The application of Enrobé à Module Élevé in flexible pavements

Prepared for Quarry Products Association, Refined Bitumen Association and Highways Agency

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Executive Summary

In the UK there is a need for a high quality binder course/ upper base course material for use on highly trafficked roads where durability and good load spreading abilities are essential qualities. As a consequence of this need an investigation was carried out into the properties of a high modulus asphalt material that was designed using the French design method with ingredients readily available in the UK. The asphalt mixture was designed using the methodology developed by Laboratoire Central des Ponts et Chausséees (LCPC) as an Enrobé à Module Élevé (EME) Class 2 material, and a 290 mm thick pavement structure incorporating this material was built and tested under full-scale loading in the Pavement Test Facility (PTF) at TRL.

Testing was carried out on a full-width inlay to directly compare the performance of the pavement using EME with that of a conventional pavement using Heavy Duty Macadam (HDM). This allowed the performance of the 'new' material to be calibrated against a material that experience has shown to perform well in the field. A one metre wide (wheel-track) trench inlay was also trafficked to confirm that it could be included as a realistic and sustainable alternative maintenance treatment on highly trafficked roads. A more sustainable approach to pavement design and maintenance that conserves materials and minimises energy consumption, pollution and road congestion is becoming increasingly important.

Measurement of rut development under full-scale wheel loading at 40ºC showed that EME Class 2 material deformed less than the HDM and no cracking was observed along the joint adjacent to the trench. Laboratory testing confirmed the improved performance of EME relative to HDM for deformation. As proxy measures of durability, Indirect Tensile Fatigue Testing (ITFT) and Indirect Tensile Stiffness Modulus (ITSM) testing before and after saturation with water and permeability measurements were carried out. No reduction in stiffness was measured after 50 days of soaking, and the fatigue performance of the EME Class 2 was similar to the HDM. EME stiffness was measured using the Indirect Tensile Stiffness Modulus (ITSM) Test and was found to be similar to that measured in a previous investigation carried out by TRL (Nunn and Smith, 1994).

Test pavements were built using full-scale plant for paving, rolling and planing and this confirmed that construction involving EME did not require any special measures. Very low air voids in both the HDM and the EME binder courses were obtained, showing that conventional plant was appropriate. The trial suggested that it is not necessity to saw the vertical interfaces of the longitudinal joints of a trench inlay in the wheel path. Investigations by coring indicated that for the as-planed condition, compaction close to the vertical joints was equally as good for the sawn joints.

An interim specification for EME Class 2 has been developed by the research partners and is given in Appendix B. This specification is intended to be used on pilot contracts on the trunk road network and will be subject to ongoing amendment to reflect current French practice. When finalised, it is intended that it will be published in the Specification for Highway Works.

1 Introduction

This report describes research sponsored by the Highways Agency, Quarry Products Association and the Refined Bitumen Association. The overall objective of this research was to improve the performance of asphalt pavements to ensure that they continue to perform well under the more demanding conditions that are likely to be encountered in the future. Increased traffic, higher axle loads and greater use of super-single tyres are some of the factors that need to be taken into account.

Previous work by the sponsors (Nunn *et al.*, 1997) demonstrated that deterioration in well-constructed flexible pavements, built above a threshold strength, is normally confined to the surface layers and that these roads will have a very long structural life provided that surface deterioration is remedied in a timely fashion. In these heavily trafficked, *long-life* roads, deterioration will normally take the form of cracks developing at the surface or deformation occurring in the surface course and the layer immediately beneath. For these roads, maintenance treatments will therefore be principally concerned with replacing the surface and binder course.

To ensure durable, and hence more sustainable construction, it is essential that asphalt materials in the upper layers of the pavement are designed to resist rutting and cracking. The surface layers generally used in the UK consist of a thin surface course and a dense macadam binder course with a 28 mm aggregate size. Thin surface courses are now proprietary materials and Highways Authorities Product Approval Scheme (HAPAS) accreditation ensures that they are *fit for purpose*. However, thin surfacing can be more permeable than hot rolled asphalt (HRA) surface course which was widely used until quite recently. This emphasises the need for the layer immediately beneath the thin wearing course to be as impermeable as possible to prevent moisture from seeping into the pavement and causing problems. Furthermore, longitudinal joints in all pavement layers need to be well constructed to avoid them being a source of weakness from which longitudinal cracks and other forms of deterioration can develop. Poor construction practice can result in weakly bonded materials with high air voids in the vicinity of joints which permit moisture to enter the pavement and accelerate deterioration.

The use of materials with higher binder contents and a finer aggregate grading, than have been traditionally used in binder course materials in the UK, would help to improve the quality of the material close to longitudinal joints. These changes would aid compaction and reduce the risk of localised material variations caused by segregation.

A suitable binder course material to fulfil this role is high modulus material conforming to the French Standard for EME (Enrobé à Module Élevé). EME is designed to have good load spreading ability, good resistance to deformation and cracking and, by virtue of its high binder content, in France it is considered virtually impermeable when well compacted. It also utilises an aggregate grading that is finer than that traditionally used in the UK and this results in a more homogenous material.

This report examines the performance, under controlled conditions in the TRL Pavement Test Facility (PTF), of EME as a binder course material under a thin surfacing both in new construction and as a maintenance treatment for long-life flexible pavements. Generally, in this situation, material in the layers close to the wheel-track rut badly or crack from the surface down. More sustainable maintenance can be achieved by replacing only a longitudinal strip of damaged material in the vicinity of the wheel-track, rather than the full width of the traffic lane. This will involve planing out a trench of material and reinstating with an inlay and then covering the whole lane with a new surface course.

The study described in this report examines the performance of full-scale pavements constructed with an EME binder course and a pavement that has been maintained by planing out a longitudinal strip of material in the wheel-track and inlaying with high modulus material conforming to the French standard. The performance of these pavements was compared with that of a control pavement constructed using a traditional HDM (Heavy Duty Macadam) binder course in the TRL-PTF.

2 Factors influencing pavement durability

The move towards thin surface courses, and the move away from traditional HRA surface and binder courses in the UK, has increased the risk of moisture entering the road. This is the case especially if the layer immediately below the binder course comprises of a relatively lean, coarse graded mixture that is not well compacted. This situation has resulted in some instances of problems relating to water ingress. In many cases these problems occurred close to longitudinal joints or when the layer below the surface course was poorly compacted under adverse conditions. Under these conditions bonding between layers is often minimal. The risk of this happening is increased when very hard binders, requiring higher mixing and compaction temperatures, are used.

2.1 Durability issues

For good pavement durability, all asphalt layers need to be satisfactorily compacted and contain sufficient binder. The asphalt in the surface layer should be impermeable to water and both the foundation and surface drainage should function so that water is not trapped in the road and does not weaken the foundation. In a long-life road the surfacing layers should resist deformation and not be prone to surface cracking.

It is essential to pay attention to construction detail. Longitudinal construction joints for the various layers should not coincide with the wheel-path, and joints in different layers should be staggered and stepped. Material should be well compacted and there should be a good bond across joints. Asphalt layers should be well bonded to one another to enable the full thickness of asphalt to act as a single unit.

2.2 Moisture damage

Several mechanisms can be responsible for damage resulting from the ingress of moisture into the pavement. The most important of these is stripping. Stripping is a physiochemical process in which separation of bitumen binder film from aggregate surfaces occurs as a result of prolonged contact with moisture and/or moisture vapour. The potential for an asphalt to strip is related primarily to the aggregate type, binder grade, binder content, and air voids content.

Recently in the UK another form of moisture damage has been noted. When water enters the pavement and can become trapped between two layers of asphalt, the asphalt can fail as a consequence of traffic loading creating high hydraulic pressure gradients and movements of the trapped water. This in turn can cause it to physically scour the bitumen from the aggregate. The action can be so aggressive that all asphalt will probably fail rapidly under these conditions. This form of stripping is a mechanical failure of the asphalt pavement system, and the classical moisture sensitivity tests do not simulate this action and are therefore irrelevant.

To avoid these problems, water should be prevented from penetrating the road surfacing, and if it does the underlying layers should not be susceptible to moisture damage. The area of the road that is most susceptible to trapped water is in the region of layer interfaces and longitudinal construction joints. An impermeable binder course coupled with good construction practice will provide added protection against these forms of pavement deterioration.

2.3 Delamination

Bond between asphalt layers is important. Theoretically, the degree of layer bonding can be shown to have a large effect on the bearing capacity of the pavement. If layers are not bonded, relative movement between the layers is possible and the horizontal strains will not be fully transmitted across the interface. However, in practice, friction forces will act across the interface and, if delamination is deep in the pavement, these may be enough to transmit the necessary shear forces. Nevertheless, for reasons of waterproofing, it is good practice to have a good bond between layers.

3 Role of the binder course

The role of the binder course was reviewed by Weston *et al.* (2001) and it is defined as the layer on which the surface course is placed. A prime function of the binder course is to help dissipate the high stresses close to the tyre. For this, it must also possess adequate deformation resistance to withstand the high shear stresses induced by a loaded tyre near the pavement surface. Where permeable surface courses are used the binder course must also be impermeable**.**

The binder course and surface course are often grouped together and designated collectively as surfacing. The surfacing is required to:

- reduce the stresses and strains in the base and foundation to an acceptable level;
- keep water out of the material below;
- provide a satisfactory riding quality, and
- provide satisfactory skid resistance.

The binder course would be expected to contribute to the first three functions. More recently the binder course has been treated as an additional thickness of base to reduce the stresses and strains in the underlying layers (Powell *et al.*, 1984). In reality, the binder course has to resist higher shear stresses close to the tyre more effectively than base material. This implies that the binder course should have a higher internal stability than the base layer to resist the higher shear forces. Traditionally, the materials used in the binder course have been generically similar to base materials, but they usually employ a smaller nominal size aggregate and have a higher binder content, rendering them less permeable than bitumen macadam base. The provision of a binder course also helps the surface profile tolerances to be more easily achieved.

3.1 Improved binder course

Thin surface courses are now generally used in the UK. These are proprietary materials and HAPAS accreditation ensures that they are *fit for purpose*. However, with thin surfacing, there is a suspicion that with high texture depth requirements and a thin layer, the thin surfacing is likely to be porous in some locations. This places more emphasis on the binder course being impermeable.

Experience with-long-life pavements (Nunn *et al.,* 1997) has shown that cracks initiate at the surface and propagate downwards. The investigations by TRL have indicated that the top few millimetres of the surface course can harden substantially over time. Cracks are then initiated when the thermal and traffic induced stresses exceed the strength of this relatively thin layer. This experience has been obtained from pavements with traditional HRA surface course. Experience of the ageing characteristics of the new generation of thin surface course materials, often containing proprietary binder systems, has yet to be accumulated.

Durability of asphalt binder course material can be enhanced by good material design. The mixture should be very stable with a good aggregate skeleton and a high binder volume that practically fills all the voids in the fully compacted material without causing the asphalt to become unstable by overfilling. The *in situ* air voids content of the resultant mixture should be low enough to make the mixture impermeable to water. Permeability falls rapidly for materials with air voids of less than 8% and it is virtually zero for air voids below 4%. This is illustrated in Figure 3.1.

Materials should have adequate binder film thickness and ideally this should be related to the specific surface area of the aggregate. The bitumen film thickness is one of the major indicators for durability as it influences the incidence of moisture damage, age hardening and cracking.

The binder course material or upper base material should have good stability to resist the high shear forces generated close to the loaded tyre. It should also have a good stiffness modulus so that it can contribute to the load spreading ability of the pavement.

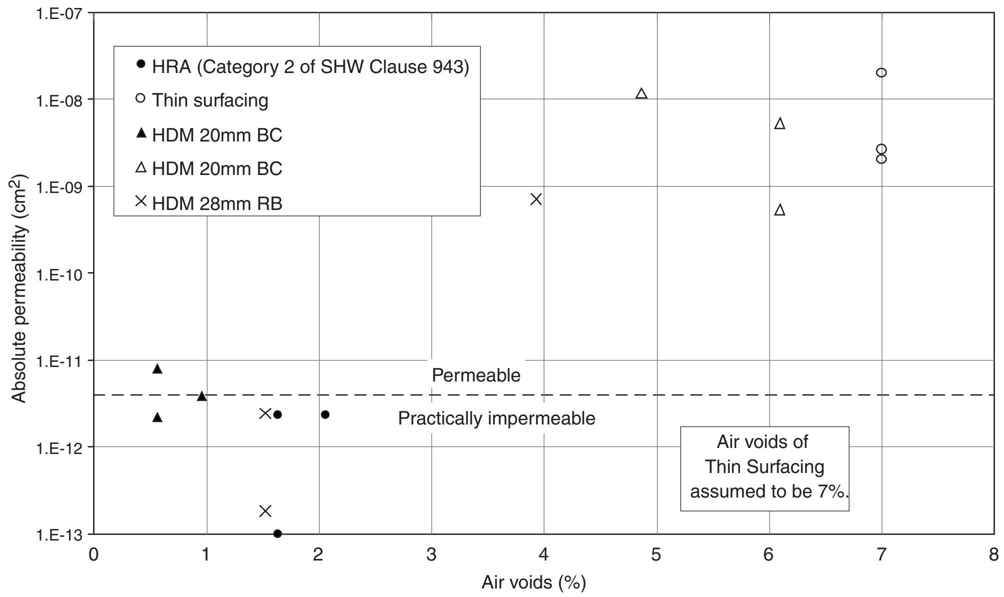

Figure 3.1 Permeability versus air voids

In addition to these requirements segregation can cause local variations in material composition and produce material that does not conform to the expected standard. There are no specifications to control this but it is generally recognised that the problems of segregation reduce if the maximum size of the aggregate is reduced.

In summary a binder course material should have the following attributes:

- high stiffness modulus;
- high resistance to deformation;
- good cracking resistance;
- impermeability;
- not be prone to segregation.

Experience has shown that although under well controlled conditions it is possible to achieve these attributes with a dense macadam that has been modified by using a very hard binder (Nunn and Smith, 1997 and 1994), it may not always be possible to achieve good properties under adverse laying conditions. However, experience in France has demonstrated that richer materials containing a hard binder and finer aggregate grading perform well. These materials, known generically as Enrobé a Module Élevé (EME), conforming to the French Standard (AFNOR, 1999, NF P 98-140 and NF P 98-141) appear to fulfil all of the above requirements. It was therefore decided to carry out trials of such a material in the TRL-PTF, designed according to the French Standard.

This new high modulus binder course should be ideally suited for use as a maintenance inlay on high performance asphalt pavements as well as for new construction. Rutting and/or cracking within wheel-tracks is often significantly more severe than in the rest of the pavement, which often remains in good condition. The wheel-track inlay treatment will be an alternative to the more usual full-width treatment and thus should provide a more sustainable alternative. Situations where this treatment would be used are where damage to a pavement is largely confined to the upper layers within the wheel-track 'wander'. The outcome of this study will therefore help to provide an additional and sustainable maintenance option for heavily trafficked asphalt pavements.

The aim of the trial was to investigate whether a wheel-track inlay is a viable maintenance technique and whether a high modulus binder course can significantly reduce rutting and waterproof the road. In addition, findings of the trial will assist in the drafting of guidance on good practice for inlay treatments.

The objectives of this trial were therefore to:

- Compare the performance of EME used as a binder course with conventional HDM binder course.
- Compare the performance of a maintenance treatment in which a longitudinal strip of deteriorated material is planed out of the wheel-path and replaced with an EME inlay and thin surface course with that of conventional treatment.
- Evaluate construction practices that ensure good compaction up to the edge of the inlay and good bonding between layers.

4 Description of EME

EME is a base/binder course material with a high content of hard bitumen and low air voids content designed to combine good mechanical performance with impermeability and durability. It has been in widespread use in France for nearly 20 years. The mixture is designed in the laboratory to be workable and durable and to have high elastic stiffness, high deformation resistance and good fatigue resistance

EME base material is defined in the French standard NF P 98-140 (AFNOR, 1999). This gives minimum requirements on the hardness, angularity and cleanliness of aggregates and for acceptable grades of binder. The designer is free to select an appropriate binder that provides the properties required to satisfy end performance criteria for the mixture. EME is designed to satisfy criteria determined using laboratory tests developed by LCPC to measure the performance properties of laboratory compacted test specimens in respect of compactibility, water sensitivity, deformation resistance, stiffness and fatigue.

The material is laid as a binder course and base in lifts 60 mm to 150 mm thick using 0/10 mm, 0/14 mm or 0/20 mm aggregate gradings. Examples of the use of EME in France are described by Serfass (1992) and Goacolou and Dimitri (1992).

The superior structural properties of high modulus material justifies thickness reductions of 25 to 40% in French road designs compared to 'grave bitume' (AFNOR, NF P 98-138, 1999).

There are two grades of EME in the French specifications, EME Class 1 and EME Class 2, with the Class 2 material having a significantly higher binder content, as defined by richness modulus defined in Annex B of Appendix B. A 0 /20 mm EME was selected for trials in UK as this size was considered most economical, particularly in terms of aggregate usage, and best suited to UK practice. The richer, Class 2 material was chosen with the aim of producing an extremely durable high performance material for use on long-life heavily trafficked roads. In France, there is extensive use of 0/10 mm and 0/14 mm in both EME, and BBME (Bitumineux Beton Module Élevé), which is a similar binder course mixture.

4.1 French mixture design methodology

The method of design outlined in this section deals with EME materials but similar design principles are applied to all asphalt layers in France. The philosophy is to design a mixture that is very stable which, as a consequence, may not be very workable. Very heavy pneumatic-tyre rollers that weigh up to 45 tonnes, although not essential, are often used to compact EME to a level where it cannot be further compacted and is therefore resistant to rutting by traffic.

The most commonly used aggregate gradings, for EME, are 0/10 mm, 0/14 mm and 0/20 mm and for BBME 0/10 mm and 0/14 mm. Two classes of EME and three classes of BBME are defined: EME Class 2 and BBME Class 3 are specified for the most heavily trafficked roads. These materials utilize a high binder content (≈ 6.0% by mass of the total aggregate) which is defined by a binder richness modulus (K) that is a function of the aggregate grading (see Annex B of Appendix B). This is a surrogate for the thickness of the binder film surrounding the aggregate, and is related to the specific surface area and the density of the aggregate. The mixture design procedure, in which the material is designed to satisfy mechanical criteria determined by laboratory tests, is illustrated in Figure 4.1 and it is described more fully by Delorme (1992).

Initially several different aggregate gradings with a single binder content are normally investigated for acceptable workability using the gyratory shear compactor test (PCG test - Presse à Cisaillement Giratoire test). This test simulates the action of compaction plant on-site and enables the voids content obtained on-site with a heavy, pneumatic-tyre roller to be estimated.

The PCG test is used to determine a composition to achieve a minimum performance in terms of this test rather than an optimum composition. EME Class 2 must achieve a voids content of 6 percent or less and BBME Class 3 must achieve a voids content of 5% or less in the PCG test. If a low voids content can be achieved easily the material is likely to lack internal stability as measured in the LCPC rutting test. Material that is to be placed as a thinner layer is designed to be more workable. For example, the recommended laying thickness of BBME with a 0/10 mm aggregate is 60 to 70 mm and this material has to achieve its target density in fewer gyrations in the PCG test.

When a grading has been found that satisfies the PCG design criterion, the binder content, or binder richness modulus defined in Annex B of Appendix B, is recalculated for the grading selected using a formula which takes into account the specific surface area and the density of the aggregate. The sensitivity of the mixture to stripping by water is then checked by carrying out unconfined compression tests (Duriez test) on two sets of cylindrical samples, one set after conditioning in water. If the ratio of the results after and before conditioning is above a certain value, the material is deemed to be acceptable.

Material is then prepared in the LCPC pneumatic-tyre slab compaction apparatus from which test samples can be cut for the performance tests listed in Figure 4.1. If the samples in each of these tests do not achieve the performance criteria specified in Table 4.1 changes are made to the composition and the design tests repeated until a satisfactory mixture is obtained.

4.2 Manufacture, laying and compaction

Whenever new mixture constituents are used the laboratory design exercise must be carried out to determine an appropriate mixture formulation. If the mixture has been used before, the testing required can be restricted to the PCG test and the Duriez test to verify the formulation.

Mixing and laying EME is no different to conventional materials, provided the temperatures are maintained at the appropriate level.

Laying thicknesses for the different aggregate gradings of EME (0/10 mm, 0/14 mm and 0/20 mm) are respectively 60 to 100 mm, 70 to 120 mm and 100 to 150 mm, and for BBME (0/10 mm and 0/14 mm) the recommended laying thicknesses are 60 to 70 mm and 70 to 90 mm respectively. The requirements for laying are that the surface on which the high stiffness material is to be laid should be clean and tack coated at the rate of 250 grams of residual bitumen per m^2. The air voids in the permanent works must be less than 6% for EME Class 2 and in the range 4% to 9% for all classes of BBME.

5 Research programme

The objective of the research was to demonstrate that the performance of heavily trafficked flexible pavements could be enhanced by incorporating a binder course

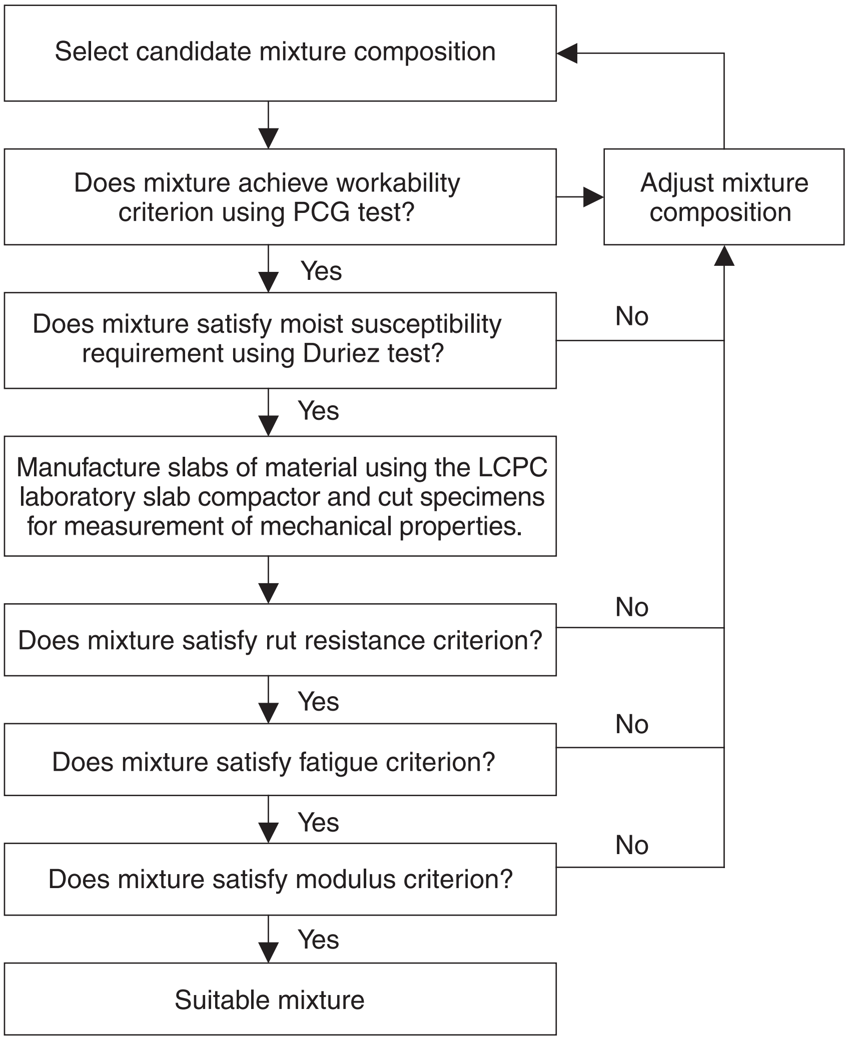

Figure 4.1 French mixture design procedure

Table 4.1 Design criteria using LCPC performance tests

Test	*EME Class 2*	*BBME Class 3*
PCG test 0/10 mm 0/14 mm 0/20 mm	≤6% air voids, after 80 gyrations 100 gyrations 120 gyrations	4 to 9% air voids, after 60 gyrations 80 gyrations (and, ≥11% after 10 gyrations)
Duriez test (after and before immersion ratio)	≥0.75	≥0.80
Rutting test (60˚C, 30,000 cycles on 100mm slab)	≤8%	≤5%
Complex modulus test (15˚C, 10 Hz)	≥14 GPa	≥12 GPa
Fatigue test (10˚C, 25 Hz - tensile micro-strain for 10^6 cycles)	≥130	≥100
Binder richness modulus 0/10 mm 0/14 mm 0/20 mm	 3.4 3.4 3.4	 3.5 3.3 –

consisting of high modulus material conforming to French mixture design methodology. This involved:

- Carrying out a mixture design study with cooperation from the UK asphalt industry.
- Laying full thickness asphalt pavements in the TRL-PTF and studying the rutting behaviour of:
  - a conventional control pavement using HDM binder course;
  - a test pavement with EME binder course;
  - a pavement maintained by removing a longitudinal strip of cracked or rutted material from the vicinity of the wheel and replacing with a trench inlay using EME binder course and a new thin surface course.
- Comparison of the performance of these systems to assess the performance of EME and of the innovative maintenance treatment relative to conventional materials and treatment.
- Extracting samples of material for more detailed studies, including an examination of compaction close to the longitudinal edge of the trench inlay.

More details are given in the following sections.

5.1 Material design study

To evaluate EME under pilot-scale conditions, it was first necessary to design an EME using ingredients that are readily available in the UK. Consequently a design study for a 0/20 mm EME Class 2 material was carried out by courtesy of Nynas Bitumen with aggregates supplied by Tarmac Group Limited. The EME was designed using the French mixture design methodology, illustrated in Figure 4.1, using the PCG, Duriez, rutting, complex modulus and fatigue tests.

The properties of the basic ingredients are given in Tables 5.1 and 5.2 and the results of the design study are given in Table 5.3.

It should be pointed out that the mixture design in Table 5.3 is not a unique solution. The design process involves a subjective element on how to change the composition. For example, if the material has low workability, it would be possible to improve it by modifying the aggregate grading or replacing a proportion of crushed sand by rounded sand.

Table 5.1 Properties of mixture constituents

Properties of mixture constituents	
Aggregate:	
Source	Carboniferous limestone
Aggregate crushing value	19
Ten percent fines value (dry)	200 kN
Ten percent fines value (wet)	220 kN
Aggregate impact value (dry)	19
Aggregate impact value (wet)	21
Los Angeles abrasion value	18
Aggregate density:	
Oven dried	2.71 Mg/m^3
Saturated surface dried	2.73 Mg/m^3
Apparent relative	2.76 Mg/m^3
Water absorption	0.9 %
Bitumen:	
Penetration at 25ºC	18 dmm
Ring and ball temperature	66ºC

Table 5.2 Properties of 15/25 grade bitumen used in the trial (prEN13924 requirements)

Essential requirement *Surrogate characteristic*	*Test methods*	*Unit*	*15/25 grade bitumen*
Consistency at intermediate service temperature			
Penetration at 25°C	EN1426	0.1mm	18
Consistency at elevated service temperature			
Softening point	EN1427	°C	66
Durability(resistance at 163°C, EN12607-1 or 3)			
Change of mass		%	0.07
Retained penetration	EN1426	%	70
Softening point after ageing	EN1427	°C	72
Increase in softening point	EN1427	°C	6
Other properties			
Viscosity at135°C	EN12595	mm^2/s	1490
Fraass breaking point	EN12593	°C	-3
Flash point	EN2592	°C	250
Solubility	EN12592	% (m/m)	99.9

Properties according to prEN13924 – Annex B (informative)

Property	*Unit*	*Test method*	*15/25 Nynas*
$T_{S=300MPa}$ by BBR, maximum	°C	XP T 66-062 [4]	-12
$T_{m=0,3}$ by BBR, maximum	°C	XP T 66-062 [4]	-12
G* at 15°C and 10Hz by DSR	Pa	IP PM-CM/99 [3]	6.22×10^7
$T_{G^*/\sin\delta=1kPa\ at\ 1.6Hz}$ min., by DSR	°C	IP PM-CM/99 [3]	>80

Table 5.3 Results of the design study

Composition	*Design mixture*	*French specification NFP 98-140*
Sieve size (mm)	Percent by wt passing	
20.0	99.6	–
14.0	92.3	–
10.0	89.1	–
6.3	75.5	–
4.0	53.0	–
2.0	26.4	–
1.0	17.7	–
0.315	12.5	–
0.08	8.8	–
Binder		
Binder richness modulus (K)	3.65	≥3.4
Specific gravity (Mg/m^3)	–	–
Test		
PCG Test (gyratory compactor)		
Compaction after 120 gyrations (% air voids)	1.8	≤6.0
Duriez test		
Compaction (% air voids)	–	–
Mechanical resistance at 18°C (MPa)	19.7	–
Ratio before and after water immersion	0.97	≥0.75
Fatigue test (10°C, 25Hz)		
Compaction (% air voids)	2.6	
Tensile micro-strain for 10^6cycles	130 (±9 με)	≥130
Complex modulus (15°C, 10Hz)		
Compaction (% air voids)	2.6	–
E^* (GPa)	14.05	≥14.0
Rutting test (60°C, 30,000 cycles)		
Compaction (% air voids)	5.0	–
Rut depth (mm)	5.8	≤7.5

Two different design studies could produce different solutions but the designer would seek to produce the most economic mixture from the point of view of the supplier.

The properties of the resultant design mixture, shown in Table 5.3, were in general well above the specified criteria. The designed material in this case has excellent load spreading properties, characterised by a high complex modulus, and very good resistance to rutting.

6 Experimental design

Design of flexible pavement layers has traditionally focused on fatigue initiating at the lower bound interface and rutting of the subgrade. However, for flexible pavements with bound layers greater than about 160 mm thickness, rutting has been noted to occur predominantly in the upper layers of asphalt, rather than the foundation (Nunn *et al.*, 1997). It follows that for the pavement to be resistant to deformation and fatigue, the base layer should be fatigue resistant, and the binder course resistant to deformation. This being the case, the resistance of the binder course to deformation was the primary focus of the experiment. To avoid the uncertainty of extrapolating test results obtained from laboratory specimens to full-scale behaviour, a decision was made to carry out full-scale wheel-tracking tests on a thick pavement constructed in the TRL-PTF.

6.1 Description of the Pavement Test Facility (PTF)

The TRL-PTF is an accelerated traffic loading test facility where the performance of full-scale pavement structures and materials can be assessed. Test pavements are constructed within a 25 m by 10 m pit to a depth of 3 m using conventional construction plant. Test sections are typically 10m long and can be instrumented to monitor stress, strain and deflection responses to applied wheel loads. The indoor computer controlled facility enables test conditions to be accurately reproduced and replicated allowing accurate comparative performance assessments to be made.

Key features of the PTF are:

- trafficking rates of up to 1000 applications per hour;
- 24 hour operation for rapid testing;
- uni- or bi- directional wheel loading;
- trafficking speeds of 1-20 km/h (± 0.25 km/h);
- wheel loads of 2.3-10 tonnes (± 2%);
- use of dual or wide based single wheel assemblies;
- pavement heating capabilities;
- canalised or laterally distributed wheel passes (centreline up to ± 450 mm).

6.2 Construction of the test pavements

The trial was designed to investigate the behaviour of four fully flexible asphalt pavement configurations. The full-scale pavement, were constructed with approximately 280 mm of asphalt on a 430 mm granular subbase and a clay subgrade. The total asphalt thickness comprises 30 mm of proprietary thin wearing course, 60 mm binder course (HDM or EME Class 2) and 190 mm of HDM base. Details of the test pavements are given in Table 6.1 and plans of the test sections and pavement cross sections are given in Figure 6.1 and 6.2.

6.2.1 Foundation

The preparation of the test sections commenced in May 2003. The subgrade was levelled and moisture conditioned to ensure that the condition of the clay was consistent across the area of the pavement sections. Detailed testing of the subgrade was carried out using a Mexicone penetrometer . The overall subgrade condition, together with the subbase was also tested using a Falling Weight Deflectometer (DMRB, 1994), following placement and compaction of the granular Type 1 subbase material (MCHW, 2004). Test results are given in Appendix A. The subbase was compacted in three 150 mm lifts using a CAT120 twin drum vibratory roller.

The construction of the foundation resulted in a foundation stiffness of between 80 MPa and 120 MPa, i.e. typical of that found for good performance of asphalt pavements on major roads in the UK (Goddard, 1990).

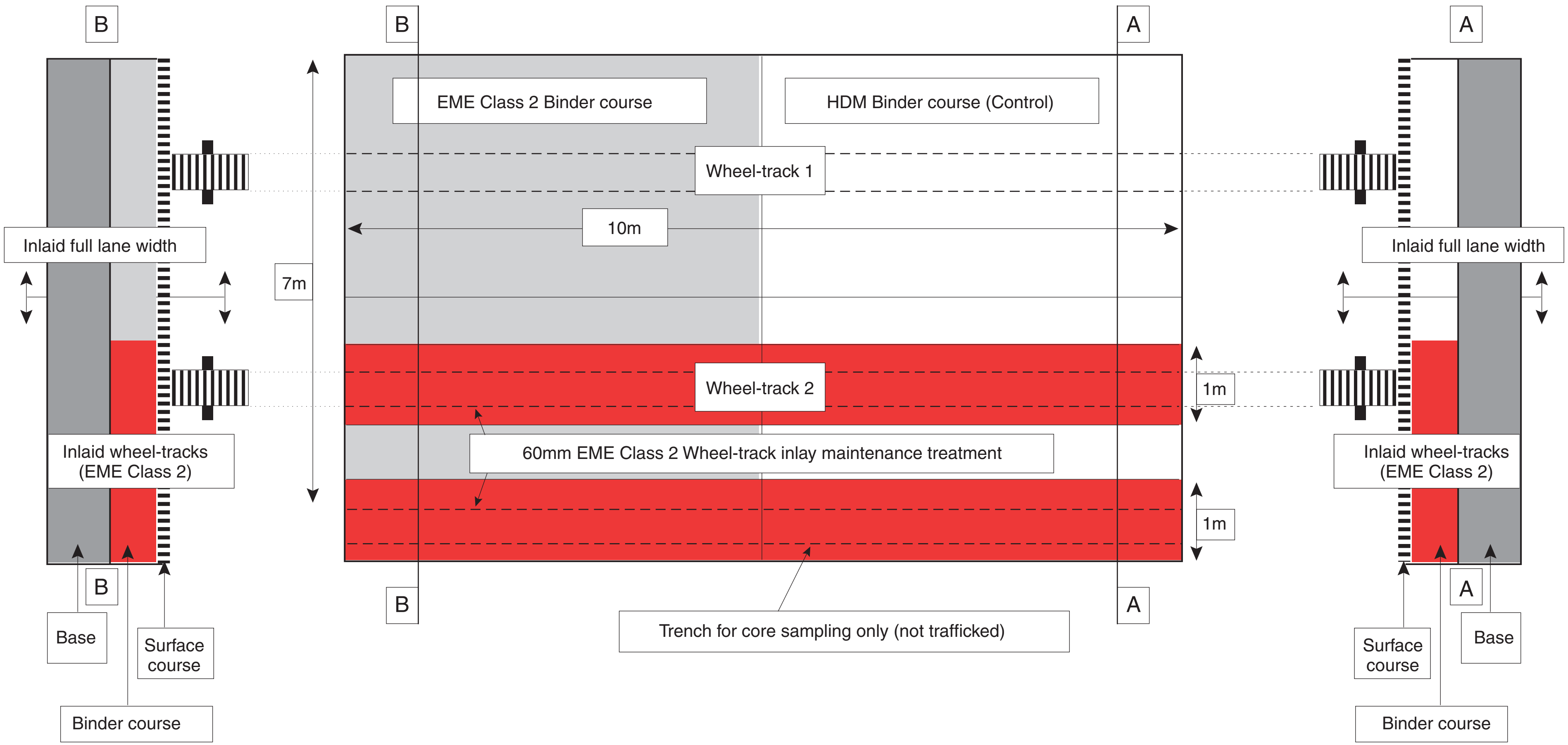

Figure 6.1 Plan and cross sections of test sections in the TRL pavement test facility

Table 6.1 Construction details

Layer	*Control*	*Test Pavement 1*	*Test Pavement 2*	*Test Pavement 3*
Surface course	30 mm thin proprietary surface course			
Binder course	60 mm HDM (20 mm, Table 15, BS4987: Part 1)	60 mm HDM with EME trench inlay	60 mm EME	60 mm EME with EME trench inlay
Base	190 mm HDM(28mm, table 3 BS4987: Part 1)			
Subbase	430 mm Type 1 subbase			
Subgrade	Clay with a Californian bearing ratio of 3.5%			

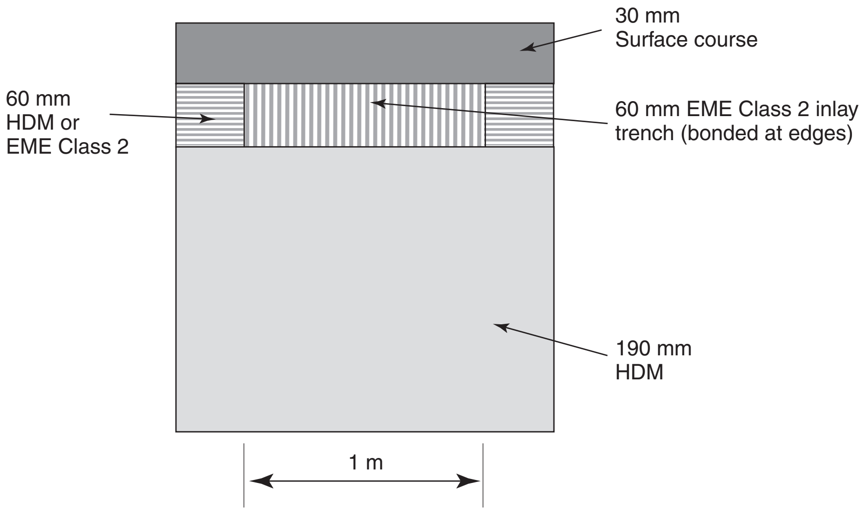

Figure 6.2 Details of trench inlay

6.2.2 Bound layers

The bound layers were laid over 2 days. On the first day, the pavement was constructed up to the top of the binder course. Approximately 190 mm of 28 mm HDM was placed in two lifts, followed by a 60 mm binder course of either 20 mm HDM or EME Class 2 (see Figure 6.1 for the test layout). A Dynapac F16 paver and Bomag BW161D roller were used to construct the pavement.

On the second day of construction, two 1 m wide strips were planed out to a depth of 60 mm (i.e. down to the top of the base layer). One side of each of these trenches followed current normal practice and was cut with a diamond saw to give a sharp clean edge after planing, whereas the other side remained as the milling machine had left it. This trial would help to determine best practice, as the benefits of a sawn edge appear questionable when considerations of cost, time and health and safety are taken into account.

To promote good adhesion between layers and thus low interface permeability, particular care was taken to ensure that vertical joints and horizontal interfaces were clean and rich in binder tack coat (Figure 6.3). The EME Class 2 material was placed in the trenches by hand and compacted using a Bomag BW135AD roller. The second inlay was constructed to provide material samples to investigate, for example, the degree of compaction at the edges of the trench.

Following the compaction of the trenches, 30 mm of thin surface course was applied over the entire test area using the same plant as was used for the full width placement of the base and binder course layers.

Throughout the whole laying process the density of the compacted asphalt was monitored continuously using a Troxler nuclear density gauge. These results together with other monitoring information are given in Appendix A.

6.2.3 Trafficking

The trafficking was carried out under severe conditions intended to resemble those found on a congested trunk road on a hot summer day with a maximum air temperature of around 30°C. This was to ensure that the recommendations from this research would prevent serious rutting in most UK situations. Pavement temperatures were monitored at three positions along the pavement at depths of 0, 40 and 200 mm to enable the temperature of the pavement to be controlled throughout the test. The sensor at 40 mm was subsequently used to control the pavement temperature during trafficking to between 40°C and 45°C. Trafficking at elevated temperature enabled the deformation resistance of the pavements to be assessed rapidly.

Figure 6.3 Bitumen emulsion tack coat being applied to the trenches

For the main trial, a wide-base single tyre was used. This type of tyre was chosen because it would provide more severe loading than the dual configuration of traditional narrower tyres. The wheel loading characteristics are given in Table 6.2. The tyre, load and inflation pressure are typical of those found on a fully laden trailer with a tridem-axle in the UK.

Table 6.2 Wheel loading characteristics applied in the PTF

Characteristics	
Temperature (°C)	40
Tyre	385/65 R22.5
Load (kN)	40
Tyre pressure (MPa)	0.83
Speed (km/h)	20
Lateral wander (m)	± 0.36

The lateral distribution of wheel loads shown in Figure 6.4 simulated realistic in-service traffic conditions. Also, with this width of *wander,* the edge of the tyre was positioned on one side of the vertical longitudinal joint of the trench inlay and would therefore apply a shear load to the vertical face at the joint. This is the most severe *in situ* loading condition likely to be applied in practice. The wheel load was applied in both directions.

Wheel-track 2 (the wheel-track inlay) was trafficked first to enable samples to be taken from the other wheel-track inlay at the interface positions whilst trafficking was in progress on wheel-track 1 (the full-width inlay).

Trafficking commenced once the pavement had been brought up to the target temperature of 40°C. Initially, the procedure was to apply a few passes of the wheel load to check that all systems were functioning correctly. Subsequently, 30,000 passes were applied in stages over a period of 19 days. This level of trafficking in the TRL-PTF was considered by Weston *et al.* (2001) to be equivalent to 15 years of normal in-service traffic. The machine was stopped after each loading stage to conduct a visual inspection and to measure rutting. Skid resistance and texture depth measurements were made at the end of the trafficking. The heating system was switched off and moved to give access for making measurements. Consequently after each measurement cycle the pavement had to attain the correct temperature gradient before the loading recommenced. Measurements in wheel-track 2 were taken at approximately every 300 passes up to 2000 passes, then every 350 passes up to 4000, every 400 passes up to 8000, 500 up to 10,000 and then every 2000 passes to the end of the test. The application of loading on wheel-track 1 was similar except that the frequency of taking measurements was reduced slightly.

Rut depth was measured under a 2 m long straight edge at every 0.5 m interval along each test section after each loading stage. In addition, optical levels were taken at the same transverse locations across each test section at close

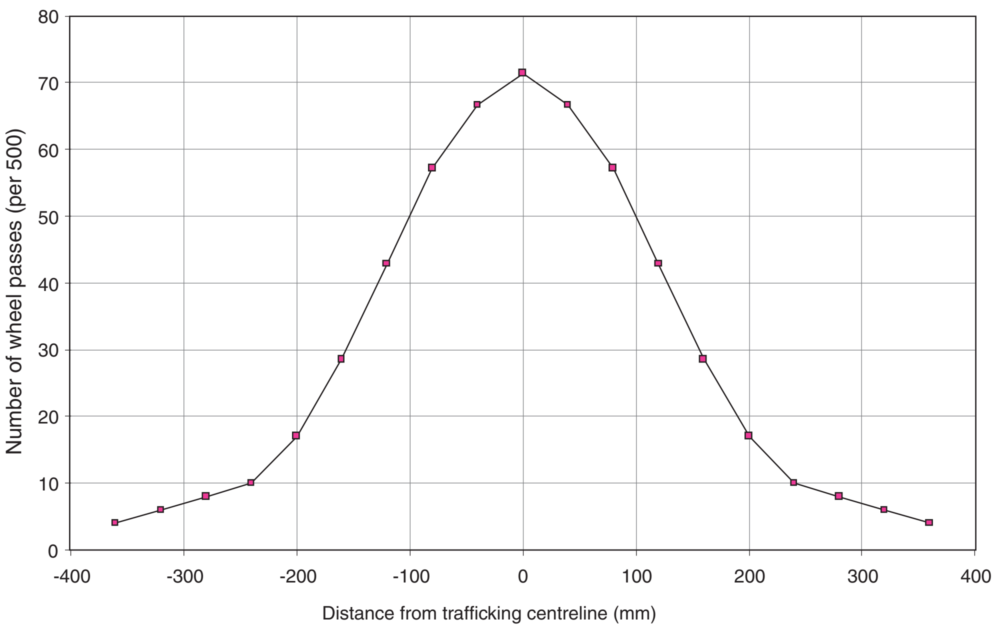

Figure 6.4 Lateral distribution of wheel loads in the PTF

intervals (40mm) near the centre of the rut widening to 200 mm intervals at the edge of the test section. From these measurements a transverse profile was determined.

At the conclusion of the trial, two large transverse beams were cut from each section of the pavement to obtain a direct measure of the deformation in each layer. The results of these measurements are given in Section 8.

Compaction in the vicinity of the trench was measured using the nuclear density gauge across the second wheel-track inlay designated for sampling and material testing. Samples were cut for deformation and stiffness modulus testing. Details of the locations from where the samples were taken are given in Appendix A together with the test results.

7 Material testing

A summary of material sampling and laboratory testing for the binder course and base materials is given in Appendix A. Testing was focussed on comparing the material properties of the EME Class 2 with HDM binder course, as HDM is a well established material that has been shown to perform well in heavily trafficked situations in the UK.

In addition to the normal material composition tests, the tests carried out included:

- BS Wheel-Tracking Test (BS 598: Part 110: 1998).
- Indirect tensile modulus test (BS DD 213).
- TRL permeability test.

To assess the practicability of maintenance by means of a trench inlay in the wheel path, attention was focused on material adjacent to the longitudinal joint of the trench inlay.

7.1 Conventional tests

Conventional testing of the trial pavement layers was carried out and these included measurement of grading, binder content, recovered binder properties, maximum density and air voids. These tests showed that the materials complied with either the standards specified in the Specification for Highway Works or target properties specified for the materials and that the intended grades of bitumen had been used. A summary of the binder and volumetric tests is given in Appendix A.

7.2 Structural properties

Indirect tensile stiffness modulus (ITSM) tests were carried and the results are summarised in Table 8.2 and resistance to deformation was assessed using the Wheel-tracking test BSI (1998). The detailed results are given in Appendix A.

7.3 Permeability tests

Permeability testing was carried out with the TRL permeability cell on 6 cores taken from material between the wheel-tracks, as described below.

The TRL permeability cell (Figure 7.1) is similar to that developed by the Cement and Concrete Association (C&CA, since renamed the British Cement Association, BCA) by Grube and Lawrence (1984) and Leeds University (Hassan and Cabrera, 1997). Measurement of air permeability is carried out by sealing the curved surface of 100 mm diameter cores within a cylindrical mould and applying pressurised air to one side of the specimen. The pressure gradient across the specimen results in a flow of air, which is measured at the other side using a flowmeter. The test pressure is 1Bar and the duration is less than 30 min, depending on the air voids content and the continuity of voids of the tested asphalt.

Figure 7.1 The TRL permeability cell

The intrinsic air permeability can be determined from the measurements of flow rate according to the modified D'Arcy's equation as follows:

$$K = \frac{2v\eta LP_2}{A\left(P_1^2 - P_2^2\right)}$$

Where: K = intrinsic air permeability (m²)

v = flow rate (m³/sec)

η = viscosity of air (1.82×10^{-5} N.s/m² at 20°C)

L = length of the specimen (m)

A = cross-sectional area of the specimen (m²)

P_1 = inlet absolute applied (gauge) pressure (bar)

P_2 = outlet pressure at which the flow rate is measured (bar), usually 1 bar

The values for air permeability are converted to an 'estimated water permeability' value using the following formula

$$y = 2.53 + 1.12x \qquad \left(r^2 = 0.95\right)$$

Where: y = L_nK_w = Water permeability (m²)

x = $L_n K_o$ = Oxygen permeability (m²)

7.4 Moisture susceptibility tests

To indicate the effect of prolonged contact of water, and hence a proxy for durability, the following procedure devised by TRL in earlier collaborative research was used (Weston, 1999: Nunn, 2001):

1 ITSM values were measured prior to saturation with water.

2 Samples were saturated by using the Rice Density equipment and applying a vacuum for 5 minutes before release.

3 Samples were continuously immersed in water at 20°C for 50 days.

4 Samples were removed for ITSM measurements at intervals of 1 day, 10 days, 25 days and 50 days.

Test results are given in Section 8.4.

8 Test results

8.1 Rut development

The development of rutting in wheel-track 1 is shown in Figure 8.1. The average rut depth for each test section was calculated from measurements under a 2 m straight edge at 0.5 m intervals along each section where the speed of the loading wheel was constant. Figure 8.1 shows that the rate of rutting on the section with EME Class 2 binder course was consistently less than that on the HDM binder course section.

The development of the average transverse profiles in wheel-track 1 is shown in Figures 8.2 and 8.3 for the sections with the full width inlays of EME Class 2 binder course and HDM binder course respectively. The transverse profiles are very similar although the HDM shows slightly more deformation and pushing. The heave (or pushing) on the right side of the wheel-track is slightly greater than that on the left.

The development of rutting during trafficking on the sections with the wheel-track inlay is summarised in Figure 8.4.

Figure 8.4 shows that the rut depth in both the trench inlay sections is greater than the rut depth in the sections with the full width inlay, shown in Figure 8.1. Indeed, the final rut depth is almost double that for the full width inlay. The precise reason for this is not known. The EME Class 2 and HDM in the wheel-track inlays were compacted to a similar level to the material in each of the full width inlays. It is possible that the tack coat applied to the trench prior to the inlay, had a lubricating effect at the interface and this may have resulted in more rutting. The TRL-PTF trial involved planing a trench in newly laid material. In this circumstance the tack coat is likely to be superfluous especially prior to laying a binder course containing 5 to 6% bitumen. A real-life maintenance situation will involve planing old material that is likely to absorb the tack coat better.

The wheel-track inlay material was EME Class 2 installed in a planed out strip of EME Class 2 binder course in one section (positions 1.5 m to 5 m) and a planed out strip of HDM in the other (positions 5 m to 9 m). The transverse rut profiles are shown in Figures 8.5 and 8.6. These transverse profiles are reasonably similar and symmetrical with the sawn and milled edges causing no obvious differences.

8.2 Transverse cross sections

At one of the transverse measuring points in each section, transverse beams were cut from the pavement using a circular saw. They were lifted clear from the pavement using a crane attached to rawl bolts that had been glued into place in holes drilled in the beams. When the beams had dried, the interfaces between asphalt layers were carefully marked on the sides from which the final thickness of each layer was determined from measurements made at 50 mm intervals along the length of the beam.

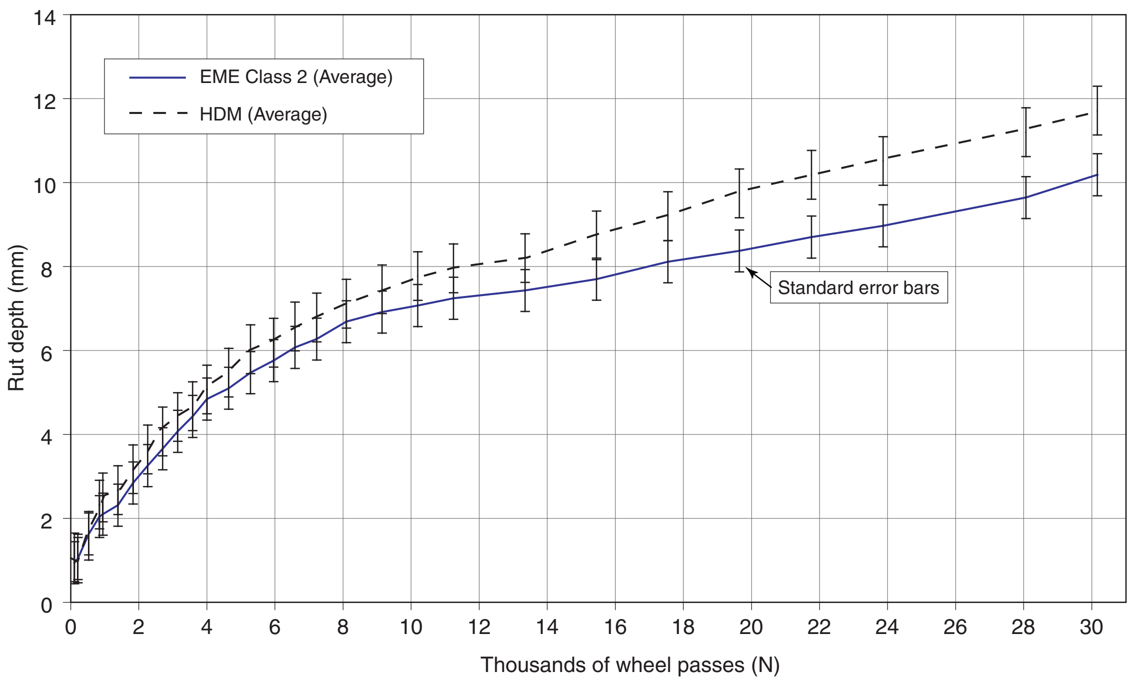

Figure 8.1 Development of rut in wheel-track 1

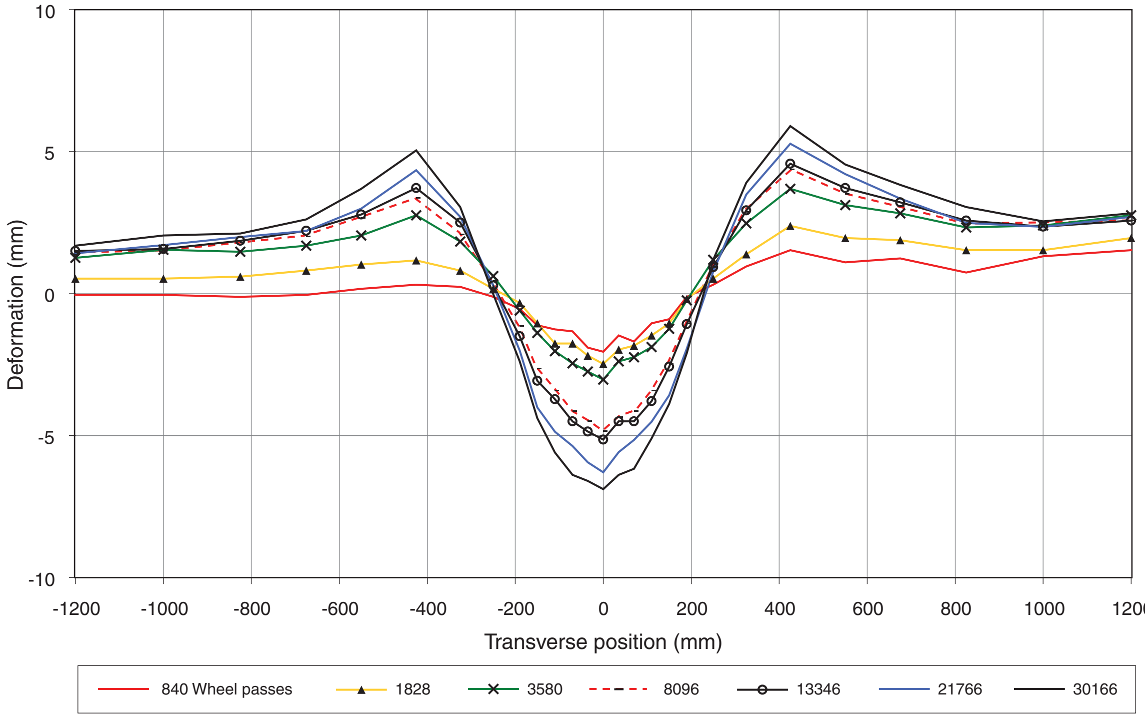

Figure 8.2 Development of transverse profile in wheel-track 1 (Full width inlay of EME Class 2 binder course)

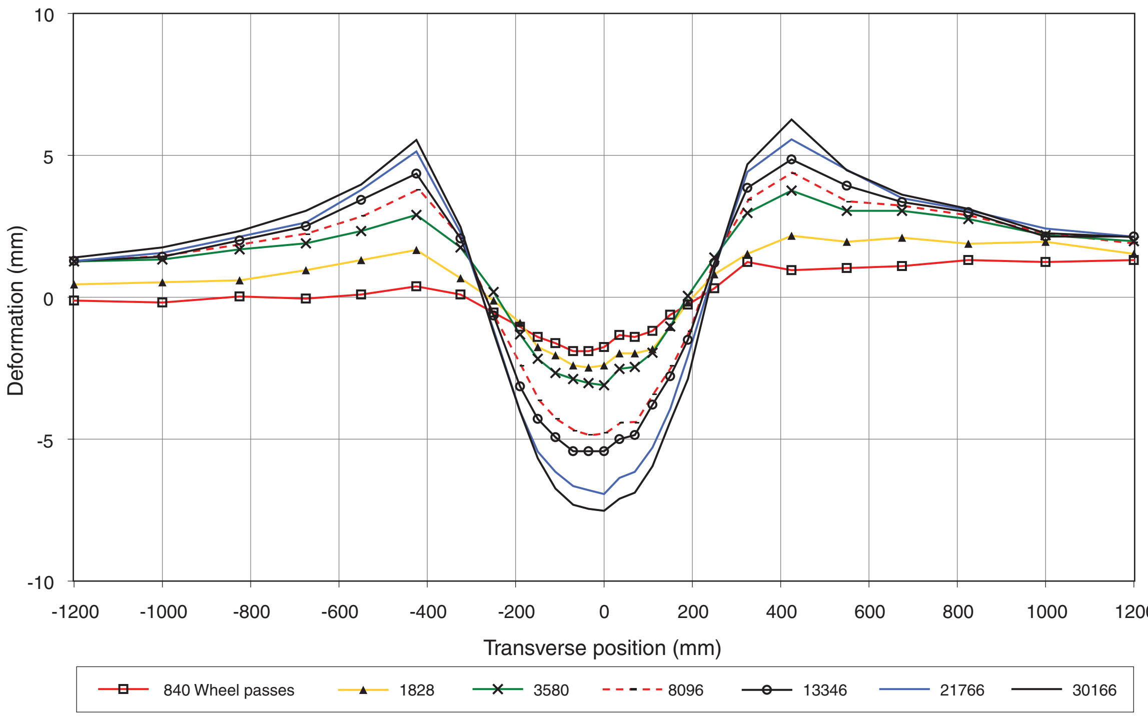

Figure 8.3 Development of transverse profile in wheel-track 1 (full width inlay of HDM binder course)

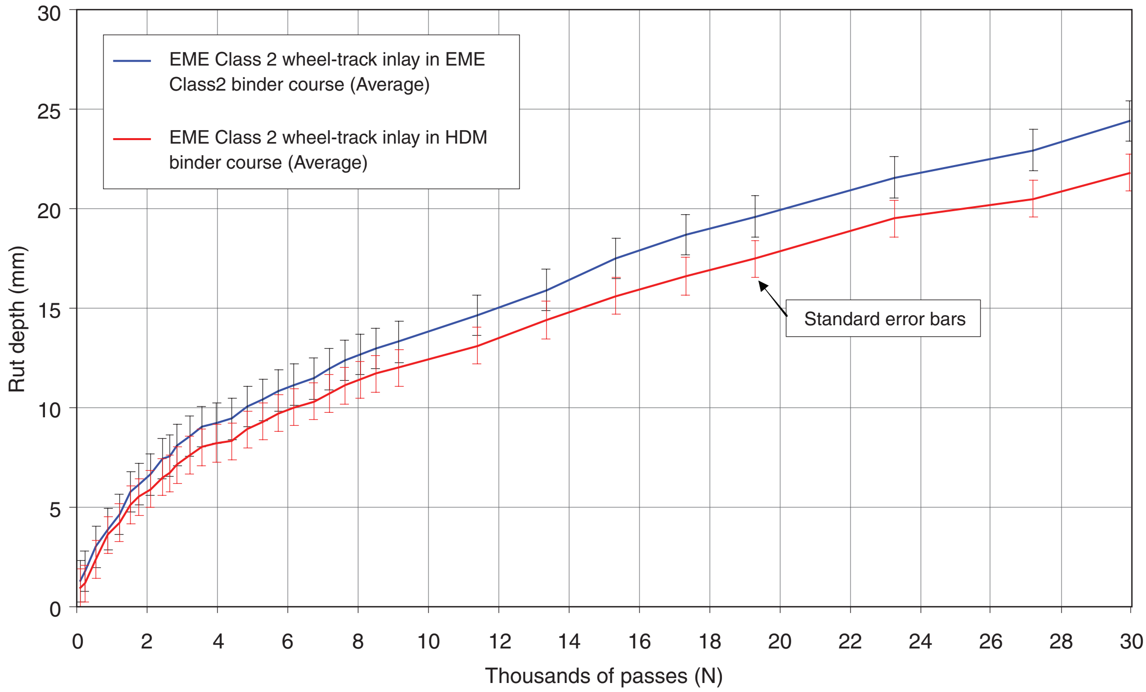

Figure 8.4 Development of rut in wheel-track 2

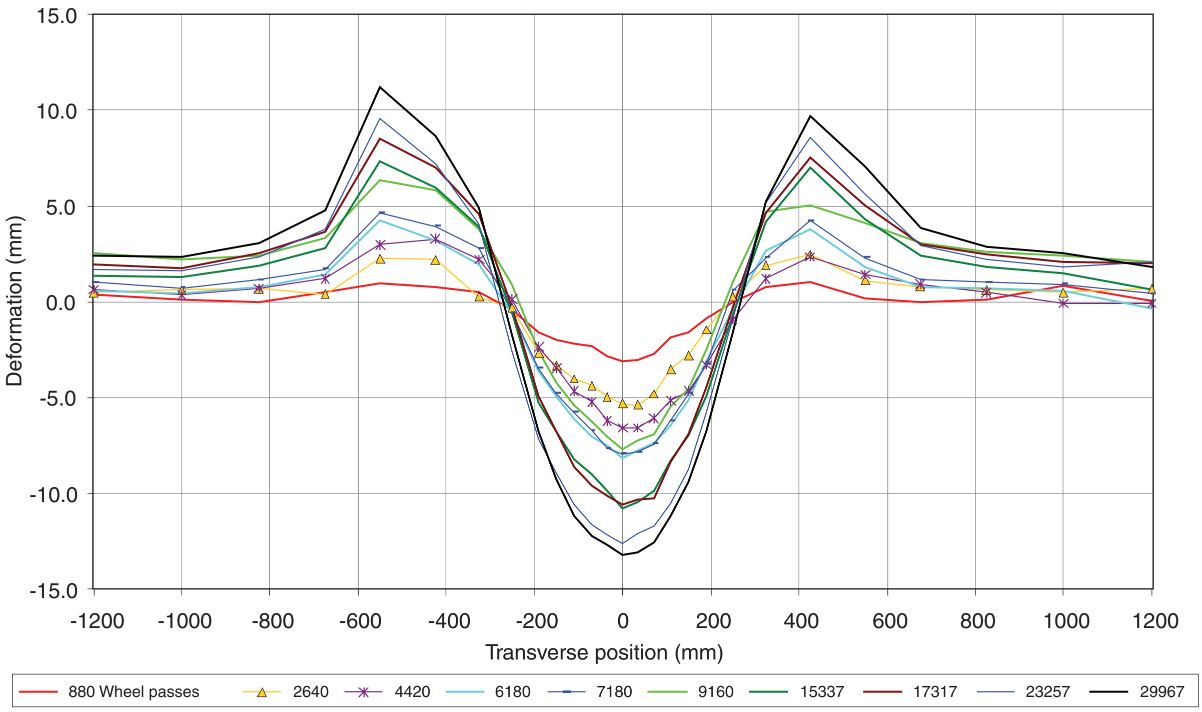

Figure 8.5 Development of transverse profile in wheel-track 2 (EME Class 2 wheel-track inlay in EME Class 2 binder course)

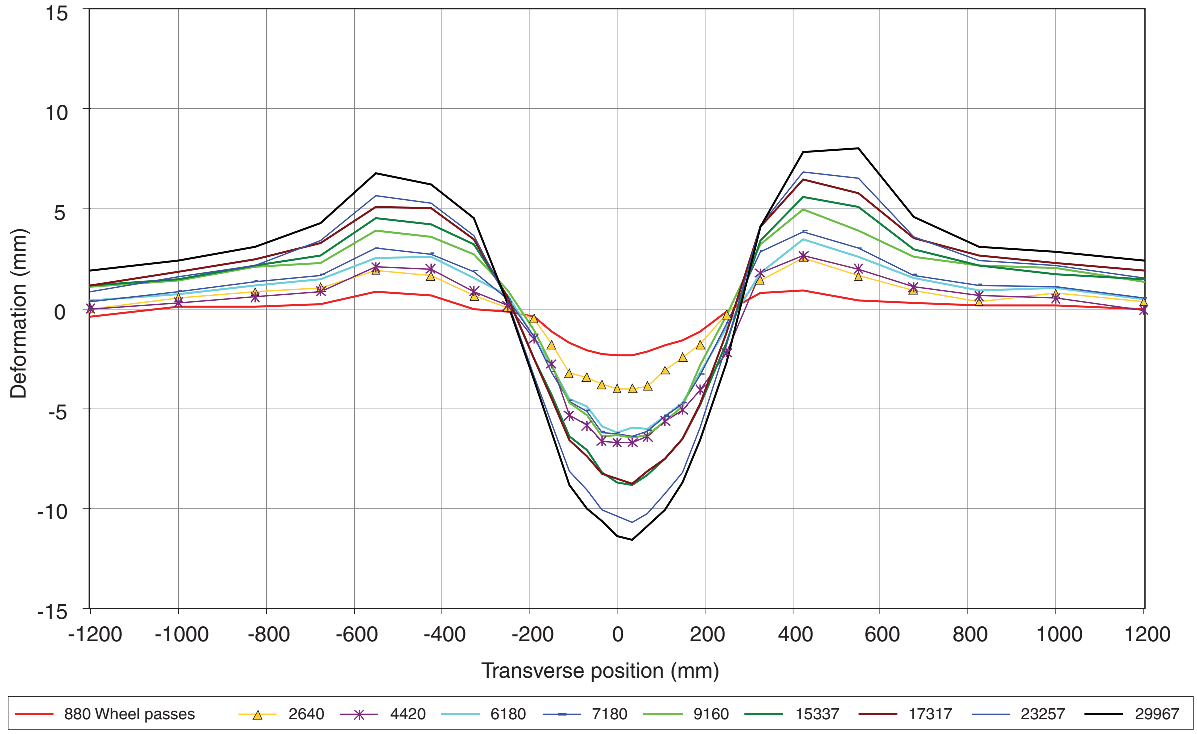

Figure 8.6 Development of transverse profile in wheel-track 2 (EME Class 2 wheel-track inlay HDM binder course)

Initially a visual inspection was made whilst the beams and the edges of the holes in the pavement were drying as this presented the best opportunity to observe any cracking. No cracking was observed in the pavement sections even in the vicinity of the edges of the trench. The bonding of the edge that had been just milled out was equally as good visually as that of the sawn edge which is the current recommended practice in the UK.

Figures 8.7 to 8.10 are photographs of each beam over the central 1.2 m. The photographs illustrate that rutting predominately occurred in the upper asphalt layers.

Table 8.1 gives the average thickness of the three upper bound layers measured on the four beam samples at the centre of the wheel-path and 0.5 m from the centre of the wheel-path. The latter position corresponds to the shoulder of the rut and the thickness reduction given by the difference between these two measurements will be the contribution each layer makes to the rut depth. It was not possible to determine accurately the thickness of the lower base layer because its thickness at each measurement point depended on the uneven interface between the top of the subbase and the underside of the lower base layer.

Table 8.2 compares the rut depths determined directly from the measurements made in the TRL-PTF and the rut depths calculated from the deformations measured in the individual layers.

Table 8.2 shows that the agreement between the two methods was reasonable, bearing in mind, the results in Figure 8.1 were average values from measurements carried out at seven transverse positions and the results in Table 8.1 were from a single location and that there may be small measurement discrepancies from the measurements made on the beam samples. The rut depths calculated from the thicknesses of the cross-sectioned layers were well within the range of surface rut depths measured directly in the TRL-PTF.

In wheel-track 1, the three upper layers contributed to the majority of the rutting with 28% of the rut depth attributable to the EME Class 2 binder course and 43% occuring in the HDM binder course. In wheel-track 2 with the EME trench inlay, it was not possible to directly compare between the components of rutting from the EME Class 2 binder course (in the trench) in each half of the wheel-track. This was because the depth of planing could not be carried out with sufficient precision to just remove the binder course. Also, the milling machines do not leave a smooth, well defined interface where material is removed (Figure 8.11). Consequently, the deformation below the surface layer has been shown in Table 8.1 as that occurring in the inlaid binder course (EME Class 2) plus the upper base layer (HDM). In practice, one would expect similar deformations to occur in these two sections because both have been inlaid with the same EME Class 2 binder course. However, in one section the binder course adjacent to the inlay is EME Class 2 and on the other section HDM.

The reasonable agreement between these two different methods of determining the rut depth is a strong indication that significant rutting does not occur in the lower base layer. Also the evenness of the interface between the upper and lower base layers, shown in Figures 8.7 to 8.10, suggested that the lower base layer did not appear to contribute to rutting: the deformation measured in the surfacing layers and the upper base layer accounted for all the rutting observed at the surface.

Figure 8.7 Transverse section of wheel-track 1 at 2.5m (EME Class 2 full width inlay)

Figure 8.8 Transverse section of wheel-track 2 at 2.5m (EME Class 2 wheel-track inlay in EME binder course)

Figure 8.9 Transverse section of wheel-track 1 at 7.5m (HDM full width inlay)

Figure 8.10 Transverse section of wheel-track 2 at 7.5 m (EME Class 2 wheel-track inlay in HDM binder course)

Table 8.1 Reduction in thickness of pavement layers after accelerated testing in the TRL-PTF

	Thickness of layers (mm)								
	Surface layer			*Binder course*			*Upper base layer*		
Test section	*Before ALT*	*After ALT*	*Thickness reduction*	*Before ALT*	*After ALT*	*Thickness reduction*	*Before ALT*	*After ALT*	*Thickness reduction*
WT1EME	35.5	35	0.5	62.5	59	3.5	90.5	82	8.5
WT1HDM	36.5	31.5	4.5	67	61	6	96	92.5	3.5
				Binder course plus upper base layer					
				Before ALT		*After ALT*		*Thickness reduction*	
WT2 EME-EME	30.8	24	6.8	166.0		146.0		20.0	
WT2 EME-HDM	29.3	22.5	6.8	161.5		146.5		15.0	

Table 8.2 A comparison of rut depths determined using two different methods

		Rut depth (mm)		
Wheel -track	*Material (binder course)*	*Mean*	*Range of measurements in TRL-PTF*	*Calculated from cross-sections*
1	EME	11.7	9.4 to 14.3	12.5
	HDM	10.2	7.3 to 14.0	14.0
2	EME inlay in EME	24.4	13.0 to 28.4	20.0
	EME inlay in HDM	21.8	11.0 to 26.0	15.0

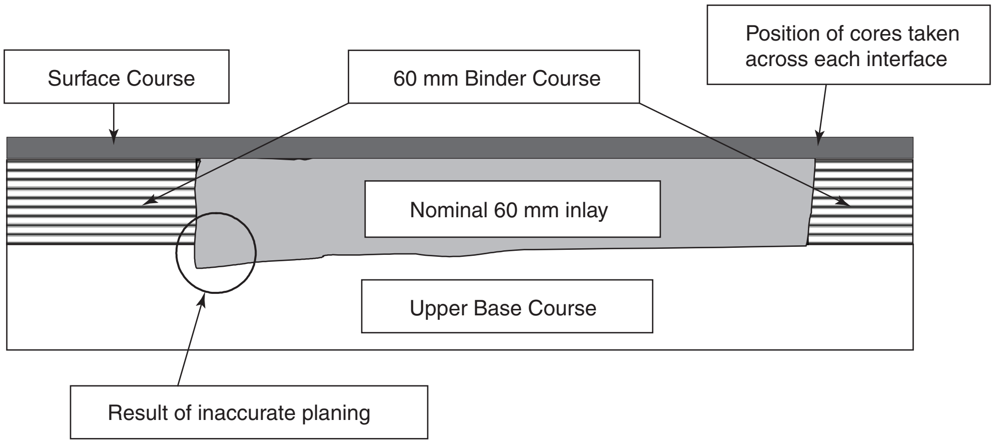

Figure 8.11 Transverse section of wheel-track 2 after milling original binder course

8.3 Surface characteristics

Surface characteristics of the test section were assessed through texture depth measurements using the sandpatch test (BSI, 1998) and skid resistance measurements using the portable skid resistance tester (PSRT) or otherwise known as the pendulum test (BS: EN 2003). Detailed results comparing measurements made before and after accelerated load testing are given in Appendix A.

Results showed that the texture was that expected on a UK trunk road when laid and it remained similar after trafficking. Following accelerated loading, the values of skid resistance measured by the PSRT were reduced by 24% in wheel-track 1 and by 19% in wheel-track 2. This was considered to be the result of the raised temperature (40°C.) throughout the trafficking. This led to the surface course being smoothed by the action of the wheel. It is considered unlikely to be typical of in-service conditions.

8.4 Laboratory testing

8.4.1 Density at wheel-track inlay vertical interfaces

To investigate the degree of compaction achieved along the vertical interfaces, 12 cores were taken at intervals of 1 m, excluding the first and last 2 m of the test strip, along each edge of the trench that was not used in the accelerated loading tests (see Figures 6.1 and 8.11). The cores were cut through the thin surface layer and centred on the vertical interface between the wheel-track inlay and the original binder course. For one set of cores, the vertical interface had been milled and for the other the interface had been cut with a diamond saw.

The cores were then cut in half at the interface and values of density for each half were determined in the laboratory. The density measurements are given in Table 8.3.

Table 8.3 shows that the compaction achieved in the EME Class 2 inlay close to edge of the trench was equally as good as the compaction within the full width EME Class

Table 8.3 Density measurements adjacent to the vertical interfaces of the non-traffficked wheel-track inlay

	Milled interface				*Sawn interface*			
Material	*EME-Mat**		*EME-Inlay#*		*EME-Inlay#*		*EME-Mat**	
*Core location (m)***	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*
2	2.447	0.6	2.410	2.1	2.357	4.21	2.446	1.17
3	2.428	1.3	2.431	1.2	2.434	1.09	2.456	0.76
4	2.441	0.8	2.445	0.7	2.420	1.66	2.472	0.12
	Milled interface				*Sawn interface*			
Material	*HDM-Mat**		*EME-Inlay#*		*EME-Inlay#*		*HDM-Mat**	
*Core location (m)***	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*	*Density (mg/m^3)*	*Air voids (v/v%)*
6	2.479	0.2	2.451	0.4	2.447	0.6	2.509	0
7	2.478	0.0	2.457	0.2	2.428	1.3	2.503	0
8	2.487	0.0	2.400	2.5	2.441	0.8	2.470	0

* *Half of the core in the original binder course layer.*

** *Distance measured from the south edge of the PTF test pit.*

\# *Half of the core in the EME Class 2 binder course wheel-track inlay.*

2 binder course layer. The good compaction was aided by the relatively fine grading of the mixture.

Whether the vertical interface edge was sawn or just milled did not appear to make any difference to the compaction achieved in the inlay close to the edge.

8.4.2 Density measurements in the mat and in the trenches

Detailed plots of gamma-ray core scanner measurements of cores taken in the mat and in the trench are given in Appendix A. Results show how densities vary between layers and how layer interfaces tend to give values noticeably smaller than those from the main layer.

8.4.3 Stiffness modulus

Indirect tensile stiffness modulus tests (BSI DD 213,1996) were carried out on a total of 24 samples cored from the binder and road base courses. A summary of the results is shown in Table 8.4 with the detailed results tabulated in Appendix A.

The measured stiffnesses of EME are similar to those measured during an earlier investigation into the properties of EME at TRL given in Table 8.5 (Nunn and Smith, 1994).

8.4.4 Moisture susceptibility tests

The susceptibility of the EME Class 2 to moisture damage was assessed by monitoring the stiffness of material subjected to prolonged soaking. The results are summarized in Table 8.6 and details of the testing are given in Appendix A.

The behaviour is similar to that observed for other materials tested with 'high' binder contents in previous work at the TRL (Weston, 1999) and 2001 (Nunn, 2001) in which stiffness tests before and after soaking were carried out on asphalt mixtures with combinations of limestone and granite aggregate, high (4.3%) and low (3.5%) binder contents and two binder grades (10/20 pen and 40/60 pen). The results showed that the stiffness could increase by about 15% over the first few days before the material properties stabilised for mixtures with high binder contents.

The results indicate that the EME Class 2 material is insensitive to the effects of soaking in water, which is to be expected with the relatively high binder content of 5.9%.

8.4.5 Rut resistance

The wheel-tracking test (BSI, 1998) was used to measure the resistance to permanent deformation of the EME Class 2 and HDM binder course materials. The results for individual test specimens are given in Figure 8.12. Initial testing was conducted in a temperature controlled environment of 45°C. Then, to investigate the temperature susceptibility of the material, tests were repeated at 60°C. Results show that the rate of rutting of the EME Class 2 is less than that for the HDM at 45°C. As HDM binder course has superior rut resistance to other materials commonly used in major road construction in the UK, this result is considered significant. Furthermore, wheel-tracking tests that were conducted on the EME Class 2 binder course samples at 60°C show that its rate of rutting is not affected significantly by the increase in temperature.

Table 8.4 Summary of ITSM test results

Material	*Number of measurements*	*Mean ITSM (GPa)*	*Standard deviation (GPa)*
0/20 mm EME Class 2	5	6.38	0.54
28 mm HDM Binder course	6	6.02	0.58
28 mm HDM Upper base	6	5.68	1.06
28 mm HDM Lower base	6	3.92	0.79

Table 8.5 Comparison of stiffness measurements (GPa) carried out in 1994 (Nunn and Smith, 1994)

Material	*French reference condition (15ºC, 10Hz, 3-point bending test)*	*UK reference condition (20ºC, 5 Hz, 3-point bending test)*	*ITSM (20ºC, 2.5 Hz, NAT)*
EME Class 2	9.9	6.4	6.0
EME Class 1	12.5	8.9	7.5
DBM 15 base	11.0	8.0	7.2
DBM15 binder course	14.0	10.2	9.3

Table 8.6 Change in ITSM of EME Class 2 with time

Days of soaking	*Percentage increase in stiffness*						
	Core 19	*Core 20*	*Core 21*	*Core 22*	*Core 23*	*Core 24*	*Mean*
0	0	0	0	0	0	0	0
1	2	7	13	4	6	19	9
10	3	8	15	7	2	25	12
25	7	11	16	7	10	24	13
50	8	10	17	4	11	27	13

8.4.6 Permeability testing

The results of the permeability testing showed that the permeability of the EME Class 2 was so low that no readings could be recorded. The relative permeability of typical asphalt materials is illustrated in Table 8.7. The measurements indicated that EME Class 2 laid in these trials would have a permeability of less than 10^{-11} m/s.

Table 8.7 Relative permeability of bituminous materials (Nicholls, 1998)

Material	*Typical void content (%)*	*Approximate water permeability (m/s)*
Mastic asphalt	<1	$<10^{-11}$
HRA surfacing (30% stone)	2 to 8	10^{-11}-10^{-10}
HRA surfacing (55% stone)	2 to 6	10^{-11}-10^{-10}
Asphalt concrete	3 to 5	10^{-10}-10^{-8}
Close graded bitumen macadam	4 to 7	10^{-8}-10^{-5}
Open-graded bitumen macadam	12 to 20	10^{-8}-10^{-3}
Porous asphalt	15 to 25	10^{-4}-10^{-2}

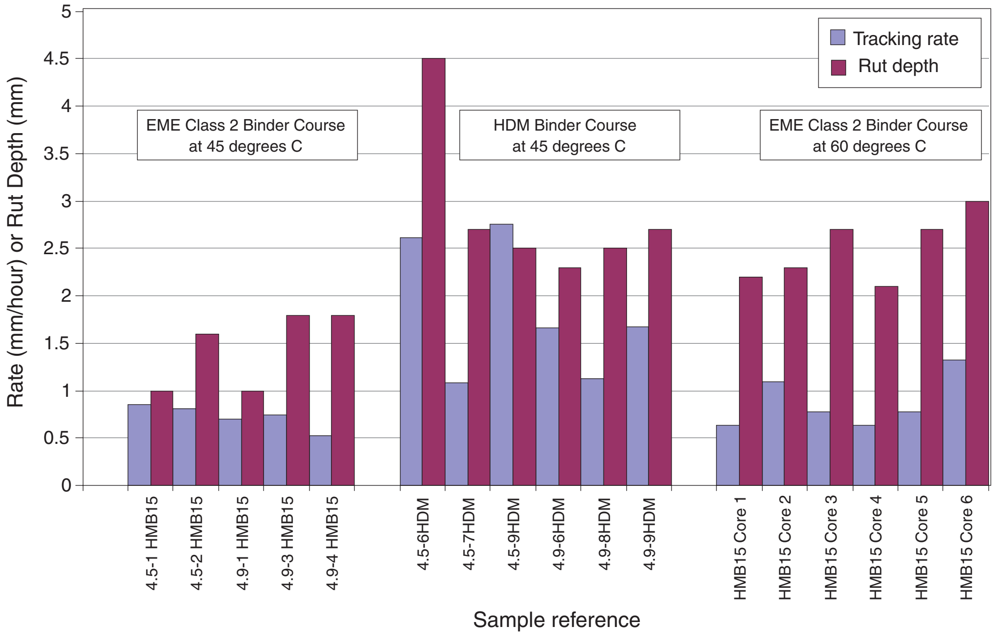

Figure 8.12 Summary of wheel-tracking test results for EME Class 2 and HDM binder courses

8.5 Fatigue testing

Figure 8.13 shows the fatigue characteristics of the EME and 28 mm HDM derived from measurements using the Indirect Tensile Fatigue Test (ITFT) (BSI DD ABF 1995). This shows the fatigue resistance of EME to be marginally better than that of HDM, but the difference is not statistically significant.

9 Summary of results

The analysis of results has concentrated on the comparison of the development of rutting and cracking during the accelerated loading of the pavements. In particular the performance of the section with the EME Class 2 binder course was directly compared with that of the section of the HDM binder course. In addition, the performance of the sections with the EME Class 2 binder course wheel-track inlay was compared with that of the sections with the full-width binder course layers.

9.1 Performance in the TRL-PTF

Testing in the TRL-PTF was conducted at 40°C. At the completion of tracking no cracking in the pavement surface was observed, except for a small separation of

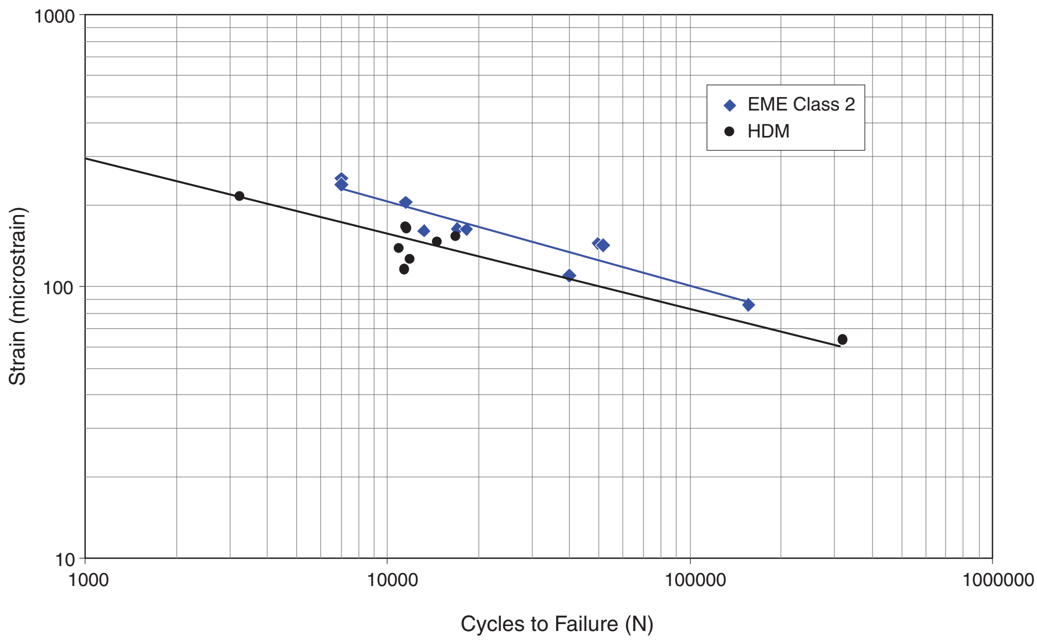

Figure 8.13 Comparison of ITFT fatigue behaviour of EME Class 2 and HDM

material at the surface of the heave on either side of the rut. The major deterioration was in the form of rutting. Figure 8.1 shows that the rate of rut development was less on the section with the EME Class 2 binder course than on the section with the HDM binder course. HDM is resistant to rutting compared with other asphalt materials used in the UK so the superior performance of the EME Class 2 binder course is encouraging.

The rate of rut development is a good measure of the susceptibility of a material to permanent deformation. Accordingly the graphs of rut development (Figures 8.1 and 8.4) were analysed to provide rates of rutting after the initial phase of rapid rut development. In addition, to help establish that the performance of the pavement section constructed with HDM was typical of earlier trials carried out in the TRL-PTF, the rutting behaviour reported by Weston, *et al.* (2001) was used as a comparison (see Figure 9.1). Weston *et al.* assessed the rutting behaviour of typical surfacing systems designed for heavily trafficked pavements in the UK. Table 9.1 compares the values of rutting rates, obtained by regression analyses, of the test pavements examined in this study and those reported by Weston *et al.*

Three main points can be inferred from the values in Table 9.1:

1 The EME full-width inlay clearly shows the best performance (29% better that the next lowest rut rate).

2 The performance of the HDM section in Wheel-track 1 was similar to the HDM tested in 2001 (TRL Report TRL456).

3 The inlay trench performed poorly compared to the full-width inlay.

Table 9.1 Analysis of rates of rutting

Data source / *Section*	*Rate of rut development (mm/1000 wheel load)*	*Correlation coefficient (R^2)*	*Ratio of rut rates: Rut rate material 'x' / HDM 2003 rut rate*
Wheel-track 1			
EME	0.15	0.992	0.71
HDM	0.22	0.999	1.0
Wheel-track 2			
Trench in EME mat	0.56	0.989	2.58
Trench in HDM mat	0.50	0.990	2.32
TRL Report TRL456, Section 3			
Initial linear part	0.32	0.995	1.48
Final linear part	0.23	0.999	1.04
Complete linear parts	0.28	0.987	1.29

There are no clear reasons why the trench inlay rutted more than the other test section, and as the material in the trench inlay was shown to have very similar densities to that of the mat, other factors must contribute. It is noted that the deep rutting values are due largely to high shoulder heave (see Figures 8.5 and 8.6) and not as a result of material compression. The reason for the high shoulders is thought to be due to a combination of the high traffic levels in the 'early-life' of the material and the geometry of the trench and, possibly, the result of horizontal of vertical interfaces being lubricated with tack coat. The high trafficking temperature combined with tack coat would reduce the shear resistance between the inlaid material and the mat and thus facilitate the development of lateral movement and shoulders.

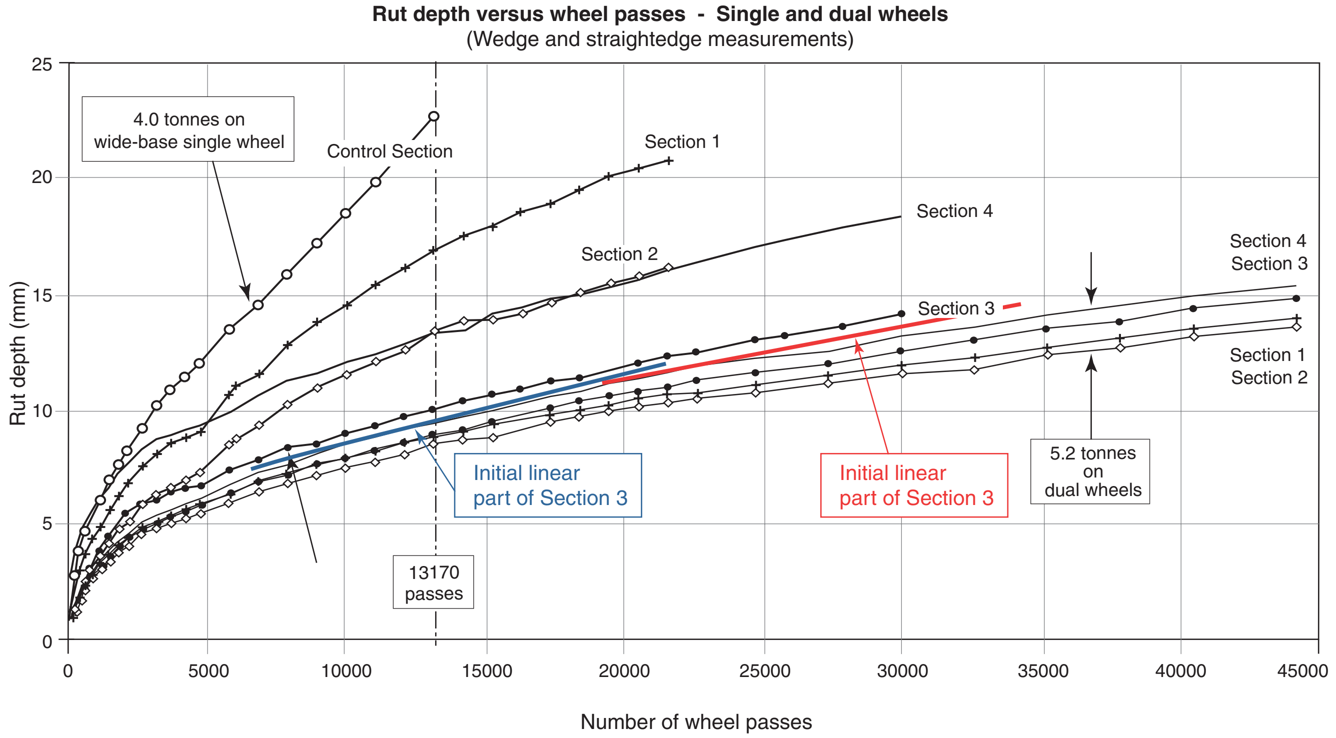

Figure 9.1 Rut depth versus wheel passes (Weston *et al.*, 2001)

In the transverse beam samples taken across the EME Class 2 wheel-track inlay, it was not possible to identify precisely the amount of deformation that occurred in the binder course for the following reason. During the installation of this innovative maintenance treatment, the original binder course had been planed out, and thus during the process, the original horizontal layer interface datum between the binder course and upper base was destroyed. Table 8.1 shows that deformation had occurred in the combined binder course inlay and upper base. However, the cores extracted across the vertical interfaces at the vertical joints of the wheel-track inlay showed that similar compaction (to that found in the full-width EME Class 2 binder course) had been achieved even at the edges within the inlay. Since the material came from the same mixed batch it is reasonable to assume that provided the material was compacted to the same density then its behaviour under traffic loads should be similar. This concept is supported by the wheel-tracking laboratory test results summarised in Figure 8.12 which show that the EME Class 2 binder course has a low temperature susceptibility and excellent resistance to rutting.

The low air voids measured in the mat and at the joints show that the EME Class 2 material could be compacted very well with conventional equipment and did not require especially heavy rollers.

9.2 Laboratory testing

9.2.1 Stiffness

The measured stiffness of the EME Class 2 is similar to the value measured in 1994 in a previous trial (Nunn and Smith, 1997), i.e. an average of 6.5 GPa in 2004 compared with an average of 6.0 GPa in 1994. In addition, in 1994, LCPC obtained asphalt samples taken from various contracts in France which were tested at TRL. Test results showed that material from three of the four sites had stiffnesses between 6.0 GPa and 6.5 GPa which gives further confirmation that the material placed and tested in the PTF is representative of materials in the field. Results are given in Table 8.4 and Table A.7 of Appendix A.

Soaked stiffness

Successive stiffness measurements of EME Class 2 material soaked in water at 20°C show the stiffness of the material to increase by between 5% and 25% over 50 days, with most of the increase happening in the first 10 days. In terms of stiffness, the results show that the material is not adversely affected by water. This is similar to the findings of earlier testing on high modulus material with high (4.3%) binder content and low (approximately 4%) air voids (Nunn, 2001). The previous research found that the binder content was the most significant of the parameters investigated. Therefore, as the EME Class 2 material had a higher binder content and lower air voids, the results of the recent testing showed, as expected, low moisture susceptibility.

9.2.2 Resistance to deformation

Wheel-tracking tests

Results of the wheel-tracking tests carried out on the EME Class 2 and HDM binder course materials are shown in Figure 8.12. Temperature susceptibility of the material was investigated by testing the material first at 45°C and then at 60°C.

Test results show that rut resistance of the EME Class 2 is superior to that of the HDM at 45°C which is significant, as HDM is typically used as a binder course in major road construction due to its good rut resistance. Furthermore, wheel-tracking tests that were conducted on the EME binder course samples at 60°C show that its rate of rutting is not affected significantly by the increase in temperature.

These laboratory test results support the outcome of the rutting trials in the PTF and suggest that the EME Class 2 material is expected to have good resistance to rutting in practice. This has been shown to be the case in France where use of EME is widespread (Observatoire des Techniques de Chaussees, 1997).

9.2.3 Fatigue

ITFT testing has shown the EME Class 2 material to perform slightly better in fatigue than a conventional HDM base material. The results in Figure 8.13 show that EME Class 2 material is more fatigue resistant than the 28 mm HDM material, and that the difference in the fatigue performance of materials reduces with a reduction in tensile strain.

9.2.4 Permeability testing

Results of the permeability testing carried out on the EME Class 2 material showed the EME Class 2 material to be practically impermeable, due largely to the relatively high percentage of binder in the mixture (5.9% by mass), and good compaction that resulted in an air voids content of less than 2%.

10 Design and economic considerations

A number of factors need to be taken into account to carry out an assessment of the economic benefits of EME. These include:

1 The commercial cost of the material when produced in large amounts.

2 The mode of deterioration considered when carrying out a comparison, i.e. rutting versus cracking, for instance.

3 The type of treatment(s) applied to the pavement to ensure user safety and keep it structurally sound.

4 The period over which an analysis is applied.

5 The assumptions made for other ‘site factors’ such as the type of road/pavement being evaluated and the traffic management adopted.

From analysis of the plots of rutting it is noted that the section with the EME Class 2 binder course had a lower rate of rutting and at the end of 30,000 load repetitions at 40°C, the rut depth was approximately 15% less than that of the HDM section. Also, and more significantly if the rate of rutting in the linear part of the two plots is compared (see Section 8), the rate of rutting for the EME is approximately 29% lower. This suggests that EME Class 2 binder course could take approximately 40% more traffic for the same rutting performance as HDM. This implies that there will be obvious benefits for maintenance intervention for rutting if an EME Class 2 binder course is used. However, for an economic comparison between HDM and EME binder course, modes of deterioration of all the pavement layers needs to be considered, as interventions may be required for other reasons.

Where EME is used to replace rutted or cracked material only in the wheel-tracks, less material will be used than for the case of a full-width inlay. Using indicative rates from industry, the estimated relative costs for supplying and constructing full width inlays and wheel-track inlays are given in Table 10.1. These calculations do not include the costs of disposing of planed material, which will be less than for the full-width treatment. This implies that in terms of material costs, there will be further cost savings when the wheel-track trench treatments are used in preference to the full-width treatment.

Table 10.1 Material and construction costs for binder course inlays (% difference in cost)

Type of vertical interface	*2 × 1m wheel-track# inlays (EME Class 2)*	*1 × 1m wheel-track# inlay (EME Class 2)*	*HDM 3.7m width*
Planed	-8	-49	0 (Reference condition)
Sawn	+5	-41	+4##

 # The trench inlay has been assumed to be 60mm into the binder course. The cost of a single one-metre trench has been taken as 55% of the cost of the double trench.

It is assumed that the inlay will have a saw cut on one side only.

10.1 Design considerations – general

The EME mixture was designed using a specific binder grade and aggregate type according to the French design procedure. If different ingredients are used a new design study will have to be undertaken and therefore either the French design procedure will have to be adopted in the UK or the design procedure will need to be modified for UK use. The adoption of a new material specification for high modulus binder course will require agreement between Industry and the Highways Agency.

The PTF trials have demonstrated the potential benefits of introducing an EME binder course into the UK. However, to ensure that problems do not arise with the more general introduction of high modulus materials, initially the laying and compaction of materials will require monitoring in road trials under contractual conditions.

Compliance

As current UK site compliance procedures have evolved from experience with relatively lean macadams, they are likely to be inappropriate for a rich laboratory designed material like EME. The design procedure for EME ensures, amongst other things, that it has good workability and also resistance to deformation. SHW Clause 929 takes another approach and aims to ensure good deformation resistance by controlling the air voids at the refusal density and in the permanent works. With respect to air voids, strict conformity with SHW Clause 929 is unlikely to lead to EME achieving optimum performance in the field. The compliance procedures given in this clause therefore require re-examination for use with EME.

10.2 Design considerations – thickness design

The analytical design method in the UK was initially developed by Powell *et al*. (1984), and then modified in 1997 to deal with the concept of long-life design for heavily trafficked pavements (Nunn *et al.*, 1997). The modification was made to incorporate the finding that a threshold thickness existed above which it is not necessary to build thicker pavements to achieve longer life. Recently the design method has been made more versatile to allow a wider range of materials to be introduced (Nunn, 2004) which will improve the sustainability of pavement construction and maintenance.

The elastic stiffness modulus values used for design differ from the early life values measured using the ITSM test. This is because the design value is an effective in-service modulus that includes an element of curing. Also, the ITSM loading time equates to load frequency of approximately 2.5 Hz compared to the design frequency of 5.0 Hz. The mean ITSM of 6.0 GPa measured for material extracted from the PTF trial will equate to a design stiffness of 8 GPa using the relationships that were used to determine the end performance stiffnesses and design curves in Clause 944 of the SHW.

To investigate the consistency of results of the present investigation with those of previous work, a relationship between ITSM, penetration of recovered binder and binder content (percentage by mass) derived by Nunn and Smith (1997) has been used.

$$Log_{10}\left(S_m\right) = 1.86 - 0.0138P - 0.144B \qquad (10.1)$$

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

The results of ITSM testing in the present investigation are plotted against curves derived from Equation 10.1 in Figure 10.1. This figure shows that the measured results agree well with the relationship derived from previous test results and provides more confidence in the results of the investigation.

The recently developed 'more versatile' analytical design method (Nunn, 2004) allows foundation classes of different strengths and stiffnesses to be used. The foundation stiffness classes are defined in terms of the equivalent half-space stiffness of the composite foundation. The following four divisions are proposed for design:

- Class 1 ≥ 50 MPa
- Class 2 ≥ 100 MPa
- Class 3 ≥ 200 MPa
- Class 4 ≥ 400 MPa

The standard UK foundation (equivalent to 225 mm of Type 1 subbase on a subgrade with a CBR of 5%) will

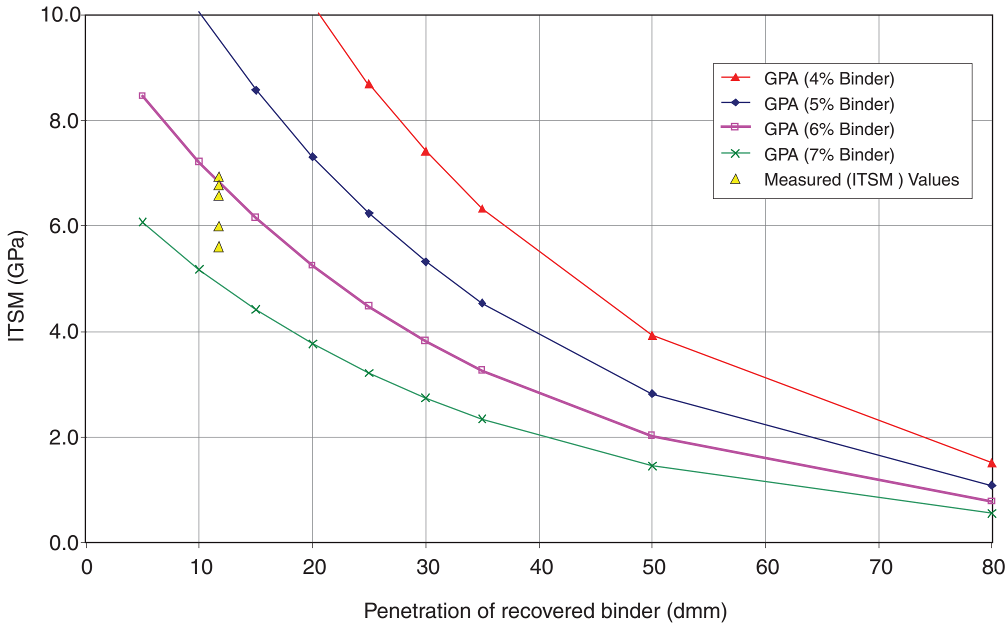

Figure 10.1 Comparison of theoretical and measured values of stiffness

correspond to Class 2. The Class 1 construction platform is applicable to construction on a capping layer and Class 3 and 4 foundations will involve bound subbases.

The design criterion for fully flexible pavements, to achieve a design life of N msa for a permissible level of tensile strain (e_r) induced by a standard wheel load at the underside of the base layer is given in Equation 10.2 in the more versatile approach.

$$N/10^6 = \left(\varepsilon_r / \left(K_{Flex} . K_{Safety} 201 \times 10^{-6}\right)\right)^{4.16} \qquad (10.2)$$

The constant, K_{Flex} will depend upon the design stiffness (E) of the asphalt base and the following relationship gives a good estimate of K_{Flex}:

$$K_{Flex} = 1.089 \times E^{-0.172} \qquad (10.3)$$

The use of this criterion will ensure that pavements with stiff asphalt bases do not flex as much as pavements with a less stiff asphalt base. Equation 10.3 results in the values of K_{Flex} given in Table 10.2 and these can be used to calculate design thicknesses with a reasonable trade off between a stiffer foundation and a reduction in asphalt thickness.

Figure 10.2 shows the design curves for EME using the versatile design criterion for a Foundation Class 2 (equivalent to 225 mm of Type 1 subbase and a 5% CBR subgrade) and assuming a design stiffness modulus of 8 GPa. The design curves are compared with that of a standard HDM material. These designs assume that the road contains 30 mm of thin surface course. The long-life designs are given in Table 10.3 rounded up to the next 5 mm.

Table 10.2 Values of K_{Flex}

Material	*Design stiffness(GPa)*	*K_{Flex}*
HDM	6.2	0.796
EME Class 2	8.0	0.752

Table 10.3 Long-life designs (80msa) for EME

Binder course (60mm thick)	*Base material type*	*Combined asphalt thickness in mm (including 30 mm of thin surface course)*
HDM	HDM	320
EME Class 2	HDM	315
EME Class 2	EME Class 2	295

The calculations predict that the thickness of asphalt could be reduced by up to 25 mm using a mixture similar to that used in the PTF trial. This is a significant reduction in thickness over conventional materials and may be particularly useful where overhead clearance requirements prevent the design thickness of conventional asphalt materials being used. Similarly, a reduced asphalt thickness over structures may be beneficial, or where heights of kerbs and thresholds need to be maintained.

11 Conclusions

- An investigation into the engineering properties of a 'new' high modulus material in the UK has been carried out in the laboratory and in the TRL-PTF. This new material was EME Class 2 and was designed using the approach developed by LCPC in France. The material is intended for use as a high quality pavement layer for both new construction and maintenance treatments.
- Compared to conventional HDM binder course material, EME Class 2 has been shown to be deformation resistant, and its high binder content helps ensure that it is durable and impermeable to water. Furthermore, its load spreading ability is superior to HDM. These attributes make it an ideal component in the construction and maintenance of durable modern, high performance heavily trafficked flexible pavements.

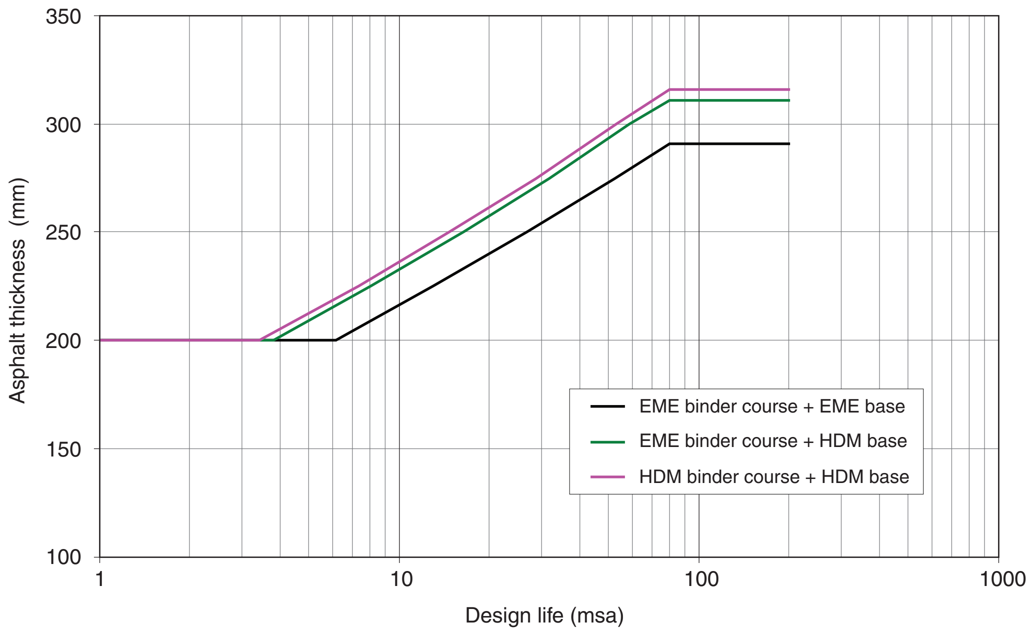

Figure 10.2 A comparison of design curves for EME and HDM with Foundation Class 2

- Density measurements have shown that the EME Class 2 material can be very well compacted in the mat and as a trench inlay using conventional equipment.
- In new pavements, construction thicknesses can be maintained with more assurance of achieving the same structural design life as that of a pavement constructed using HDM. The thick binder film and impermeability of EME will also help ensure that the pavement is waterproof and at less risk of any problems caused by the ingress of water.
- The trials have demonstrated that a full lane inlay or a longitudinal trench inlay of EME binder course covered by a thin surfacing is an effective maintenance treatment to remedy surface rutting or cracking in long-life pavements. The richer material with a finer grading makes it more user-friendly and the trials have demonstrated that excellent compaction can be achieved adjacent to a longitudinal joint.
- The use of EME should result in more sustainable flexible pavement construction: in the maintenance situation material savings can be achieved using a trench inlay in the wheel-track, and in both new construction and maintenance the impermeable binder course will be more durable and long-lasting and protect the underlying pavement structure.
- The economic, environmental and sustainability benefits of the innovative binder course have been provisionally assessed. To be economically employed, whole-life costs should be considered to ensure that the optimal maintenance strategy is used.
- A 60 mm binder course inlay has been shown to be a viable maintenance option for surface deterioration (top-down cracking and rutting). Both EME Class 2 and HDM binder courses have excellent resistance to rutting, with EME Class 2 showing better overall qualities.
- Analytical pavement design indicates that the use of EME Class 2 material (with properties similar to those measured in the trials) could result in the bound layer thicknesses being reduced by around 25 mm for a predicted life of 80 msa compared with HDM.
- A new specification for high modulus material, similar to EME, tailored to suit UK conditions has been developed jointly by the HA and UK industry. This is given in Appendix B.
- The trials described in this report relate an EME material design according to French procedures. The results of this trial may not be typical and cannot be generalised. The properties of a wider range of EME materials involving different ingredients and laid under a variety of contractual conditions need to be evaluated to establish generally applicable properties.

12 Acknowledgements

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The project was led by a steering committee with the following membership:

Mike Head	TRL Limited (Chairman from 2004)
Les Hawker	Highways Agency
John Williams	Highways Agency
Ramesh Sinhal	Highways Agency
Maurice White	Quarry Products Association
Tony Harrison	Refined Bitumen Association
Colin Loveday	Tarmac Ltd
David Williams	Lafarge Aggregates
Chris Rayner	Esso Bitumen
Chris Southwell	Nynas Bitumen
Tony Parry	TRL Limited
Mike Nunn	TRL Limited
Bob Collis	TRL Limited
Paul Sanders	TRL Limited
Darren Merrill	TRL Limited

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Appendix A: Test details

A.1 Materials used in the construction of the trials

A.1.1 Foundation

Details of the foundation used in the TRL-PTF for the FORMAT project are given in Table A.1.

Table A.1 Foundation materials used in TRL-PTF test pavements

Pavement layer	*Material type*	*Specification*
Subbase	Granular Type 1	Specification for Highway Works (SHW)
Subgrade	London Clay	CH (Casagrande Classification: HMSO, 1952)

A.1.1.1 Subgrade

The subgrade strength was determined using a Mexicone penetrometer at 1 m intervals along the subgrade in the direction of the loading wheel. Five separate lines were surveyed in order to cover the area on which the test pavements were built. The results are given in Figure A.1 and they show that the bearing capacity of the subgrade is consistent at between 3.0 and 3.5% CBR over the test area.

A.1.1.2 Subbase

The granular Type 1 subbase was laid and compacted with a grading as given in Figure A.2.

A set of optical level measurements was made on the surface of the subgrade over a grid at 0.5 m spacing to cover the area to be used in the trial. These measurements were repeated on the surface of the compacted subbase and the thickness of the subbase was determined by subtraction. Table A.2 gives the results of these measurements.

After compaction of the subbase FWD measurements were made at 0.5 m intervals along the two wheel-tracks of the wheel load. Wheel-track 1 is in the full-width inlay and wheel-track 2 is in the wheel-track inlay. Two loads were applied through the FWD loading plate to investigate the non-linear elastic response of the granular foundation. Figure A.3 shows that the foundation stiffness was broadly uniform with a surface stiffness of between 80 MPa and 110 MPa along the test lines. This level of stiffness is considered to be satisfactory for a foundation under a heavily trafficked road in the UK. The graphs show that the foundation stiffness decreases slightly with applied load.

A.1.2 Asphalt layers

Details of the asphalt layers are given in Table A.3.

The thin surfacing used in this study is a proprietary material manufactured and applied by Tarmac Ltd. It comprises of a penetration grade bitumen binder, cellulose fibres, limestone filler and graded coarse and fine aggregates. It is supplied in three gradings; 14 mm, 10 mm and 6 mm depending on the class of road where it is being used. For this trial, where the pavement is of motorway construction standard, the 14 mm option has been used to ensure that the required texture depth is attained. Because the surfacing material is a proprietary system, details of its constituent parts are not reported. The material has been subjected to performance testing by the UK Highways Agency and has the HAPAS certificate number 01/H052 which permits its use on UK motorways and trunk roads.

Table A4 gives the aggregate grading of the base course and binder course materials used in the trial.

Information about the binder used in the base course and binder course materials is given in Table A.5.

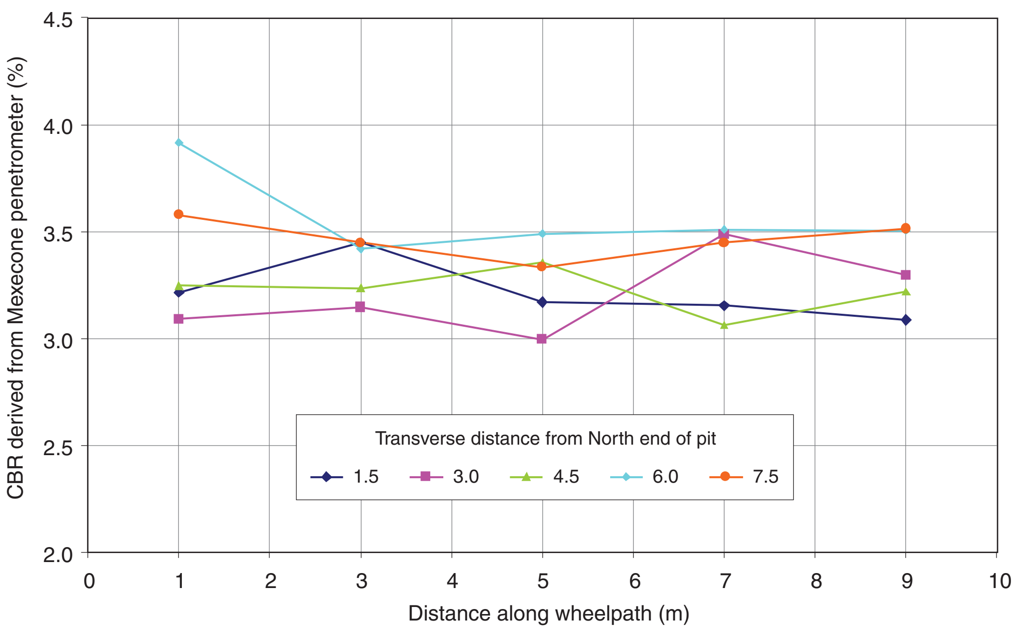

Figure A.1 Subgrade strength from Mexecone penetrometer testing

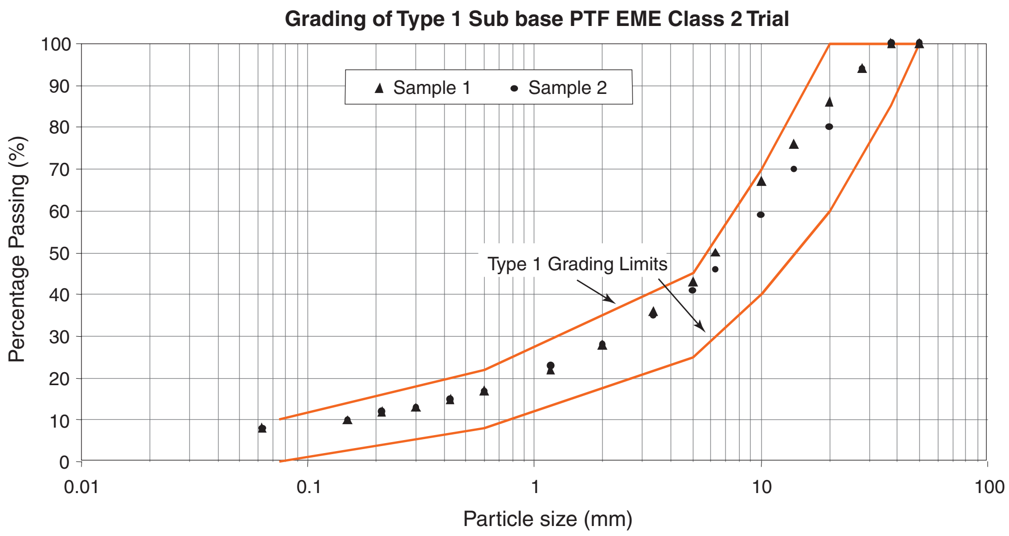

Figure A.2 Grading of subbase

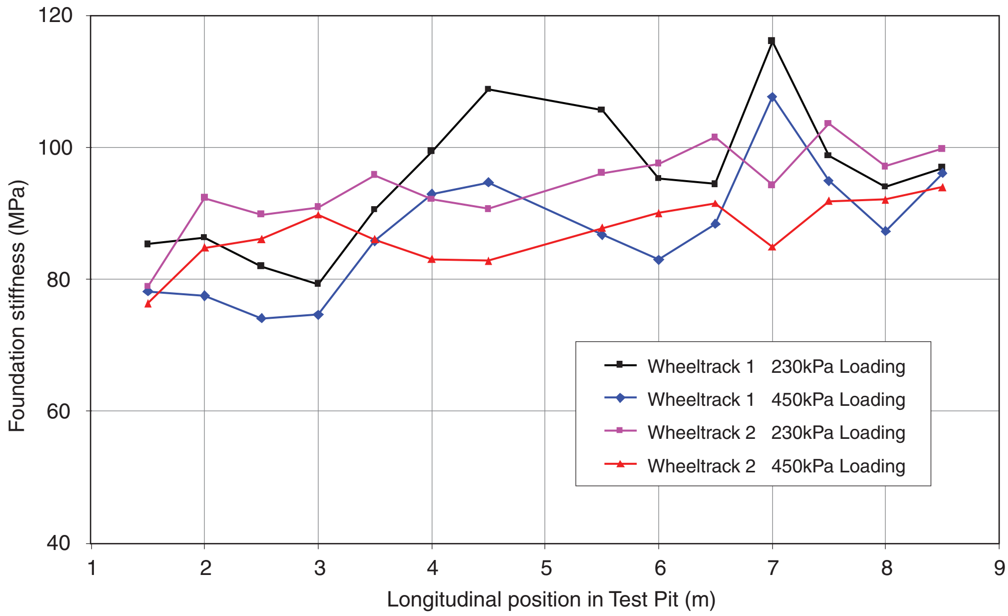

Figure A.3 PTF foundation stiffness derived from FWD deflections (before asphalt was placed)

Table A.2 Thickness of subbase layer

	Thickness of subbase layer (mm)	
Property	*Wheel-track 1*	*Wheel-track 2*
Maximum	459	446
Minimum	413	407
Average	438	430

Table A.3 Asphalt layers used in TRL-PTF test pavements

Pavement layer	*Material type*	*Specification*
Surface course	14 mm SMA thin surface course	HAPAS certificate 01/H052
Binder course	EME Class 2	Norme Francais. NF-P-98-140 (AFNOR 1999)
Binder course	20 mm HDM	BS 4987 (2003)
Base	28 mm HDM	BS 4987 (2003)

Table A.4 Aggregate grading of base course and surfacing materials (BS 4987, 2003)

Aggregate grading	*28 mm HDM base course*	*20 mm HDM binder course*	*EME Class 2 binder course*	*Thin surface course*
Sieve size (mm)	*Percent passing*	*Percent passing*	*Percent passing*	*Percent passing*
37.5	100	100	100	–
28	90-100	100	100	–
20	71-95	97	98	–
14	58-82	80	82	100
10	–	63	74	53
6.3	44-60	50	60	29
5	–	–	55	27
4	–	–	47	–
3.35	32-46	40	39	26
2	–	–	35	24
1.18	–	–	26	22
1	–	–	24	–
0.6	–	–	19	19
0.425	–	–	17	–
0.315	–	–	16	–
0.3	7-21	18	15	15
0.212	–	–	13	13
0.150	–	–	11	12
0.075	7-11	10.7	–	10.3

Table A.5 Binders used in the asphalt layers

Material	*28 mm HDM base*	*20 mm HDM binder course*	*EME Class 2 – Full width inlay*	*EME Class 2 – Wheel -track inlay*	*Thin surface course*
Binder grade	40/60	40/60	15/25	15/25	n/a
Binder content (% by mass)	3.8	4.4	6.0	5.8	5.6

A.2 Laboratory testing of asphalt materials

Three sizes of cores were extracted from the test pavements for the purposes of conducting laboratory tests on the binder course materials. The cores were extracted after the thin surfacing course was laid. These cores were used to investigate the degree of compaction achieved at the edges of the inlay. For determining indirect tensile stiffness modulus, 150 mm diameter cores were extracted and 200 mm diameter were extracted for wheel-tracking tests. These were taken from areas that would not be trafficked by the loaded wheel. The locations from where the cores were extracted are shown in Figure A.4.

A.2.1 Density

During construction, density measurements were made using a Troxler nuclear density gauge on the surface of the base and the binder course layers. Eight measurements were made along the centre line of each wheel-track. In addition, cores were extracted from between wheel-tracks 1 and 2 for general density measurements and from across the edges of the wheel-track inlays to investigate the compaction achieved up to the edge. Table A.6 gives the density of the binder course and base course measured using the Troxler gauge and on the surface course determined from cores. The density values for each binder

Table A.6 Overall average density of each layer

Layer *Material*	*Density (mg/ m³) Wheel-track 1*	*Density (mg/ m³) Wheel-track 2*	*Scanner density (mg/ m³) between wheel-tracks (from cores)*
Surface course			
SMA	2.276	2.258	2.282
Binder course			
EME Class 2	2.450	2.420	2.484
Binder course			
20 mm HDM	2.425	–	2.546
Base			
28 mm HDM	2.403	2.447	2.477

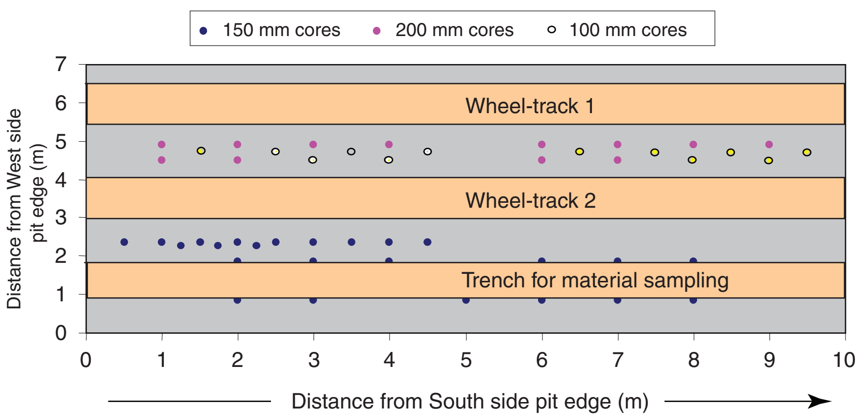

Figure A.4 Core positions for material sampling course were averaged from four readings. Table A.6 also shows the average density values obtained from the cores taken from between the wheel-tracks and measured using a nuclear core scanner. Plots of the nuclear core scanner readings are given in Figures B.5 to B.7.

Table A.6 shows that the values determined from the cores are slightly higher than those measured *in situ* using the nuclear density gauge.

A.2.2 Density at the interface of wheel-track inlay and original binder course

The density measurements made on cores extracted from across the vertical joints at the edges of the inlays is discussed in section 8.4 of this report and is highly relevant to the construction and performance of the wheel-track inlay treatment.

A.2.3 Indirect tensile stiffness modulus

The Indirect Tensile Stiffness Modulus (ITSM) test is used to measure the stiffness of a cylindrical asphalt specimen of diameter 100 mm, 150 mm or 200 mm and with a thickness of between 30 mm and 75 mm. The sample is placed so a vertical load with a rise time of 124 ms is applied vertically across a diameter and the resultant deflection is measured in the horizontal direction. The stiffness of the mixture is then derived from the load-deflection relationships. A detailed description of the test is given in DD 213 (BSI 1996). The ITSM results are given in Table A.7.

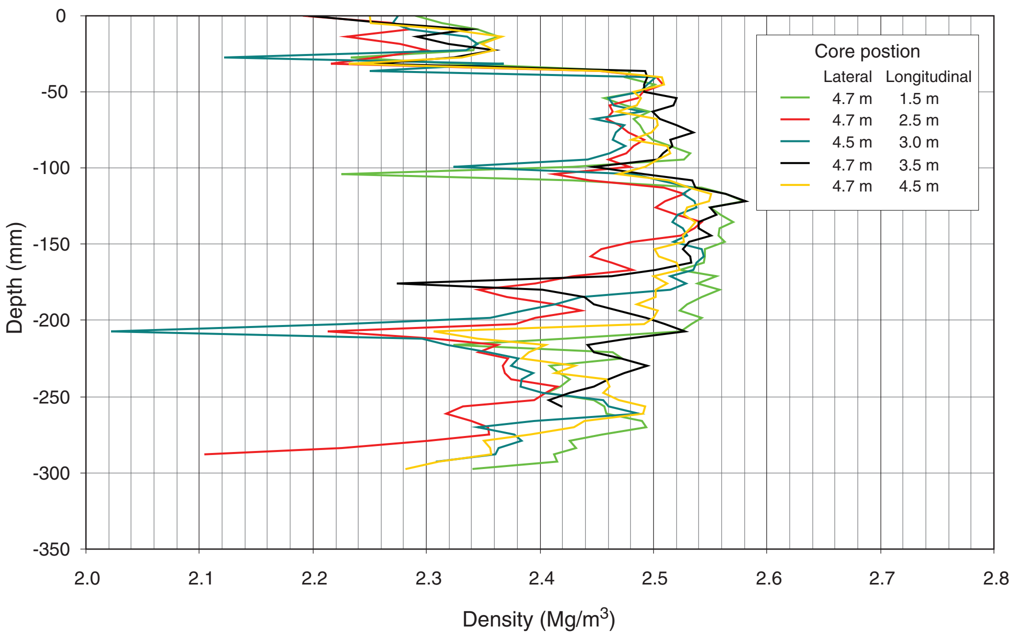

Figure A.5 Density profile of cores from the untrafficked EME Class 2 section

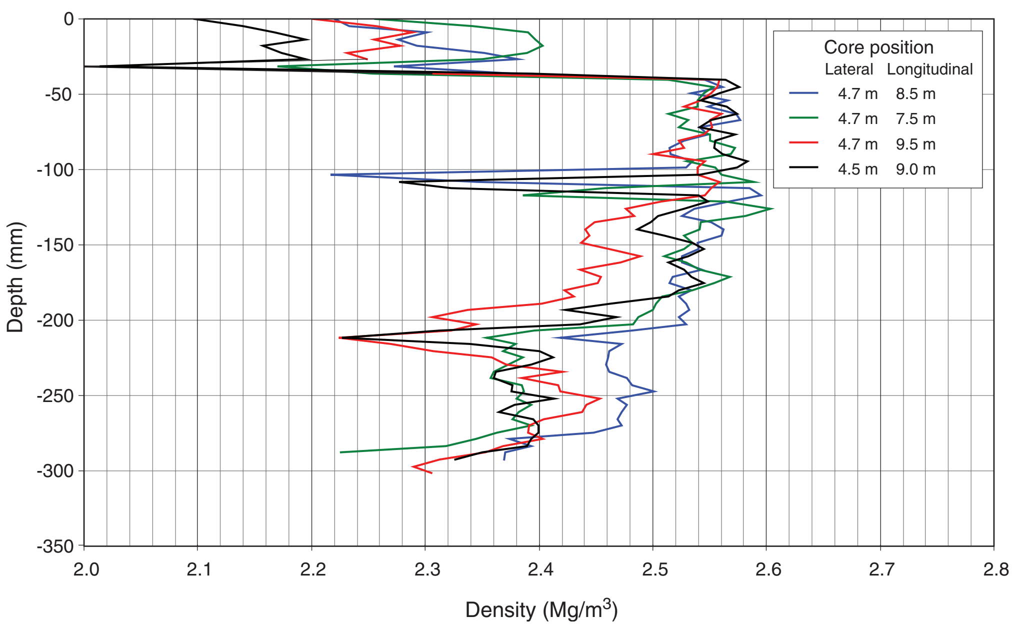

Figure A.6 Density profile of cores from the untrafficked HDM section

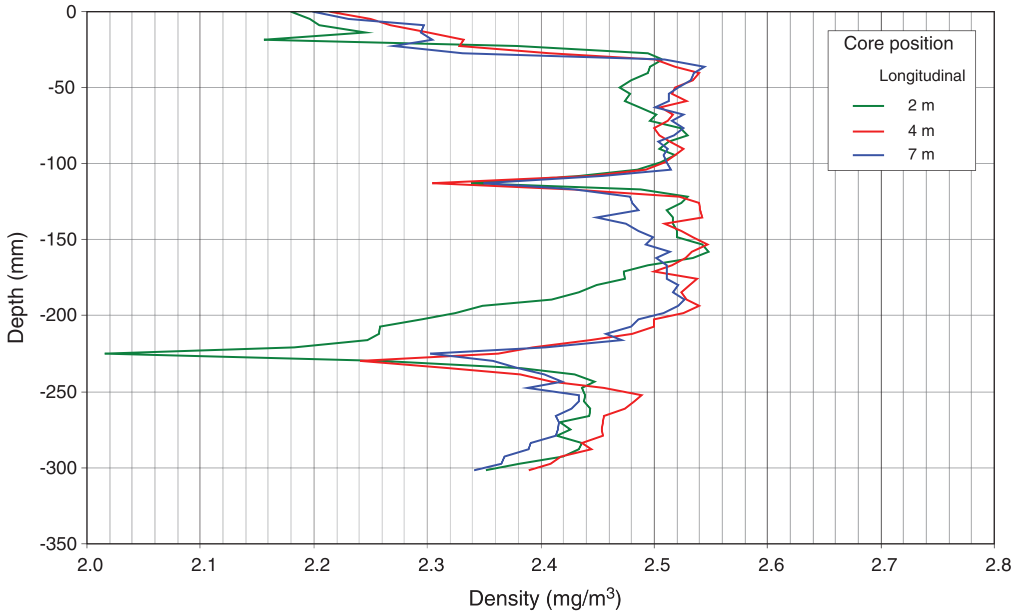

Figure A.7 Density profile of cores from the untrafficked trench inlay of EME Class 2

Table A.7 Indirect tensile stiffness modulus results

Material	*Position across test section (m)*	*Stiffness (ITSM) (GPa)*
Cores taken between wheel-tracks		
EME Class 2 binder course	1.3	6.58
	2.5	6.93
	3	5.61
	3.5	6.78
	4	6.00
	Mean (standard deviation)	6.38 (0.54)
HDM binder course	6.5	6.77
	7.5	6.56
	8	3.99
	8.5	5.17
	9	5.90
	9.5	5.73
	Mean (standard deviation)	6.02 (0.58)
HDM upper base layer	2.5	5.46
	3.5	7.11
	4	6.84
	4.5	5.28
	6.5	4.84
	8	4.54
	Mean (standard deviation)	5.68 (1.06)
HDM lower base layer	2.5	3.62
	3.5	5.11
	4	4.30
	4.5	2.88
	6.5	4.23
	8	3.38
	Mean (standard deviation)	3.92 (0.79)

ITSM test results from twenty three 100 mm diameter cores taken from between the wheel-tracks of the binder course and base layers are given in Table A.7.

A.2.4 Wheel-tracking testing

Ten 200 mm diameter cores were extracted from between wheel-tracks 1 and 2 (Figure A.4) for wheel-tracking testing of the two binder courses. Five samples from each binder course were prepared by sawing from the full depth core. The tests were conducted according to the British Standard (BS598, 1998) in a temperature controlled environment of 45°C. The results from the individual samples are given in Figure 8.12 of the main report.

The rate of rutting from the samples was quite variable although it was generally low in absolute value. The maximum rut depth during the test was only exceeded by one sample (HDM). Overall, on average the rate of rutting of the EME Class 2 was less than that of the HDM but the range of the results was fairly wide. It should be borne in mind that the innovative material EME Class 2 used in the wheel-track inlay was compared with a HDM binder course that is already superior to other materials used in major road construction.

Wheel-tracking testing can also be carried out at a controlled temperature of 60ºC. A comparison of the test results at both temperatures on the same material gives a measure of its temperature susceptibility in relation to its resistance to rutting. Wheel-tracking tests were conducted on the EME Class 2 binder course samples at 60ºC and the results are shown in Figure A.8. These results show that as regards the rate of rutting, the EME Class 2 binder course has a low susceptibility to temperature.

A.2.5 Moisture susceptibility testing

The results of the moisture susceptibility tests for the individual samples are given in Tables A.8 and A.9 and Figure A.9.

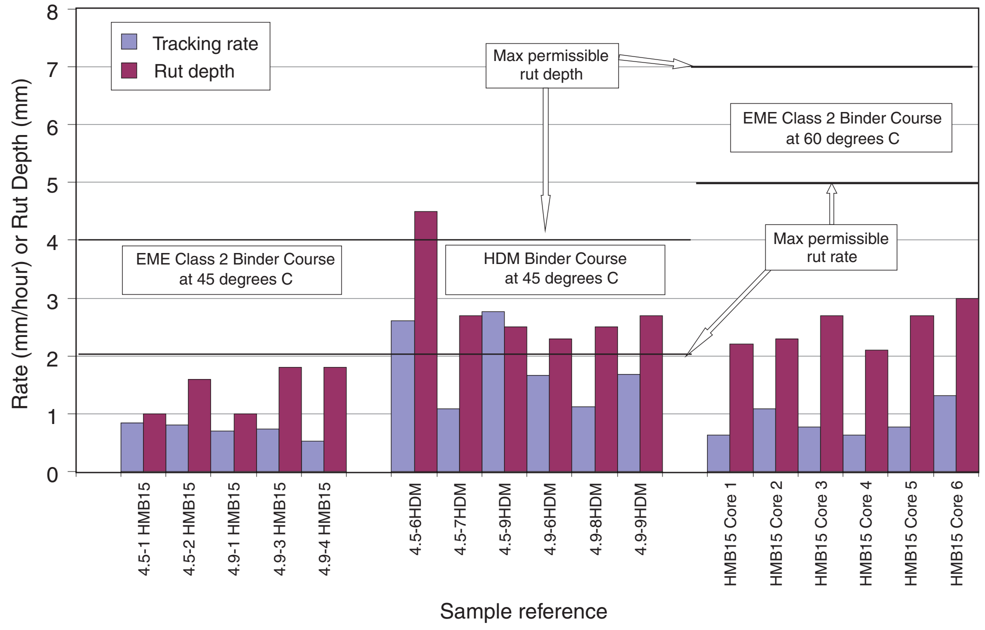

Figure A.8 Wheel-tracking test results of HDM and EME Class 2

Table A.8 Moisture susceptibility (ITSM versus time)

Time (days)	*Core No.* 19	20	21	22	23	24
0	6.407	6.638	5.882	7.074	6.807	6.321
1	6.539	7.135	6.67	7.323	7.248	7.523
10	6.583	7.165	6.787	7.579	7.603	7.883
25	6.865	7.382	6.804	7.585	7.503	7.866
50	6.949	7.314	6.876	7.343	7.558	8.02

Table A.9 Moisture susceptibility (percentage change in ITSM over time)

Time (days)	*Core* 19	20	21	22	23	24	*Average*	*Max*	*Min*
0	0	0	0	0	0	0	0	0	0
1	2.1	7.5	13.4	3.5	6.5	19.0	8.7	19.0	2.1
10	2.7	7.9	15.4	7.1	11.7	24.7	11.6	24.7	2.7
25	7.1	11.2	15.7	7.2	10.2	24.4	12.7	24.4	7.1
50	8.5	10.2	16.9	3.8	11.0	26.9	12.9	26.9	3.8

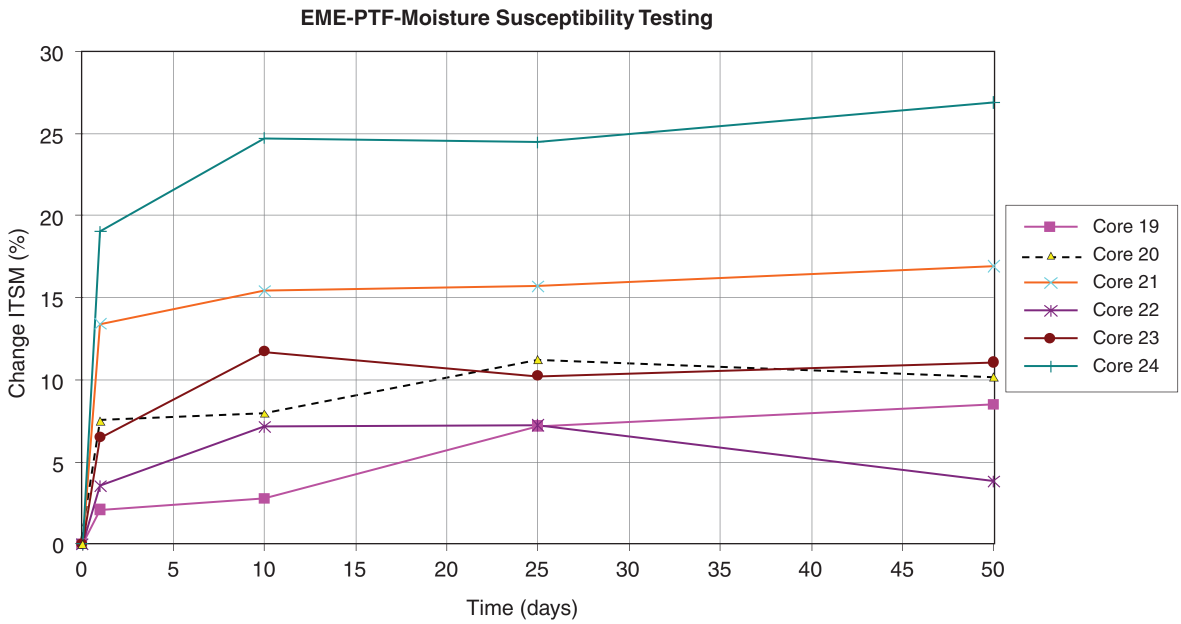

Figure A.9 Moisture susceptibility test results

A.3 Non destructive testing of test pavements

A.3.1 Stiffness derived from FWD tests

The stiffness values of the bound layers and the foundation were derived from FWD testing carried out along each wheel-track on the surface of the completed pavements before the pavements were loaded in the PTF. The results are given in Figure A.10.

The values of back-calculated stiffness for the foundation appear reasonable, but the stiffness for the bound layers incorporating the trench inlay is less than that for the full width inlay. It is possible that the presence of the wheel-track inlay may be responsible as the vertical interfaces at the edges of the inlay could introduce discontinuities in the area of the deflection bowl. Similar reductions have been noted elsewhere when the FWD has been used close to road edge reinstatements.

A.3.2 Surface texture measurements

Measurements of surface texture were made using the Sand Patch Test (BSI, 1998). In this test, texture depth is derived from measurements of the diameter of a circular 'patch' of sand formed with a measured volume of sand which is used to fill in spaces between surface aggregate.

The texture depth at nine positions along each wheel-track was measured before and after trafficking at 1m intervals. These results, which are given in Tables A.10 and A.11, show that the texture level is typical of that expected for newly laid material on a UK trunk road and it remained relatively unchanged after trafficking.

Table A.10 Texture depth results for wheel-track 1 (from sand patch testing)

	Texture depth (mm)	
Position (m from east pit edge)	*Before trafficking*	*After trafficking*
1	2.00	1.70
2	1.52	1.65
3	1.51	1.69
4	1.11	1.20
6	1.60	1.56
7	1.48	1.62
8	1.45	1.46
9	1.52	1.54
Average	1.52	1.55

Table A.11 Texture depth results for wheel-track 2 (from sand patch testing)

	Texture depth (mm)	
Position (m from east pit edge)	*Before trafficking*	*After trafficking*
1	1.86	1.77
2	1.51	1.64
3	1.71	1.89
4	1.76	1.86
6	1.95	1.90
7	1.71	1.91
8	1.67	1.75
9	1.93	1.83
Average	1.76	1.82

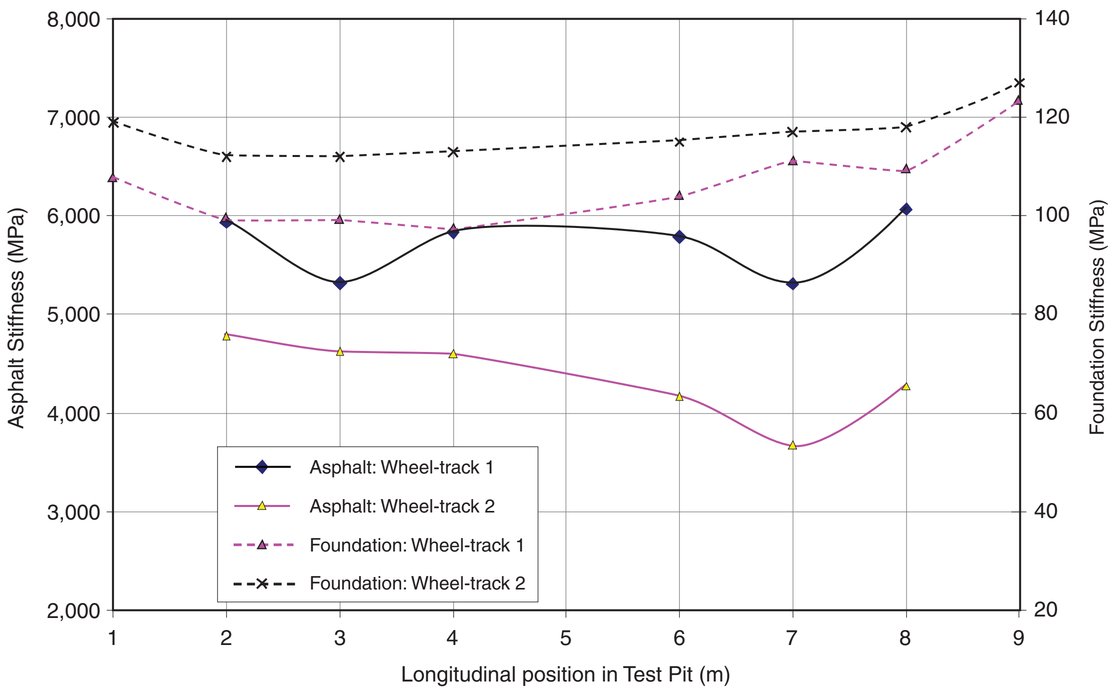

Figure A.10 Stiffness of the bound layers and the foundation derived from FWD measurements

A.3.3 Skid resistance measurements using the Portable Skid Resistance Tester-PSRT

The Portable Skid Resistance Tester is a device used to measure the frictional resistance between a rubber slider (mounted on the end of a pendulum) and the road surface. Details of the use of the apparatus are given in BS EN 13036-4 (2003). The PSRT was used on nine positions spaced at 1m intervals along the two trafficked wheel-tracks before and after trafficking. The skid resistance values for the wheel-tracks are given in Tables A.12 and A.13. Clearly, before trafficking the Skid Resistance Values (SRVs) should be the same all over the pavement surface and indeed the average SRV along both wheel-tracks is the same.

As a result of the accelerated loading, values of skid resistance measured by the PSRT were reduced by 24% in Wheel-track 1 and by 19% in Wheel-track 2. This is thought to be due to the effects of the raised temperature (40°C) leading to the surface course being smoothed by the action of the wheel, and is considered unlikely to be typical of in-service conditions.

Table A.12 Skid Resistance Values (SRV) for wheel-track 1 (from the pendulum test)

	SRV	
Position (m from east pit edge)	*Before trafficking*	*After trafficking*
1	82	54
2	84	65
3	79	59
4	85	64
6	83	64
7	75	62
8	82	59
9	82	69
Average	82	62

Table A.13 Skid Resistance Values (SRV) for wheel-track 2 (from the pendulum test)

	SRV	
Position (m from east pit edge)	*Before trafficking*	*After trafficking*
1	81	64
2	83	69
3	91	66
4	84	84
6	79	62
7	79	64
8	79	61
9	83	63
Average	82	67

A.4 References

l'Association Français de Normalisation (AFNOR). Paris, La Défense.

Norme Français NF-P-98-140 (1999). *Couches d'assise: Enrobés module élevé.*

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BSI Draft for Development BS DD 213 (1996). *Method for the determination of the Indirect Tensile Stiffness Modulus of bituminous mixtures.*

BSI BS598 (1998). *Sampling and examination of bituminous mixtures for roads and other paved areas: Part 105 - Methods of test for the determination of texture depth.*

BSI BS598 (1998). *Sampling and examination of bituminous mixtures for roads and other paved areas. Part 110: Methods of test for the determination of wheel tracking rate.*

BSI BS4987 (2003). *Coated macadam (asphalt concrete) for roads and other paved areas: Part 1. Table 15. Specification for constituent materials and for mixtures*.

BSI BS EN 13036-4 (2003). *Road and airfield surface characteristics. Test methods. Method for measurement of slip/skid resistance of a surface. The pendulum test.*

HAPAS. HAPAS Certificate No. 01/H052: *Masterpave thin surfacing system for highways.* Watford: British Board of Agrément.

HMSO (1952). *Soil mechanics for road engineers.* London: The Stationery Office.

Manual of Contract Documents for Highway Works (MCHW). Specification for Highway Works. London: The Stationery Office.

Volume 1 Series 800: *Road Pavements - Unbound, Hydraulically Bound. and Other Materials*

Appendix B: UK Specification for EME mixtures for use in base and binder course

Foreword

This specification is intended to be used on pilot contracts on the trunk road network and will be subject to ongoing amendment to reflect current French practice. When finalised, it is intended that it will be published in the Specification for Highway Works.

This draft specification covers the formulation, mixing, laying and compaction of bituminous mixtures for base and binder course layers incorporating hard grade binders. The designation 'EME' is from the French ' Enrobé à Module Élevé ' (High Modulus Coated), and this acronym is being retained in UK to differentiate these mixtures from the traditional UK High Modulus Base (HMB) materials which have much lower binder contents.

In France, there are two designations of EME: EME 1 and EME 2. This UK specification is based on EME 2, which requires significantly higher binder contents than EME 1. The intention is to provide an essentially impermeable and durable base and binder course material with excellent load spreading and deformation resistant properties.

This is achieved by the use of a carefully controlled aggregate grading in conjunction with a hard grade of binder. This binder is normally a 10/20 or 15/25 hard paving grade, but, as in France, there is provision for the use of 'special' or modified grades of bitumen. A specification for the bitumen is included as an Annex. This specification is intended to replicate those hard grade binders which have proved successful in EME mixes in France.

The specification has taken the requirements of the French EME specification : NF P98-140 'Couches d'assises: enrobés à module élevé (EME) and it's backing general application specification : NF P98-150 'Exécution des corps de chausses, couches de liaison et couches de roulement' and translated them as closely as possible into a format similar to BS 4987, which should be more readily understood by users in the UK. The intention is for this specification to be technically identical to the French specification.

It uses the French requirements for gyratory compaction, void content, water sensitivity and deformation resistance unchanged. This will require access to French asphalt test equipment for implementation. For dynamic stiffness, the French methods were considered rather complex and slow and use has been made of the UK ITSM method. The specification leaves open an option to use the French method for fatigue resistance, but, as this is again complex and slow, suggests that the high binder content of the EME should give confidence without the need to test.

The standard includes a requirement for a Job Mixture Verification Trial. This is based on the French principle of a 'planche de vérification' and is used to confirm both the properties of the material and the suitability of compaction equipment. These are not intended for application on all contracts but should be transferable, as with SHW clause 929 trial data.

For laying and compaction, the specification is based on BS 594 Part 2, modified where necessary to match the French requirements. BS 594 was considered more appropriate than BS 4987 as it deals exclusively with hot materials. The choice of suitable rollers is based on the current French LCPC guidance; 'Compactage des enrobes hydrocarbonés à chaud '. This includes a system for classification of rollers based on type, weight and vibrating characteristics. This system and guidance appears appropriate for adoption in respect of EME in the UK.

Annex A includes requirements for hard grade binders. This is based on the draft European Specification prEN 13924 for hard grade bitumens. It is further based on the French selection of properties from prEN 13924 with certain additional safeguards for use in UK conditions.

Annex B describes the method for determination of the 'Richness Modulus' of an asphalt mixture.

B.1 Scope

This standard specifies the requirements for EME mixtures for use as base and binder course. These are high modulus asphalt mixtures incorporating hard grade binders.

B.2 Normative references

BS 594 Part 1– *Hot rolled asphalt for roads and other paved areas. Specification for constituent materials and asphalt mixtures.*

BS 594 Part 2 – *Hot rolled asphalt for roads and other paved areas. Specification for transport, laying and compaction of hot rolled asphalt.*

BS 598 – *Sampling and examination of bituminous mixtures for roads and other paved areas.*

BS EN 58 – *Bitumen and bituminous binders. Sampling bituminous binders.*

BS EN 197-1 – *Cement. Composition, specifications and conformity criteria for common cements.*

BS EN 1426:2000, BS 2000-49:2000 – *Methods of tests for petroleum and its products. Bitumen and bituminous binders. Determination of needle penetration.*

BS EN 1427:2000, BS 2000-58:2000 – *Methods of test for petroleum and its products. Bitumen and bituminous binders. Determination of softening point. Ring and ball method.*

BS EN 12591 – *Bitumen and bituminous binders. Specifications for paving grade bitumens.*

BS EN 12592:2000, BS 2000-47:2000 – *Methods of test for petroleum and its products. Bitumen and bituminous binders. Determination of solubility.*

BS EN 12593:2000, BS 2000-80:2000 – *Methods of test for petroleum and its products. Bitumen and bituminous binders. Determination of the Fraass breaking point.*

BS EN 12595:2000, BS 2000-319:2000 – *Methods of test for petroleum and its products. Bitumen and bituminous binders. Determination of kinematic viscosity.*

BS EN 12607-1:2000, BS 2000-460.1:2000 – *Methods of test for petroleum and its products. Bitumen and bitumenous binders. Determination of the resistance to hardening under the influence of heat and air. RTFOT method.*

BS EN 12697-5 – *Bituminous mixtures. Test methods for hot mix asphalt. Determination of the maximum density.*

BS EN 12697-6 – *Bituminous mixtures. Test methods for hot mix asphalt. Determination of bulk density of bituminous specimen.*

BS EN 12697-22 – *Bituminous mixtures. Test methods for hot mix asphalt. Wheel tracking.*

BS EN 12697-26 – *Bituminous mixtures. Test methods for hot mix asphalt. Stiffness.*

BS EN 12697-31 – *Bituminous mixtures. Test methods for hot mix asphalt. Specimen preparation by gyratory compactor.*

BS EN 12697-33 – *Bituminous mixtures. Test methods for hot mix asphalt. Specimen prepared by roller compactor.*

pr EN 12697-35 – *Bituminous mixtures. Test methods for hot mix asphalt. Part 35: Laboratory mixing.*

BS EN 13043 – *Aggregates for bituminous mixtures and surface treatments for roads, airfields and other trafficked areas.*

BS EN 13302:2003, BS 2000-505:2003 – *Methods of test for petroleum and its products. Bitumen and bituminous binders. Determination of viscosity of bitumen using a rotating spindle apparatus.*

pr EN 13924 – *Bitumen and bituminous binders. Specifications for hard paving grade bitumens.*

Specification for Highway Works. Highways Agency. London: The Stationery Office.

Sector Scheme 15 - Sector Scheme Document for The Supply of Paving Grade Bitumen. Feltham: UKAS.

DD 213: 1993 – *Method for determination of the indirect tensile stiffness modulus of bituminous mixtures.*

NF P98-140 – *Couches d'assises: enrobés à module élevé (EME) (AFNOR).*

NF P98-150 – *Exécution des corps de chausses, couches de liaison et couches de roulement* (AFNOR).

NF-P98 251-1 – *Essais relatifs aux chaussées –Essai Duriez sur mélanges hydrocarbonés à chaud* (AFNOR).

NF P98 261-1 – *Essais relatifs aux chausses-Détermination de la résistance de fatigue des mélanges hydrocarbons-Partie 1: essai de fatigue par flexion à amplitude de fleche constant.* (AFNOR).

B.3 Constituent materials

B.3.1 Binder

The binder for use in EME base/binder course asphalt mixtures shall be either 10/20 grade or 15/25 grade bitumen in accordance with prEN 13924 as elaborated in Annex A of this specification.

Alternatively, a modified binder may be used subject to agreement of the client/overseeing organisation.

B.3.2 Coarse aggregate

B.3.2.1 Type of coarse aggregate

The coarse aggregate shall be material substantially retained on a 2 mm sieve and shall conform to all appropriate requirements of BS EN 13043 and shall consist of either crushed rock or steel slag.

B.3.2.2 Particle shape

Flakiness category shall be FI_{30} in accordance with BS EN 13043 Clause 4.1.6.

B.3.2.3 Resistance to fragmentation

The resistance to fragmentation shall be category LA_{30} in accordance with BS EN 13043 Clause 4.2.2

NOTE: Aggregates with Los Angeles values above 30 but not greater than 35 may be used where there is a history of satisfactory use in asphalt base and binder courses.

B.3.2.4 Resistance to freezing and thawing

The resistance to freezing and thawing shall be Magnesium Sulfate Soundness category MS_{25} in accordance with BS EN 13043 Clause 4.2.9.2.

B.3.2.5 Fines content

The fines content of the coarse aggregate shall be $f_{NR.}$ in accordance with BS EN 13043 Clause 4.1.4.

B.3.3 Fine aggregate

B.3.3.1 Type of fine aggregate

The fine aggregate shall substantially pass a 2 mm sieve and shall be one of the following types:

- Material produced by crushing aggregate of the types described in 3.2.1.
- Sand.
- A mixture of the two above.

B.3.3.2 Fines content

The fines content shall be:

$$\left.\begin{array}{l}\text{For crushed rock/slag } f_{NR}\\ \text{For sand } f_{10}\end{array}\right\}\begin{array}{l}\text{in accordance}\\ \text{with BS EN 13043}\\ \text{Clause 4.1.4}\end{array}$$

B.3.4 Added filler

Added filler shall be limestone complying with BS EN 13043 or cement complying with BS EN 1971. The grading of added filler shall comply with BS EN 13043:2002 Clause 5.2.1.

The loose bulk density of added filler shall be in accordance with BS EN 13043:2002 Clause 5.5.5.

The stiffening properties of the added filler in accordance with BS EN 13043 Clause 5.3.3.2 shall be category ΔR&B 8/16.

NOTE: Fillers with Delta Ring and Ball values above 16 but not greater than 20 may be used where there is a history of satisfactory use in asphalt.

B.4 Composition of mixtures

B.4.1 General

The composition of the mixture shall be declared as a target grading and target binder content. The mixture shall be designed so that, at the target composition, it conforms to the relevant requirements from clauses 4.2 to 4.8 of this specification.

The binder content and grading of the freshly-mixed coated material, when sampled and tested in accordance with clause 6.3, shall conform to the binder content and aggregate grading limits obtained by applying the tolerances stated in Table 3 to the target binder content and target grading.

B.4.2 Designation and grading

EME shall be designated as EME 0/10, EME 0/14 or EME 0/20 according to aggregate size. The target grading should fall within the appropriate limits stated in Table B1.

B.4.3 Binder content

At the target binder content the Richness Modulus K, determined in accordance with Annex B shall be greater than or equal to 3.4.

B.4.4 Void content under gyratory compaction

The void content of specimens compacted in the gyratory compactor in accordance with BS EN 12697 31, using the appropriate number of gyrations from Table B2, from mixtures at target composition prepared in the laboratory in accordance with pr EN 12697 35 shall be less than or equal to 6%.

B.4.5 Water sensitivity

The retained strength of specimens manufactured at target composition and tested in accordance with the Duriez test to NF P 98 251-1 shall be not less than 0.75.

B.4.6 Deformation resistance

The deformation resistance of the mixture, at target composition, tested in accordance with the large wheel tracking test to BS EN 12697 22 on slabs compacted in accordance with BS EN 12697 33 shall have deformation not greater than 7.5%.

Table B1 Limiting values for target gradings for EME 0/20, EME 0/14 and EME 0/10

Test sieve aperture size (mm)	*EME 0/20*	*EME 0/14*	*EME 0/10*
31.5	100	–	–
20	90 - 99	100	–
14	75 - 95	90 - 99	100
10	60 - 90	–	90 - 99
6.3	42 - 75	42 - 65	55 - 80
4.0	–	–	35 - 65
2.0	20 - 35	19 - 42	27 - 45
0.250	8 - 18	8 - 18	8 - 18
0.063	5 - 9	5 - 9	5 - 9

Limiting envelopes for target gradings are not used in the French standards for EME. It is however normal practice to use this approach in the UK and thus Table B1 has been included here. The values are based on UK experience and some information on general practice in France. It may be possible that target gradings outside these envelopes result in perfectly satisfactory mixtures, so long as all of the performance criteria are met.

Table B2 Number of gyrations

EME 0/10	80 gyrations
EME 0/14	100 gyrations
EME 0/20	120 gyrations

B.4.7 Stiffness modulus

The mean Indirect Tensile Stiffness Modulus of a set of six 150 mm diameter cored specimens taken from a trial strip or a section of road tested in accordance with DD 213/ BS EN 12697 26 shall be not less than 5.5 GPa.

NOTE: As experience is gained with these mixtures it may prove possible to achieve higher ITSM values. In this event, a higher minimum value may be used which could justify a higher design stiffness for use in analytical pavement designs.

B.4.8 Fatigue properties

When resistance to fatigue is of particular importance it may be specified by either of the following:

- Require a richness modulus equal to or greater than 3.6.
- Determine resistance to fatigue in accordance with the French standard NF P 98-261-1. The result (microstrain for 10^6 cycles at 10^0C and 25 Hz at 3-5% voids) should be equal to or greater than 130 micro-strain.

NOTE: The French fatigue test is very lengthy and not generally available in UK. EME is a very binder rich mixture and it is recommended that the default value of 130micro-strain is assumed without the need for fatigue testing. Greater confidence may be achieved by ensuring a slightly richer mixture by specifying the slightly higher value for richness modulus specified in this clause.

B.5 Mixing

B.5.1 General

EME shall be mixed either by the batch process or in a continuous or drum mixer.

The moisture content of the fresh mixture on discharge when tested in accordance with BS 598 Part 102 shall be not greater than 1% by mass.

On discharge from the mixer, the aggregate shall be completely coated with binder and there shall be no evidence of balling of the fine aggregate.

B.5.2 Temperature of mixed material

The temperature of the mixed material shall not be greater than 200 deg C at any stage.

B.6 Sampling and testing

B.6.1 Binder

Bitumen shall be sampled and tested in accordance with BS EN 58 and any additional requirements in Annex A.

B.6.2 Aggregates and filler aggregate

Coarse and fine aggregates and added filler shall be sampled and tested in accordance with the appropriate methods referenced in EN 13043.

B.6.3 Analysis of mixed material

The mixed material shall be sampled and tested in accordance with BS 598 Parts 100, 101 and 102. The grading of the mineral aggregate fraction of the mixture shall be determined by means of wet sieving. No wet/dry sieving correction shall be employed.

The tolerances given in Table B3 shall be applied about the Target Composition to give the composition limits for conformity of analysis results.

B.7 Laying and compaction

B.7.1 General

EME shall be transported, laid and compacted in accordance with the requirements of BS 594 Part 2 applicable to hot rolled asphalt base and binder courses and any specific or additional requirements in this standard.

B.7.2 Laying thickness

Compacted thickness shall fall within the appropriate range given in Table B4.

B.7.3 Tack coat and bond coat

Tack coat or bond coat shall be applied to any concrete or bituminous substrate before laying EME. This shall be generally in accordance with BS 594 part 2 Clause 5.5, but the target rate of application shall be 0.25 kg/m^2 residual bitumen in all cases.

B.7.4 Laying temperature

The 'paver out' temperature of the mixture shall not be less than 140^{0}C.

NOTE: For modified binders paver out temperatures should be recommended by the supplier and agreed.

Table B3 Tolerances for conformity of analysis results

Test sieve aperture size (mm)	*Tolerance EME 0/20*	*Tolerance EME 0/14*	*Tolerance EME 0/10*
31.5	± 0	–	–
20	-9 +5	± 0	–
14	± 9	-8 +5	± 0
10	± 9	–	-8 +5
6.3	± 7	± 7	± 7
4.0	–	–	± 7
2.0	± 7	± 6	± 6
0.250	± 5	± 4	± 4
0.063	± 3	± 2	± 2
Soluble binder	± 0.6	± 0.5	± 0.5

Table B4 Layer thicknesses

Mix size designation	*Nominal thickness range (mm)*	*Minimum thickness (mm)*
EME 0/10	60-100	50
EME 0/14	70-130	60
EME 0/20	90-150	80

B.7.5 Compaction

Compaction shall be undertaken with a selected combination of rollers working to a predetermined rolling pattern. The effectiveness of this procedure shall be established by means of a job mixture verification trial as described in clause B.8.

The mat shall be compacted such that the rolling mean of each six *in situ* void contents is not greater than 6%. These shall be determined on pairs of 150 mm diameter cores taken at 500 m intervals, or, where confidence has been established in their calibration from the results of indirect devices such as nuclear gauges.

NOTE: EME is a binder rich mixture and, if correctly designed, should compact more easily, with fewer passes than leaner dense graded mixtures, despite the use of hard grade binder. It is, however necessary to select rollers of appropriate weight and vibration capacity. The French have made characteristically comprehensive studies of compaction. They recommend that compaction of EME (EME 2) should be undertaken with one of the following combinations:

- *Tandem vibrating rollers*
- *Mixed tandem rollers (pneumatic front, vibratory rear)*
- *Static rollers plus pneumatic tyred rollers*
- *Tandem vibrating rollers plus pneumatic tyred rollers*

In each case, rollers are classified in terms of their linear mass and vibrating characteristics and it is important that the appropriate equipment is used. It is recommended that use is made of the French system for classification of rollers when making a selection and deciding on a procedure. Roller manufacturers should be able to produce this information on request.

EME is designed as a binder rich low permeability mixture. It should be expected to have a rich finish on completion of compaction and some 'fatting up' is normal and not an indication of problems.

Polyglots will find useful information in 'Compactage des enrobés hydrocarbonés à chaud' published by LCPC in 2003.

B.8 Job mixture verification trial

B.8.1 General

For each mixture, a job mixture verification trial shall be carried out to verify the properties of the mixture and the effectiveness of the compaction plant and rolling procedures.

The trial area shall be not less than 30 m long and shall be of an appropriate width for the laying and rolling procedures being demonstrated. Mixing, laying and compaction plant and procedures shall be as close as possible to those to be encountered on full scale works.

NOTE: A job mixture verification trial has the purpose of demonstrating the practicality of adequately compacting the mixture with the proposed plant and of determining the anticipated in situ stiffness modulus. The conditions of the trial should be as close as possible to those which will be encountered in the full scale works, in particular in respect of substrate stiffness and layer thickness. For large works of significant duration it may be appropriate to undertake a trial specifically for an individual contract. In general, and particularly for smaller scale works, the results of earlier trials should be used.

B.8.2 Mix analysis

During the laying of the trial area, samples of loose mixture shall be taken at three evenly spaced locations along the trial length, in accordance with BS 598: Part 100. These shall be analysed for soluble binder content and grading to demonstrate conformity with the target composition as described in clause B.6.3.

B.8.3 Maximum density

At each of the locations described in B.8.2, a further loose mix sample shall be taken for maximum density determination. The maximum density of each sample shall be determined in accordance with BS EN 12697-5. The average value of maximum density r_{Max} expressed in Mg/m^3 shall then be used for subsequent calculation of the air void content of the compacted mixture.

B.8.4 Bulk density and void content

At three locations, pairs of 150 mm diameter cores shall be taken in accordance with BS 598 Part 100, six cores in total. Two of the core locations shall be in the wheel-track zones (between 0.5 m and 1.1 m and between 2.55 m and 3.15 m of the nearside lane marking) of the completed lane or mat, the third shall be selected as appropriate.

The initial bulk density ρ of each core shall be determined in accordance with BS EN 12697-6 Procedure A.

Void contents shall be calculated to $\pm$ 0.1% as follows:

- Air voids content = $(1- \rho/\rho_{Max}) \times 100\%$
- The average value of the six air void contents shall be less than or equal to 6%.

B.8.5 Dynamic stiffness

The six cores taken under clause B.8.4 shall be used for the preparation of specimens for testing of indirect Tensile Stiffness Modulus in accordance with DD 213 1993. The mean result shall be used to determine conformity with clause B.4.7.

B.8.6 Calibration of nuclear gauge

If a nuclear gauge or other indirect device is to be used to monitor and control compaction during the main works, it may be convenient to use the core results of the job mix verification trial to calibrate against core density.

Annex A: Selected and additional requirements for hard grade binders for use in UK EME mixtures

Hard grade binders for use in EME shall conform to EN 13294 and the requirements of this annex.

NOTE: This annex is necessary because EN 13924 is not a Performance-Related specification, and the Standard contains options (classes) for various properties, some of which would not be appropriate for hard paving grade bitumens used in high modulus asphalt applications in England.

The levels selected for characteristics in this Annex are based on those used in France, where high modulus asphalt (known in France as EME, Enrobé à Module Élevée) was originally developed, and where there are many years experience of successful use. Nevertheless in France there remains no wholly accepted standard applicable to these hard bitumens, and their characteristics vary according to the supplier's process and source of crude oil. The values included in the following tables have been selected from within the range of properties of French binders reported.

The selected requirements are given in Tables A and B.

It is stated in EN13924 that for softening point, a restricted range of ± 5°C about a mid-point, shall be declared by the supplier; the overall range must be within the following ranges, 60-76°C for the 10/20 grade and 55-71°C for the 15/25 grade.

Table A gives the normative properties selected for use in UK EME mixtures. A number of these properties where indicated are tentative and values for each trial shall be agreed on a contract specific basis by the bitumen supplier, asphalt contractor and the Highways Agency.

For the additional properties, in Table B, typical measured values will be declared by the supplier. The data from Table B will be used to gain experience with the test parameters selected, and their relation to performance in EME mixtures.

During the pilot stage when production may be intermittent, test frequencies shall be agreed on a contract specific basis between the bitumen supplier, asphalt contractor, main contractor and the Highways Agency.

NOTE: Once the specifiction has been finalised, UK bitumen suppliers will demonstrate Factory Production Control by certification to Sector Scheme 15, but with the Type testing frequency shown in Table A. This indicates the Type testing frequencies for all the properties. Whenever a change occurs in the base materials or the production process which would change significantly one or more of the characteristics, Type testing at the frequencies shown in Table A shall be repeated for all the characteristic(s). The informative properties will be measured as part of Initial Type Testing and whenever a change occurs in the base materials or the production process, and at least once per year thereafter for FPC purposes, see Table B.

Table A Binder characteristics (ref prEN 13924)

Characteristic	Test method	Unit	Binders for EME 10/20 pen	Binders for EME 15/25 pen	FPC Test frequency
Penetration at 25°C	EN 1426	0.1 mm	10 - 20	15 - 25	D
Softening point	EN 1427	°C	63 - 73 Target value 71 max (1)	60 - 70 Target value 68 max (1)	W
Penetration index, max	prEN 13924 Annex A	–	+0.7 Target value +0.5 max (1)	+0.7 Target value +0.5 max (1)	W
Fraass breaking point,max	EN 12593	°C	Target mean (2) (3) 0 max Range -10 to +5 (3)	Target mean (2) (3) 0 max Range -10 to +5 (3)	A (Q)
Viscosity at 135°C, min	EN 12595	mm²/s	1100 (3)	900 (3)	A (Q)
Flash point, minimum	EN 2592	°C	245	245	A
Solubility, minimum	EN12592	%(m/m)	99.0	99.0	A
Pendulum cohesion, min	EN 13588or SHW Cl 939 (Reported graphically)	J/cm²	0.5 (3)	0.5 (3)	A (Q)
Binder characteristics after EN 12607-1 (RTFOT)					
Change of mass, max		%	0.5	0.5	A
Retained pen 25°C, min	EN 1426	%	65 (3)	65 (3)	A (Q)
Increase in softening point, maximum	EN 1427	°C	8	8	A (Q)
Fraass breaking point, min	EN 12593	°C	Target mean (2) (3) +2 max Range -8 to +7 (3)	Target mean (2) (3) +2 max Range -8 to +7 (3)	A (Q)
Pendulum cohesion, min	EN 13588or SHW Cl 939 (Reported graphically)	J/cm²	0.5 (3)	0.5 (3)	A (Q)

Table A Notes:

1 Target max value based on a rolling mean of the last 6 consecutive results in compliance testing or FPC as appropriate.

2 Target max value based on a rolling mean of the last 3 consecutive results in compliance testing or FPC as appropriate.

3 Values are tentative and only indicative at present. More experience of tests and the test results is necessary before limits can be set with confidence. There is concern about the precision of the Fraass test in particular, and BBR values on the same samples should be obtained to establish a correlation, the long-term aim being to use the BBR as the low temperature test in the future.

Values for those properties that are tentative shall be agreed for each pilot contract on the trunk road network on a contract specific basis by the bitumen supplier, asphalt contractor, the main contractorand the Highways Agency. During the pilot stage when production may be intermittent, all test frequencies shall be agreed on a contract specific basis.

All tests all to be carried out on sub-samples of a single bulk sample of binder.

Minimum test frequency: Indicated frequencies apply only if product is supplied to customers.

D = Daily, W = Weekly, A = Annually, A (Q) = Quarterly for the first year, then annually.

Table B Binder characteristics to be reported

Characteristic	*Test method*	*Unit*	*Binder for EME*	*FPC frequency*		
				AS	*STA*	*LTA*
Brookfield viscosity T 200cP	EN 13302	°C	TBR	A		
T 2000cP		°C	TBR		A	
T 5000cP		°C	TBR		A	
G* and phase angle	prEN 14770	Pa, degrees	TBR	A	A	A
VET temperature, G'= G", at 0.4 Hz	Clause 928	°C	TBR	A	A	A
G* at the VET temperature		Pa	TBR	A	A	A
G' and G" mastercurves 80°C to 0°C	Graphical output	Graphical output	TBR	A	A	A
G" and phase angle at 15°C, 10Hz and 20°C, 1Hz		Pa, degrees	TBR	A	A	A
$T_{S=300\ MPa,}$ by BBR	prEN 14771	°C	TBR	A (Q)	A (Q)	A (Q)
$T_{m\ =\ 0,3,}$ by BBR		°C	TBR	A (Q)	A (Q)	A (Q)

Minimum test frequency: Indicated frequencies apply only if product is supplied to customers.

D = Daily, W = Weekly, A = Annually, A (Q) = Quarterly for the first year, then annually.

AS = As supplied.

STA = After EN12607-1 (RTFOT).

LTA = After PAV85.

Annex B: Definition of binder richness modulus

Determination of binder richness modulus involves calculating the specific surface area of the aggregate grading of the mix separated on particular sieves. It will be necessary to carry out a particle size analysis of the combined aggregate (or the individual fractions) including the 6.3 mm, 0.315 mm and 0.080 mm sieves, despite the fact that some of these are not part of the sieve set adopted for use in European Standards for aggregates and asphalt.

The binder richness modulus, K, is derived from the following formula:

$$B_{PPC} = K.a\sqrt[5]{\Sigma}$$

Where:

B_{PPC} = the mass of soluble binder expressed as a percentage of the total dry mass of aggregate, including filler. (Note that this is different from the conventional UK expression of binder content B_M, which is as a percentage by mass of the total mix. $B_{PPC} = B_M \times 100/\ 100 - B_M$)

Σ = specific surface area of aggregate given by,
$\Sigma = 0.25G + 2.3S + 12s + 135f$

G = proportion* by mass of aggregate over 6.3 mm,

S = proportion* by mass of aggregate between 6.3 mm and 0.315 mm,

s = proportion* by mass of aggregate between 0.315 and 0.080 mm,

f = proportion* by mass of aggregate smaller than 0.080 mm,

a = $2.65/r_g$ which is a correction coefficient taking into account the density of aggregate (ρ_g) if this differs from 2.65 mg/m^3.

** The proportions of aggregate must be expressed as decimal fractions of the total mass (eg, if there is 38% of the mass passing 6.3 mm and retained on 0.315 mm then S would be 0.38)*

Abstract

An investigation was carried out into the properties and performance of a high modulus asphalt material designed using the French design method with ingredients readily available in the UK. The asphalt material, known as Enrobé à Module Élevé (EME) Class 2, was evaluated under full-scale loading in the Pavement Test Facility (PTF) at TRL. Two test sections were constructed using full-scale plant to provide a direct comparison of the performance of an EME binder course with that of a heavy duty macadam (HDM) binder course. This direct comparison allowed the performance of the 'new' material to be calibrated against a material that experience has shown to perform well in service. Two additional test sections were used to test a one metre wide (wheel-track) trench inlay to confirm that it could be included as a realistic and sustainable alternative maintenance treatment for surface rutting on heavily trafficked roads.

The EME Class 2 material deformed less than the HDM and no cracking was observed along the joints adjacent to the trench. Indirect Tensile Fatigue Testing (ITFT) and Indirect Stiffness Modulus (ITSM) stiffness testing before and after saturation with water, and permeability measurements indicated that EME would be durable and would act as an impermeable layer beneath a thin surface course. No reduction in stiffness was measured after 50 days of soaking, and the cracking resistance of the richer EME Class 2 was superior to that of HDM.

The very low air voids obtained in both the HDM and the EME binder courses using conventional plant, confirmed that the laying and compaction of EME Class 2 layers does not require special measures.

As a consequence of this work an interim specification for EME Class 2 has been developed and specification trials under contractual conditions are planned for the near future. These will provide confirmation of the material's structural properties and mixing, laying and compaction characteristics.

Related publications

TRL639 *Guidance on the development, assessment and maintenance of long-life flexible pavements* by D Merrill. 2005 (price £30, code EX)

TRL638 *A model set of asphalt sustainability indicators* by A R Parry. 2005 (price £30, code EX)

TRL456 *Development of a performance-based surfacing specification for high performance asphalt pavements* by D J Weston, M E Nunn, A J Brown and D Lawrence. 2001 (price £50, code L)

TRL250 *Design of long-life roads for heavy traffic* by M E Nunn, A J Brown, D J Weston and J C Nicholls. 1997 (price £50, code L)

TRL231 *Road trials of high modulus base (HMB)* by M E Nunn and T M Smith. 1997 (price £25, code E)

PR66 *Evaluation of Enrobe a Module Eleve (EME: a French high modulus roadbase material* by M E Nunn and T M Smith. 1994 (price £25, code E)

RR189 *Structural investigation of the road for the design of strengthening* by R T N Goddard. 1990 (price £20, code B)

LR1132 *Design of bituminous* pavements by W D Powell, H C Mayhew, J F Potter and M E Nunn. 1984 (price £20, code A)

CT119.1 Bituminous binders and mix design update (2001-2003) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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