8	25	17	0	0	0	100
HDM	50	12	25	17	2	6	0	112
HMB15	56	13	25	19	0	7	0	120

plant. It should be noted that these costs are an approximation based on the five trials and there may be considerable variation in material cost between contracts.

Table 10 shows that by replacing DBM with HMB15 a 37 per cent reduction in roadbase and basecourse thickness can be made. When using HMB35 and HMB25 reductions in thickness of 29 per cent and 31 per cent respectively can be made. Taking into account the increased cost of HMB15 (shown in Table 11), and the reduced layer thickness, an overall cost saving of approximately 25 per cent can be made when HMB15 is used instead of DBM and approximately 15 per cent when HMB15 is substituted for HDM. It should be noted that the relative costs are for material at the mixing plant gate. Cost savings may be diluted by other overheads such as transport, however, further savings may be possible with reduced excavation and disposal associated with the construction of a thinner pavement.

8 Conclusions

1 High modulus base and basecourse macadams made using 15 penetration grade binder (HMB15) can be manufactured, laid and compacted using standard UK plant, even under adverse weather conditions. It should, however, be recognised that the use of harder binders will restrict workability to some degree and, in consequence, HMB materials should be considered only for major projects on heavily trafficked roads.

2 The load spreading ability of HMB incorporating either a 15, 25 or 35 penetration grade binder is increased significantly compared with conventional roadbase macadams. The deformation resistance of HMB is improved without any detrimental effect on its cracking resistance. Because of variability in material composition and laying practice, the increase in stiffness can vary but these trials have demonstrated that, for pavement design purposes, the stiffness modulus of HMB15 is at least four times greater than standard DBM. The stiffness modulus is estimated to be improved by factors of 3.3 and 2.6 when 25 pen and 35 pen binders are used respectively.

3 The higher cost of HMB is offset by the reduction in material thickness required to construct a pavement with the same design life. Savings in cost of approximately 25 per cent can be made when HMB15 is used instead of DBM and approximately 15 per cent when HMB15 is substituted for HDM.

4 The high resistance to permanent deformation of HMB makes it an ideal substrate for thin wearing courses in areas of high risk of rutting. However, more work is required to determine the effectiveness of this system in reducing rutting.

5 HMB materials can be specified by a simple modification of the existing specifications for Heavy Duty Macadam and the specification should refer to Specification Clause 929. (A draft is included as Appendix C.)

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Appendix A Specification for the coated macadams in the trial

Dense Bitumen Macadam (DBM)

Dense bitumen macadam roadbase and basecourse shall be made in accordance with the general requirements of BS 4987: Part 1:(1993), and shall comply with the appropriate Tables and sections thereof for dense roadbase macadam and dense basecourse macadam.

The material shall be laid and compacted in accordance with Clause 901 of the Specification for Highway Works and shall satisfy the PRD requirement specified in that clause.

Heavy Duty Macadam (HDM)

Heavy Duty Macadam roadbase and basecourse shall be made in accordance with the general requirements of BS 4987: Part 1:(1993), and shall comply with the appropriate Tables and sections thereof for dense roadbase macadam and dense basecourse macadam.

The material shall be laid and compacted in accordance with Clause 901 of the Specification for Highway Works and shall satisfy the PRD requirement specified in that clause.

High Modulus Base (HMB15)

Dense bitumen macadam roadbase and basecourse shall be made in accordance with the general requirements of BS 4987: Part 1:(1993) subject to the following provisos, and shall comply with the appropriate Tables and sections thereof for dense roadbase macadam and dense basecourse macadam.

The material shall be laid and compacted in accordance with Clause 901 of the Specification for Highway Works and shall satisfy the PRD requirement specified in that clause.

1 The binder shall be a homogenous mixture of 15 penetration grade petroleum binder to BS 3690 Part 1. Roadbase materials shall contain 4% ± 0.6% by mass for a 28mm nominal size aggregate and 3.5% ± 0.6% by mass of the binder for a 40mm nominal size aggregate. Basecourse materials shall contain 4.7% ± 0.6% by mass for a 28mm nominal size aggregate and 4.7% ± 0.6% by mass of the binder for a 20mm nominal size aggregate.

2 The maximum temperature of the mixed macadam at any stage shall not exceed 190°C.

3 Compaction shall be substantially completed while the temperature of the mixed macadam is greater than 120°C.

Appendix B Composition of trial materials

Table B1 Composition of materials laid at site A

	Specified BS 4987		*Reported results*	
BS Sieve Size (mm)	*40mm DBM*	*40mm HMB15*	*40mm DBM*	*40mm HMB15*
	Mean aggregate grading (per cent passing BS sieve)			
37.5	95-100	95-100	100	100
28	70-94	70-94	92	89
20	-	-	-	-
14	56-76	56-76	66	63
6.3	44-60	44-60	47	46
3.35	32-46	32-46	36	37
0.3	7-21	7-21	10	11
0.075	2-9	2-9	6.7	6.9
Binder content (% by mass)	3.5 ± 0.6	3.5 ± 0.6	3.3	3.6
Initial pen of binder (0.1mm)	100 ± 20	15 ± 5	94	17
Pen of recovered binder (0.1mm)	-	-	55	12
Softening point of recovered binder (°C)	-	-	53.2	73.0
Voids content(%)	<8	<8	6.6	5.5
Percentage of refusal density	>93	>93	95.0	96.0
Voids content at refusal density (%)	-	-	1.6	1.0

Table B2 Composition of materials laid at site B

	Specified BS 4987/ Clause 929		*Reported results*	
BS Sieve Size (mm)	*28mm HDM*	*28mm HMB15*	*28mm HDM*	*28mm HMB15*
	Mean aggregate grading (per cent passing BS sieve)			
37.5	100	100	100	100
28	90-100	90-100	100	99
20	71-95	71-95	85	83
14	58-82	58-82	65	70
6.3	44-60	44-60	48	53
3.35	32-46	32-46	37	41
0.3	7-21	7-21	18	19
0.075	7-11	2-9	9.8	10.0
Binder content (% by mass)	4.0 ± 0.6	4.0 ± 0.6	4.4	4.0
Initial pen of binder (0.1mm)	50 ± 10	15 ± 5	48	14
Pen of recovered binder (0.1mm)	-	-	36	13
Softening point of recovered binder (°C)	-	-	64.2	75.2
Voids content(%)	<8	<8	0.2	0.7
Percentage of refusal density	>93	>93	98.7	99.3
Voids content at refusal density (%)	>1	>1	0.0	0.4

Table B3 Composition of materials laid at site C

BS Sieve Size (mm)	*Specified BS 4987/Clause 929*				*Reported results*			
	40mm DBM	*28mm DBM*	*40mm HMB15*	*28mm HMB15*	*40mm DBM*	*28mm DBM*	*40mm HMB15*	*28mm HMB15*
	Mean aggregate grading (per cent passing BS sieve)							
37.5	92-100	100	92-100	100	100	100	100	100
28	74-98	85-100	74-98	85-100	95	97	90	98
20	-	71-95	-	71-95	-	85	-	89
14	56-76	58-82	56-76	58-82	64	70	73	79
6.3	44-60	44-60	44-60	44-60	50	47	52	60
3.35	28-42	28-42	28-42	28-42	38	35	40	39
0.3	6-20	6-20	6-20	6-20	9	10	9	12
0.075	2-9	2-9	2-9	2-9	6.1	6.5	6.4	7.5
Binder content (% by mass)	3.5 ±0.6	3.9 ±0.6	3.5 ±0.6	3.9 ±0.6	3.6	3.8	3.3	4.1
Initial pen of binder (0.1mm)	100 ± 20	100 ± 20	15 ± 5	15 ± 5	99	99	15	15
Pen of recovered binder (0.1mm)	-	-	-	-	81	70	12	11
Softening point of recovered binder (°C)	-	-	-	-	47.8	49.2	80	85.0
Voids contents (%)	<8	<8	<8	<8	3.8	2.6	4.3	6.2
Percentage of refusal density	>93	>93	>93	>93	97.3	97.0	96.7	94.9
Voids contents at refusal (%)	>1	>1	>1	>1	1.4	0.1	1.0	0.7

Table B4 Composition of materials laid at site D

BS Sieve Size (mm)	*Specified BS 4987/Clause 929*				*Reported results*			
	28mm HDM	*20mm HDM*	*28mm HMB15*	*20mm HMB15*	*28mm HDM*	*20mm HDM*	*28mm HMB15*	*20mm HMB15*
	Mean aggregate grading (per cent passing BS sieve)							
37.5	100	100	100	100	100	100	100	100
28	90-100	100	90-100	100	100	100	100	100
20	80-100	93-100	80-100	93-100	89	100	88	100
14	58-82	70-90	58-82	70-90	73	76	74	76
6.3	42-58	39-55	42-58	39-55	54	47	54	45
3.35	29-43	29-43	29-43	29-43	35	34	36	34
0.3	8-22	8-22	8-22	6-20	12	12	13	11
0.075	4.5-11.5	4.5-11.5	4.5-11.5	4.5-11.5	8.0	8.4	9.1	8.4
Binder content (% by mass)	4.0 ±0.6	4.3 ± 0.6	4.0 ±0.6	4.3 ± 0.6	4.2	4.4	4.2	4.7
Initial pen of binder (0.1mm)	50 ± 10	50 ± 10	15 ± 5	15 ± 5	46	46	12	12
Pen of Recovered Binder (0.1mm)	-	-	-	-	34	34	9	10
Softening point of recovered binder (°C)	-	-	-	-	59.8	59.8	81.8	76.0
Voids content(%)	<8	<8	<8	<8	0.8	2.3	2.3	2.5
Percentage of refusal density	>93	>93	>93	>93	99.3	96.1	97.7	97.2
Voids content at refusal (%)	>1	>1	>1	>1	0.1	0.0	0.8	0.0

Table B5 Composition of materials laid at site E

	Specified BS 4987/ Clause 929		*Reported results*	
BS Sieve Size (mm)	*28mm HDM*	*28mm HMB15*	*28mm HDM*	*28mm HMB15*
	Mean aggregate grading (per cent passing BS sieve)			
37.5	100	100	100	100
28	90-100	90-100	100	100
20	78-100	78-100	85	87
14	58-82	58-82	66	69
6.3	42-58	42-58	48	49
3.35	29-48	29-48	34	34
0.3	8-22	8-22	13	13
0.075	6-10	6-10	8.2	8.8
Binder content (% by mass)	4 ± 0.6	4 ± 0.6	3.9	4.1
Initial pen of binder (0.1mm)	50 ± 10	15 ± 5	47	17
Pen of recovered binder (0.1mm)	-	-	30	16
Softening point of recovered binder (°C)	-	-	65.3	80.2
Voids content(%)	<8	<8	2.6	2.4
Percentage of refusal density	>93	>93	98.6	98.6
Voids content at refusal density (%)	>1	>1	1.2	1.0

Appendix C Suggested specification amendment for HMB roadbase [basecourse]

HMB Roadbase [Basecourse] shall comply with the requirements for HDM in SHW Clause 930 [930] except as detailed below:

i) The binder shall be petroleum bitumen to BS3690 of grade:

15 penetration for HMB15
25 penetration for HMB25
35 penetration for HMB35

ii) The requirements for SHW Clause 929 for mixture design shall apply.

iii) The following temperatures shall be used as the minimum required at substantial completion of compaction:

HMB15	120 °C
HMB25	115 °C
HMB35	110 °C

Abstract

This report describes the road trials of High Modulus Base (HMB), a high stiffness roadbase macadam manufactured to the standard UK composition for dense bitumen macadam (DBM) using a binder with a penetration of less than 50. The terminology used for 15 pen HMB is HMB15, for 25 pen, HMB25, and for 35 pen, HMB35. Throughout this investigation HMB15 was used and the results, together with those of the control materials, allow the properties of HMB25 and HMB35 to be predicted by interpolation. Trials were carried out at five sites by five different Contractors using different aggregate and bitumen sources and working in a range of weather conditions.

The purpose of the trials was to determine whether the material could be mixed, laid and compacted by standard UK plant and to assess its properties relative to those of standard roadbase materials.

The trials demonstrated that the material behaved in a similar way to conventional roadbase macadams, provided that appropriate mixing, laying and compaction temperatures were maintained. HMB has a very high stiffness, and therefore, better load spreading properties than DBM and heavy duty macadam (HDM), which means that a pavement designed to have the same life, but using HMB instead of conventional materials, can have a significantly thinner roadbase and basecourse. After allowance has been made for the increased production costs of HMB15, cost savings of approximately 25 per cent can be achieved compared to laying conventional DBM. Alternatively, HMB can be used to replace DBM or HDM at current design thicknesses to provide a longer pavement life.

In addition to high stiffness, HMB has a high resistance to deformation, and when used as a roadbase or basecourse in conjunction with a thin wearing course, the road pavement would have excellent rutting resistance. However further trials are required to evaluate the system fully.

Related publications

TRL250 *Design of long-life flexible pavements* by M E Nunn, A Brown, D Weston and J C Nicholls 1997 (*In preparation*)

PR66 *Evaluation of enrobé à module élevé (EME): a French high modulus roadbase material* by M E Nunn and T Smith. 1994 (price code E)

PR55 *Evaluation of performance specification in road construction* by M E Nunn and T Smith. 1994 (price code H)

RR132 *Improved roadbase macadams: road trials and design considerations* by M E Nunn, C J Rant and B Schoepe. 1987 (price code B)

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