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EVALUATION OF STONE MASTIC ASPHALT (SMA): A HIGH STABILITY WEARING COURSE MATERIAL

by M E Nunn

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Civil Engineering Resource Centre
Transport Research Laboratory
Crowthorne, Berkshire, RG11 6AU
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EXECUTIVE SUMMARY

Work is currently in progress to harmonise the standards for road building materials in the countries of the European Union. This has emphasised the importance of identifying materials that are used elsewhere in Europe that could be adopted with advantage in the UK.

This report describes an evaluation of Stone mastic asphalt (SMA), a rut resistant and durable wearing course material. SMA was originally produced in Germany as a proprietary product but recognition of its good performance led to its standardisation in the German Technical Specifications in 1984. Today it is widely used on the road network in Germany and variants of SMA have been adopted in many other countries.

After a review identified SMA to be of particular interest and relevance, a study visit to Germany was arranged to obtain information on aspects of material design, manufacture, construction practice and costs and benefits. SMA was found to be very deformation resistant due to its stable aggregate skeleton structure. The voids in the stone matrix are filled with a mastic of bitumen/crushed sand/filler to which fibres are added to prevent binder drainage. Although cellulose fibres have been found to be satisfactory and cost effective and are used in the majority of SMA production, other stabilising agents are permitted. The excellent structural properties of the material are derived from its aggregate skeleton and the fibres are used primarily as a bitumen carrier to increase the thickness of binder coating and thereby reduce oxidation.

Following the study visit, a demonstration trial was arranged at TRL. The trial enabled the mixing, laying and compaction characteristics of SMA to be examined and provided the opportunity to investigate the structural and surface attributes of the material.

The investigation showed that SMA has considerable potential and that it can be designed, produced and laid successfully using existing plant by contractors in the UK. Experience in countries that have adopted SMA has shown it to be resistant to deformation and surface cracking. Furthermore the trial has demonstrated that with a careful choice of aggregate size and grading SMA has the potential to meet UK surface texture requirements; it can be laid as a thin layer and it generates less tyre noise than hot rolled asphalt. From the successful trial it can be concluded that the material could be used in carefully monitored road trials to build up experience before considering it for general use.

EVALUATION OF STONE MASTIC ASPHALT (SMA): A HIGH STABILITY WEARING COURSE MATERIAL

ABSTRACT

This report describes the evaluation of stone mastic asphalt (SMA). SMA was originally produced in Germany as a proprietary wearing course material, but recognition of its excellent performance led to its standardisation in 1984. SMA has been found to be very deformation resistant due to its stable aggregate skeleton structure. The voids in the stone matrix are filled with a mastic of bitumen/crushed sand/filler to which a stabilising agent, which is normally cellulose fibre, is added to prevent binder drainage. Experience in countries that have adopted SMA has shown it to be very durable. Following a study visit to Germany to gain more information on material design, production and construction practice, a demonstration trial was arranged at TRL to further evaluate the potential of this material.

The trial showed that SMA can be designed, produced and laid successfully by UK contractors using existing plant, and demonstrated clearly the feasibility of its use in the UK. Furthermore with a careful choice of aggregate size and grading SMA has the potential to meet UK surface texture requirements, to be laid as a thin layer, and it generates less tyre noise. The material could be used in carefully monitored road trials to build up experience before considering it for general use.

1. INTRODUCTION

Work is currently in progress to harmonise the standards for road building materials in the countries of the European Union. This has emphasised the importance for the UK road building industry to consider the potential of unfamiliar materials that are used elsewhere in Europe. The recognition that there may be bituminous materials in use in other countries of the Europe Union which could be adopted with advantage for use in the UK resulted in the Road Engineering and Environmental Division of the Highways Agency (Department of Transport), British Aggregate Construction Materials Industries and the Refined Bitumen Association sponsoring a programme of work to identify and evaluate promising materials.

The initial stage of this research involved a review of materials that appeared to be of particular interest and relevance. For this review, standards for bituminous road materials were requested from 17 European countries represented in the Forum of European National Highway Research Laboratories (FEHRL). The two materials selected, during this review, for further consideration were enrobé à module élevé (EME), a very high stiffness French roadbase material and stone mastic asphalt (SMA) a wearing course material that was originally developed in Germany. This report describes the evaluation of SMA while EME is described in a separate report by Nunn and Smith (1994).

As part of this evaluation, a study visit to Germany was arranged with representatives of the UK Industry to obtain information on aspects of material design, manufacture, construction practice and costs and benefits. SMA has been found to be very deformation resistant due to its stable aggregate skeleton structure. The voids in the stone matrix are filled with a mastic of bitumen/crushed sand/filler to which fibres are added to prevent binder drainage. Although cellulose fibres have been found to be satisfactory and cost effective and are used in the majority of SMA production, other stabilising agents are permitted. The excellent structural properties of the material are derived from its aggregate skeleton and the fibres are used primarily as a bitumen carrier to increase the thickness of binder coating and thereby reduce oxidation.

Following the study visit, a demonstration trial was arranged at TRL before representatives from the industry. The trial enabled the mixing, laying and compaction characteristics of SMA to be examined and provided the opportunity to investigate the structural and surface attributes of the material.

2. REVIEW OF EUROPEAN MATERIALS

A review of national standards for hot-mix materials used in the leading industrial countries of Europe, identified several materials that appeared to have potential for use in the UK. Most of these countries make use of asphaltic concrete and all, except France, use the Marshall test to determine its optimum binder content. Asphaltic concrete is comparatively well understood in the UK and therefore it was not considered for further study.

France was recognised as the leading European country in developing improved materials for the main structural layers of the pavement. In France bituminous materials are designed to satisfy criteria for structural properties and susceptibility to moisture determined using laboratory tests.

Three French materials were identified to be of possible interest, these being fine graded asphalt, grave bitume and very high stiffness material known as EME. Fine graded asphalt is a closely graded material designed as a wearing course, basecourse and for strengthening in the most heavily trafficked roads. Grave bitume previously examined by Hingley, Peattie and Powell (1976) has since been improved and the standard specification was revised in 1990. It is used for basecourse and roadbase in roads designed for all traffic categories. However fine graded asphalt and grave bitume were not considered to be sufficiently different from conventional materials to warrant further investigation as part of this research.

The French material that appeared to be the most promising and worthy of detailed investigation was a very high stiffness material, known as enrobé à module élevé (EME). This material was introduced in the early 1980s as the result of energy concerns following the oil crisis in the mid-seventies. Regulations to reduce oil product usage provided the drive to decrease the thickness of the bituminous layers. As a consequence much stiffer materials were developed that enabled the thickness of the roadbase to be reduced by up to 40 percent compared with the conventional grave bitume roadbase. The detailed investigation of this material is described by Nunn and Smith (1994).

Over recent years there has been increasing interest in stone mastic asphalt (SMA) throughout Europe and elsewhere in the world. SMA was developed over 25 years ago in Germany to resist the wear of studded tyres. After studded tyres were banned in 1975 the use of SMA was continued because experience had shown it to perform better than a conventional asphaltic concrete wearing course. It was initially produced as a proprietary product but recognition of its excellent performance led to its standardisation in the German Technical Specifications in 1984. Variants of SMA have since been adopted in many countries including Sweden, Denmark, Netherlands, Belgium, France, Switzerland, Japan and more recently trials have been carried out in the USA. The review recommended this material for further investigation with the view to possible adoption in the UK.

3. CHARACTERISTICS OF SMA

3.1 DEVELOPMENT

Stone mastic asphalt (splittmastixasphalt) was originally produced in Germany as a proprietary product but recognition of its excellent performance led to its standardisation in the German Technical Specifications in 1984. Today it is the most widely used type of wearing course on the road network in Germany.

In Europe, it is now used extensively in Scandinavia, Netherlands, Denmark and France. In Germany the material is made using three nominal aggregate sizes; 0/11 mm, 0/8 mm and 0/5 mm. In Sweden where studded tyres are still used a 0/16 mm aggregate grading is normally used. The benefits of SMA are now being recognised by many national authorities and in the USA a joint Federal Highways Administration (FWHA), State and Industry Technical Working Group on SMA was formed in 1992 to coordinate technical information from current projects and develop guidelines on design, construction and use as a high quality alternative asphalt pavement surface. Preliminary trials of SMA in the USA are described by Warren (1991) following a study tour of Europe (1990) by a team of representatives from the American Association of State Highway and Transportation Officials (AASHTO). Bellin (1992) presents a comprehensive account of SMA practice in Germany and Serfass and Samanos (1992) describe the use of SMA in France for wearing courses 20 mm to 30 mm thick.

3.2 BENEFITS AND DISADVANTAGES

SMA has been found to be very deformation resistant due to its stable aggregate skeleton structure. The voids in the stone matrix are filled with a mastic of bitumen/crushed sand/filler to which fibres are added to prevent binder drainage. Initially asbestos fibres were used, but these are now prohibited on health grounds and, although other stabilising agents can be used, cellulose fibres have been found to be a satisfactory and cost effective substitute. The excellent structural properties of the material are derived from its aggregate skeleton and the fibres are used primarily as a bitumen carrier to increase the thickness of binder coating and thereby reduce the rate of oxidation. However the fibres have been shown by Serfass et al (1992) to act as a micro-reinforcement of the mastic and improve the stability of the mix and wheel-tracking tests carried out in Germany, Austria and Japan have demonstrated that the fibres further enhance the rut resistance of SMA.

SMA has been shown to be durable and resistant to age hardening by virtue of its low void content and thick binder film. Consequently it is resistant to premature cracking, ravelling and damage by moisture.

Apart from good stability and durability, that ensures a long service life, other advantages are claimed for the material. It can be laid over a rutted or uneven surface because it compresses very little during compaction. This helps to produce good longitudinal and transverse evenness. It is also claimed to give a reduction of approximately 2 dB(A) in tyre noise compared with asphaltic concrete.

The skidding resistance of SMA in its early life can be low due to the thick binder film on the exposed surface of the aggregate, although this is subsequently worn away by traffic. The early life skidding resistance can be improved by rolling in crushed sand that has been sprinkled over the newly laid material. In the longer term the skidding resistance of SMA is reduced by the polishing effects of traffic on the aggregate, as happens with all types of surfacing.

SMA consists of essentially discrete *single-sized* aggregates glued to a support and to themselves by a tack coat and mastic. At the bottom and in the bulk of the layer, the voids in the mineral aggregate are almost entirely filled by the mastic, while at the surface the voids are only partly filled resulting in a rough and open texture. This helps to provide good skidding resistance at all speeds and facilitates the drainage of surface water. A careful choice of aggregate size and grading is necessary to produce a surface that will be adequate for UK texture requirements.

SMA also has the advantage that it can be laid in thin layers. A 15 mm thick layer is possible with a 0/6 mm grading.

The disadvantages of SMA are that it requires additives, premium crushed aggregates and a high binder content compared to asphaltic concrete. The cost of production is increased due to the higher mixing temperatures, the extended mixing times required to disperse the additive and the higher standards of quality control. All these factors make SMA about 20 percent more expensive than asphaltic concrete.

3.3 COMPOSITION OF SMA

Engineers in Germany, where SMA originated, have the most experience of this material. The specification for SMA is given in *Technical Specifications and Guidelines for the Construction of Asphalt Pavements* published by the German Federal Department of Transport (1990). This specification gives requirements for the ingredients of the mix, which are summarised in Table 1.

SMA wearing course is produced in three different sizes; 0/11 mm, 0/8 mm and 0/5 mm. The composition of these materials is given in Table 2.

TABLE 1

Requirements for Mix Constituents

Ingredient	Requirements
Aggregate	High quality fully crushed rock - max 20 percent of elongated and flat aggregates. Mineral type not specified but minerals such as granite, gabbro, diabase, basalt, etc preferred. Limestone, sandstone and soft aggregates not used. Must have high polished stone value. Aggregate, sand and filler production must conform with German quality assurance standards.
Filler	Not specified but normally ground limestone.
Sand	Mineral type not specified but at least 50 percent must be crushed.
Grading	Gap graded
Binder	80 Pen for normal traffic.
	65 Pen for more than 1,800 CV/day over 2.8 tonnes.
Additives	Organic and mineral fibres, silicic acid and polymers.

TABLE 2

Composition of SMA in Germany

Sieve Size (mm)	SMA Mixes 0/11 mm	 0/8 mm	 0/8 mm	 0/5 mm
	Heavy Traffic (>1,800 CV/day over 2.8 tonne) Percent passing by weight		Normal Traffic Percent passing by weight	
16	100	100	100	100
11	90-100	100	100	100
8	≤ 70	90-100	90-100	100
5	30-50	30-55	30-55	90-100
2	20-30	20-30	20-30	30-40
0.09 (Filler)	8-13	8-13	8-13	8-13
Stabilising Additive (%M/M)	0.3 to 1.5 Organic or mineral fibres, silica or pulverised or granulated polymer			
Binder Grade (pen)	65	65	80	80
Binder content (Percent by wt of mix)	6.5-7.5	6.5-7.5	6.5-7.5	7.0-8.0
Marshall Voids	2 - 4 percent by volume			
Voids Content	≤ 6.0 percent by volume			
Layer Thickness (mm)	25 - 50	20 - 40	20 - 40	15 - 30

At least 50 percent of the aggregate fraction passing 2.0 mm must be crushed.

In Germany it is the responsibility of the Supplier to select the constituents and evaluate the mix. This information is then submitted to the Client for approval. The steps to evaluate a mix are:

1. The Contractor selects aggregate, sand, filler and additives on the basis of his experience. A trial grading within the limits given in Table 2 is chosen.

2. Trial mixes are prepared using the lowest binder content given in the standard and using 2 or 3 additional binder contents.

3. Stabilising additives are required to avoid segregation of the binder and coarse aggregate during storage, transportation and laying. A binder drainage test can be carried out but at present none is specified in the German standard.

4. Marshall specimens are prepared at 135°C and their air voids content determined. The voids content must be in the range 2 - 4 percent. If the required voids content is not achieved, changes within the limits of the specification are made to the grading, filler content or binder content.

5. The Contractor decides on the job-mix formulation and submits it to his Client for approval.

The grading of the job-mix must be contained within the composition envelope given in Table 2. Once the job-mix has been decided, tight control of the mix constituents is essential.

The additives mentioned in Table 1 can be used, but, in Germany only cellulose fibres are used extensively. Experience has shown these to be good bitumen carriers, they are chemically inert and inexpensive. Normally a minimum of 0.3 percent by weight of fibres is added.

A simple binder drainage test, devised by the Schellenberg Institute in Germany (1988), is normally used by Contractors and this test is now included in the draft American specification produced by a SMA Technical Working Group sponsored by the Federal Highway Authority (FHWA).

Other countries such as Holland (1992), Sweden (1988) and France (1990) have developed their own variants of SMA, but because the introduction is more recent, there is less experience of its use.

3.4 MATERIAL PRODUCTION

It is the responsibility of the Contractor to produce the material with the specified properties. The production of SMA using cellulose fibres as a stabilising agent is only considered in this section as this accounts for the majority of SMA production. Throughout the process good quality control is required to ensure a uniform product. Sampling is required at the mixing plant to ensure that the material is uniform and complies with the job-mix formula and during a contract material is sampled from the paver and cored from the road to check composition and compaction. The mixing, laying and compaction procedures are not specified.

3.4.1 Mixing

Both batch-mix and drum-mix plants can be used. In a drum-mix plant a separate fibre feed system is required that can accurately meter fibre into the drum at an appropriate rate to ensure continuous and uniform blending of the fibre into the mixture while in the drum. The fibres can be blown into the drum or added in pellet form. Pellets are available in which the fibres are bonded together with bitumen.

In batch-mix plants meltable plastic bags of fibre can be added through a separate inlet directly into the weigh hopper above the pug-mill by hand. Manual addition is economical and therefore is still much practised. It is, however prone to operator error. Mechanical methods of adding bags of fibres using conveyor belts, or screw-conveyers for adding pelleted fibres, are commercially available. Premixing binder and pellets in an agitated vat is considered to be the best but the most expensive method.

In batch mixing plants adequate dry mixing time is required to ensure proper blending of the aggregate and fibre. The fibres can be degraded if they are mixed too long with the hot dry aggregate. The dry mixing time is normally increased by between 5 and 15 seconds and the wet mixing time by between 5 and 10 seconds. This extended mixing time reduces the throughput of the mixing plant and adds to production costs.

The maximum mixing temperature is normally about 180°C.

3.4.2 Laying

Paving with SMA is relatively straightforward. It is laid in new construction as well as in maintenance treatment using conventional equipment. Because SMA does not compress much during compaction, a good finished profile can be obtained when it is laid over a rutted or uneven surface. Provided ruts do not exceed about 20 mm, no remedial action is required before laying. However, any localised distress would need to be repaired before application.

Immediately before application the surface must be thoroughly cleaned and a tack coat is recommended to ensure and improve the bond with the sub-strate. Good control of mixing temperatures is required and generally the temperature of the SMA in the paver hopper should not be less than 140°C and experience has shown that it is better to target above 150°C. The minimum ambient temperature specified for laying is normally 5°C.

The normal laying thicknesses are given in Table 2. The minimum layer thickness is generally about 2.5 times the maximum aggregate size.

3.4.3 Compaction

Compaction is started as soon as possible after the SMA has been laid. It is considered good practice to use two steel-wheel rollers of approximately 8 to 12 tonnes; one working tight up to the paver and the other working behind to complete the compaction. If vibratory rollers are used, vibration should be used with care and, at most, only on the first few roller passes on only the thicker layers of SMA, as excessive vibration will fracture aggregates at the stone to stone contacts in the mix. Layers of 20 mm thickness or less only require a few passes of an 8 to 12 tonne roller without vibration. Pneumatic-tyre rollers are not suitable, as they stick to the hot, rich mastic and dislodge aggregate.

The general compaction requirement is that the voids content of the compacted material shall be less than 6 percent by volume.

4. EXPERIENCE IN GERMANY

In September 1993 representatives of the Steering Committee for the collaborative research programme visited the German State Highway Agency of Baden-Württemberg (Ministerialrat - Verkehrsministerium, Straßenbauverwaltung Baden-Württemberg), to gain first-hand knowledge of German practice. The State Highway Agency is responsible for the maintenance and rehabilitation of 28,000 km of road including 1,000 km of autobahn.

4.1 UTILISATION

In Germany asphaltic concrete was the main wearing course material until the mid-80s. Gussasphalt was an alternative but was not widely used because it cost approximately twice that of asphaltic concrete. As traffic increased, there were serious rutting problems with asphaltic concrete and, in order to obtain better resistance to deformation, leaner mixes with harder binders were used but these had shorter lives because of binder oxidation and cracking.

Since 1984, the state of Baden-Württemberg in common with the rest of Germany, has been using SMA on their road system and they have not had any failures of an SMA wearing course. SMA did not crack or fret as often happened with asphaltic concrete. In roads with SMA wearing course, any rutting had generally been identified as occurring in the basecourse rather than in the SMA. To overcome this problem, 0/16 mm SMA is being used increasingly as a basecourse.

On heavily trafficked roads and autobahns, 0/11 mm and 0/8 mm material is laid to a thickness of 40 mm. These materials are often laid thinner in other applications and in some instances the 0/5 mm material is laid as thin as 10 mm. SMA is also used on concrete roads. Because of its good resistance to cracking, it is laid over stress absorbing membrane interlayers (SAMIs) covering joints. An 80 mm binder course with 40 mm SMA wearing course is laid over rocking slabs and 200 mm overlay is often laid over broken slabs.

The 10 years experience with SMA has shown that generally problems do not occur with this material and consequently a directive has been issued by the State Highway Agency of Baden-Württemberg that stipulates that all wearing courses must now be SMA.

SMA helps to reduce traffic noise. Trials carried out in Baden-Württemberg have demonstrated that there is a reduction in tyre noise of approximately 2 dB(A) compared with asphaltic concrete and that noise reduction is greater with smaller aggregate sizes.

The surface texture of SMA is far superior to that of asphaltic concrete. Unlike the UK, there is no requirement for a minimum level of texture or minimum level of skidding resistance in Germany. However crushed sand can be rolled into the surface of the newly laid material to improve its early life skidding resistance.

The information in Table 3 on the cost of the various surfacings was given:

The service life of SMA, stated in the Table, was considered to be conservative since there was only 10 years experience since it had become a National Specification. SMA had, however, been used for longer in Northern Germany where there were examples of roads still in use with the original SMA wearing course after 25 years.

4.2 MANUFACTURE

The methodology for designing a job-mix in Germany is described in section 3.3. The German specification does not influence the choice of stabilisers, because it is the responsibility of the manufacturer to guarantee the quality of his material. However, cellulose fibres are used in over 90 percent of SMAs, these are inexpensive and effective which makes it difficult for other stabilisers to compete.

Nearly all bituminous material in Germany (99 percent) is produced in batch-mix plants in which packs of cellulose fibres can be easily pre-mixed with the aggregate before the binder is added.

In Germany up to 60 percent of material is recycled in the binder and base courses and up to 20 percent in the wearing course. The addition of a proportion of recycled material to SMA, although it is practised, can alter the grading, so it is not recommended.

The quality control of SMA production has to be more strictly regulated than for other materials. The plant mixing times have to be carefully controlled and material has to be regularly sampled and tested (every 500 tonnes) to ensure conformity with the job-mix. During laying, the Client samples material from the paver hopper and by coring, at least every 6,000 m^2 of laid material, to check composition and compaction. In addition the Contractor normally has to give a 4 year warranty for his material.

TABLE 3

Relative Cost of Wearing Course Materials

Material	Service Life (Years)	Relative Bid Price
Gussasphalt		
Standard	12 - 18	200%
Polymer modified		220%
SMA		
Standard (with cellulose fibres)	10 - 15	120%
Polymer modified		130%
Asphaltic concrete		
Standard	8 - 12	100%

5. DEMONSTRATION TRIAL

The trial was made possible by the cooperation of Tarmac Quarry Products Ltd and J Rettenmaier & Söhne. Tarmac Quarry Products spent time with TRL exploring the practicalities of producing and laying SMA and visiting the German State Highway Agency of Baden-Württemberg, the Schellenberg Research Institute and German contractors, while J Rettenmaier & Söhne, a manufacture of cellulose fibres, gave advice and supplied the cellulose fibre. Tarmac Roadstone carried out the mix designs, and mixed and laid the materials.

The demonstration of laying SMA wearing course was organised at TRL before representatives of the UK Industry. During the morning a series of short presentations on SMA were given and this was followed in the afternoon by a practical demonstration of SMA being laid. The objectives of the trial were to:-

1. identify any difficulties for the Industry in the design, manufacture and laying of SMA.
2. further evaluate the potential of SMA for use in the UK.

5.1 DESCRIPTION OF TRIAL

In this trial, approximately 15 tonnes of three SMA materials using nominal size aggregates of 14, 10 and 6 mm, were laid to different nominal thicknesses in a single rip, 3.6 m wide. The 14 mm SMA was laid 40 mm thick, the 10 mm was laid 40 mm, 25 mm and 20 mm thick and the 6 mm was laid 20 mm and 10 mm thick. The layout of the trial is shown in Figure 1 together with the laid thicknesses and the gradings used.

On the day of the trial in late October the ambient air temperature was 10°C with a wind speed in the range 10 to 20 km/h. These conditions were harsh, especially for

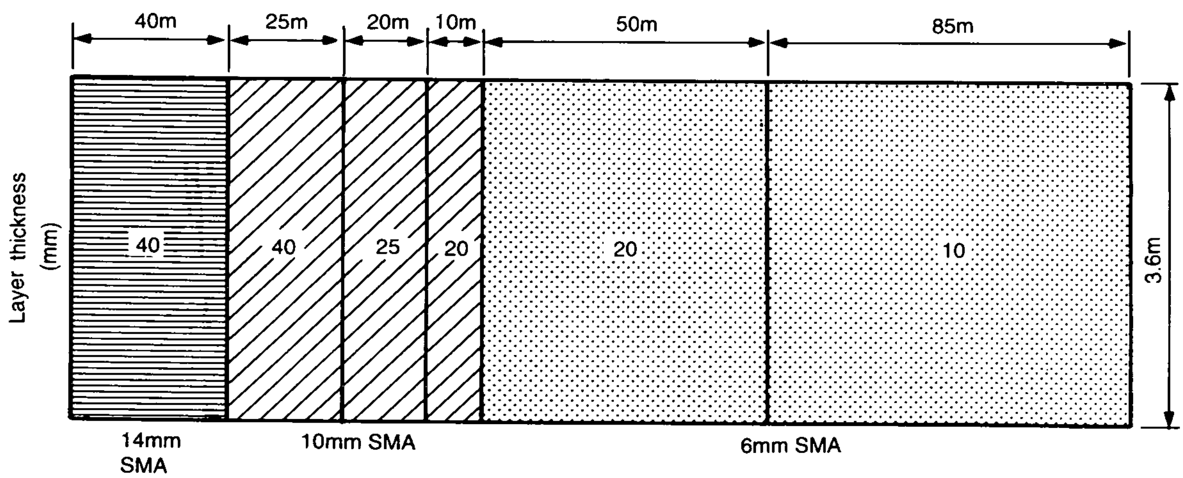

Fig. 1 Schematic plan of SMA trial

laying and compacting the thinner SMA layers. Under these circumstances a 10 mm thick layer, using the method described by Daines (1993), is estimated to cool from 140°C to 85°C in just over 1 minute, making good rolling practice essential.

Details of the materials and site conditions are given in Table 4.

6. EXPERIENCE OF THE CONTRACTOR

Before the trial the Contractor had laid several hundred tonnes of SMA to his own design and his Technical Manager had attended the German study tour.

6.1 MIX DESIGN

The Contractor broadly followed the methodology for mix design described in Section 3.3. The initial grading envelopes used to develop the job-mixes for the trial, given in Table 5, were German gradings modified to suit UK sieve sizes.

The grading was modified within these limits to produce a mix that could accommodate the minimum binder content while maintaining a target of between 2 and 4 percent of voids measured using Marshall compacted specimens. The stabilising agent was Arbocel cellulose fibres (grade ZZ81) and the Schellenberg (1988) binder drainage test was employed to check for mix stability.

6.2 MANUFACTURE

The Contractor used a batch-mix plant. The composition of SMA is critical and therefore the grading control and operation of the mixing plant were closely controlled. The cellulose fibres were added by hand into the weigh hopper; one 9 kg pack supplied in a meltable plastic bag was added to every 3 tonne batch of the mix. The mixing temperature was close to 180°C for all the material produced.

With this close control of production, no problems were reported by the Contractor.

The Contractor reported that the longer mixing cycle and the addition of fibres would increase material cost compared to HRA. In the trial the fibres were added manually, however plant in the UK tends to be larger than that in Germany and consequently in the longer term it is likely that capital expenditure would be required to install

TABLE 4

Details of Materials Laid

	SMA Grades		
	14 mm	10 mm	6 mm
Aggregate		Granite (Cliffe Hill, Leicestershire)	
Polished Stone Value PSV		55	
Aggregate Abrasion Value (AAV)		3	
Aggregate Impact value (AIV)		12	
Ten Percent Fines Value (TFV)		330	
Filler		Limestone	
Stabilising agent		Cellulose fibres (0.3% M/M)	
Binder: Penetration grade (0.1mm)	50	50	100
Void Content (%V/V) ASTM D3203	4.0	4.4	-
		LAYING CONDITIONS	
Layer thicknesses (mm)	40	40, 25 and 20	20 and 10
Ambient air temp (°C)		10	
Wind speed (km/h)		15	
Mixing temp. (°C)	180	182	180
Temp. in hopper (°C)	170	166	171
Temp. prior to rolling (°C)	147	164	148

TABLE 5

Composition Envelope used for Mix Design

Sieve Size (mm)	SMA Mixes (Percent by mass passing BS sieve) 14 mm	10 mm	6 mm
14	90-100	100	100
10	35-60	90-100	100
5	23-35	30-50	90-100
2.36	18-30	22-32	32-42
0.075	8-13	8-13	8-13
Min. Binder Content (%M/M)	6.5	6.8	7.5
Stabiliser Cellulose fibres (%M/M)	0.3	0.3	0.3

automatic dosing equipment. Higher running costs of the mixing plant would also be incurred because of greater wear resulting from the extended dry mixing cycle and fibres would increase the frequency of replacing filter bags in the dust extraction system.

6.3 LAYING AND COMPACTION

When the material arrived on site there was no evidence of the binder and aggregate segregating, even though the material had been in the lorries for between 2 and 3 hours. The delivery temperature was in the expected range, with the measured temperature of the material in the paver hopper being about 170°C. The measured temperature of the material just prior to rolling was in the range 147°C to 164°C.

The existing wearing course in the trial area was planed out to the required depths and a light tack coat was applied a few hours before laying. The laying went ahead without difficulty. The material did not drag, segregate or push. The Contractor reported that, compared to hot rolled asphalt, the material was very stiff and the paver gang found it difficult to rake and handlay. However, there was little need to do this, and it was found easy to use. An example of this was that, when a large stone jammed under the screed while laying the 10 mm thick layer, it was possible to lift the screed, remove the stone and then continue laying without trouble. The material required little attention, compared to convention HRA wearing course, and the Contractor was of the opinion that, if this trial was typical, the paving gang could be reduced in number.

Two rollers were used for compaction; an 8-10 tonne vibratory tandem and a 3-wheel deadweight of similar weight. The tandem roller, without the use of vibration, operated close to the paver while the 3-wheeled roller completed the compaction further back. Compaction consisted of between 10 and 12 roller passes distributed across the complete width of the mat and the rolling was completed within 4 minutes of laying for the thinnest layer. Most compaction occurred in the first few passes but the hump that occurred during the first change over from 14 mm to 10 mm SMA could not be completely removed by rolling. This difficulty did not arise with the second change over of material.

After successfully laying the nominal 10 mm thick layer in cold, breezy conditions, the Contractor foresaw that laying 14 mm SMA to a thickness of 30 mm would not be a problem and 25 mm as a distinct possibility.

Figure 2 shows the trial in progress and Figure 3 shows the completed trial and gives an indication of the satisfactory and uniform surface texture achieved.

7. LABORATORY AND FIELD MEASUREMENTS

The properties listed in Table 6 were measured after the material was laid.

7.1 DEFORMATION RESISTANCE

The wheel-tracking test is used to give a measure of the rutting resistance of bituminous wearing course materials. Szatkowski and Jacobs (1977) have demonstrated that the results of this test correlate well with rutting in the field. Cores were taken from the 14 and 10 mm SMA sections that had been laid 40 mm thick and tested in the wheel-track test in accordance with BS DD 184 (1990). The results show that both materials have excellent resistance to rutting. An average rate of rutting of 0.8 mm/h was recorded for the 10 mm SMA and 1.10 mm/h for the 14 mm SMA.

The results of earlier work by Jacobs (1981) predicts that a wheel-tracking rate of 2 mm/h, achievable with a good

Figure 2 The Demonstration Trial in Progress

Figure 3 The Finished Surface of the 14mm SMA

TABLE 6

Properties of SMA Measured

Property	Method of Measurement
Resistance to rutting	Wheel tracking test (BS DD 184).
Texture depth	Sand patch test. Mini-texture meter (MTM).
Surface friction	Sideways Coefficient Routine Investigation Machine (SCRIM). Braking force coefficient (BFC)
Tyre noise	Statistical coast-by method (LR 896)

HRA, would equate to a rate of rutting of 0.5 mm/year on a road carrying 6,000 commercial vehicles per day. The measured wheel-tracking rates indicate that ruts will develop at half this rate with an SMA.

7.2 SURFACE CHARACTERISTICS

The texture depth was measured using both the mini-texture meter and the sand patch test. The results are shown in Table 7.

The 14 mm SMA produced a surface texture better than the minimum of 1.5 mm required for the new surfacing of high speed roads by the Department of Transport (Specification for Highway Works, 1993). However, SMAs using the smaller aggregates did not met this requirement and thus could not be used on trunk roads and motorways. They could however be used on lower category roads. Serfass (1992) reports that after a few months of traffic the texture almost invariably improves by about 0.1 mm as the surface mastic is eroded away so that the 10 mm, with improved design, may perform acceptably on the Department's roads.

The skidding resistance of the new surface was measured with the Sideways Coefficient Routine Investigation Machine (SCRIM) described by Hosking and Woodford (1976). The results of three runs made over each surface at 50 km/h are given in Table 8. Table 9 gives measurements of Braking Force Coefficient (BFC) carried out at 50 km/h and 130 km/h.

Both the SCRIM and the BFC values relate to untrafficked material that still retains a thick binder film on the exposed aggregate surface. These values are likely to improve after a few weeks of traffic due to the binder film wearing away and then the skidding resistance would be related to the PSV of the aggregate used. The SCRIM coefficients for the newly laid SMA fulfil the requirements given by the Department (HD 28/94, 1994) for all categories of roads and they compare well with those measured early in 1994 on untrafficked porous macadam laid on the M4. These were in the range 0.49 to 0.58 over a 0.35 km length. However, SCRIM measurements are dependent on the microtexture of the aggregate and variations are expected for different sources of aggregate.

Table 9 gives BFC values for the different grades of the newly laid SMA. The difference between BFC measurements at 50 km/h and 130 km/h has been used as an indicator of the importance of texture and it is interesting that the fall-off in BFC value between 50 km/h and 130 km/h is similar for the three SMAs although they have substantially different textures. BFC values measured for eighteen new surfacings were in the range 64 to 33 at 50km/h and 47 to 26 at 130 km/h. The measurements for SMA, particularly at the higher speed, were at or below the bottom end of this range. The reason for this low behaviour was thought to be due to the very thick binder film on the exposed surface of the aggregate. Inspection after being traversed by the braked wheel showed that the braking forces had failed to remove the thick film of binder.

TABLE 7

Measurements of Surface Texture

Test Method	Texture Depth (mm) 14mm SMA	 10mm SMA	 6mm SMA
Sand patch test.	1.65	1.27	0.50
No. of tests.	12	18	6
Standard Deviation	0.23	0.12	0.06
Mini-texture meter	1.17	0.91	0.51

TABLE 8

Measurements of Sideways Skid Resistance

Surface Type	Run No.	SCRIM Coefficient
	1	0.61
6 mm SMA	2	0.59
	3	0.62
	Average	0.61
	1	0.63
10 mm SMA	2	0.66
	3	0.64
	Average	0.64
	1	0.61
14 mm SMA	2	0.62
	3	0.63
	Average	0.62

TABLE 9

Measurements of Braking Force Coefficient (BFC)

Surface Type	Braking Force Coefficient	
	At 50 km/h	At 130 km/h
6 mm SMA	32	23
10 mm SMA	36	24
14 mm SMA	37	26

It has not been possible to assess the long term durability of the surface characteristics of SMA from this trial. However, Serfass et al (1992) has measured initial texture depths using the sand patch test of between 0.8 mm and 2.2 mm on SMA layers laid on a large number of sites, including motorways, in France. He reports that texture increases slightly in the first few months and thereafter the texture depth stabilises with measurements being in the range 0.8 mm to 1.6 mm after several years of traffic. He also reports that measurements of good longitudinal skid resistance on roads up to 7 years old have demonstrated that the surface characteristics of SMA are durable.

It is important to note that the SMA tested was newly laid, untrafficked material and to obtain a true picture of its surface friction characteristics would require laying material in road trials and measuring skidding resistance over an extended period.

7.3 TYRE NOISE

The predominately tyre/surface generated noise due to a coasting vehicle was measured for all three SMA surfaces using the technique described by Franklin, Harland and Nelson (1979). For each surface, vehicle coast-by noise measurements were carried out using a microphone positioned 7.5 m from the centre of the lane and 1.2 m above the road surface. All measurements were carried out under dry, near windless conditions. The maximum average noise levels of several readings for coasting vehicle speeds of 70 km/h and 90 km/h are shown in Table 10.

The Table shows that at both speeds the noise levels increase by about 2.5 dB(A) as the maximum stone size in the SMA increases from 6 to 14 mm. The results for a hot rolled asphalt are included in this Table to enable the coast-by noise levels to be compared with a typical high speed road surface used in the UK. The values in brackets give the increase in noise levels for the HRA compared with the SMA surface.

In addition to recording the overall noise level the frequency spectra was captured for the maximum coast-by noise level. The frequency spectra measured at 70 and 90 km/h had similar characteristics and it is illustrated in Figure 4 for the higher speed.

TABLE 10

Average Maximum Noise Level

Surface Type		Average Maximum Coast-by Noise level dB(A) 70 km/h	90 km/h
6 mm SMA		70.6 (5.3)	74.5 (5.2)
10 mm SMA		72.4 (3.5)	76.5 (3.2)
14 mm SMA		73.2 (2.7)	77.0 (2.7)
HRA	Average	75.9	79.7
	Range	75.0 - 76.9	78.9 - 80.7

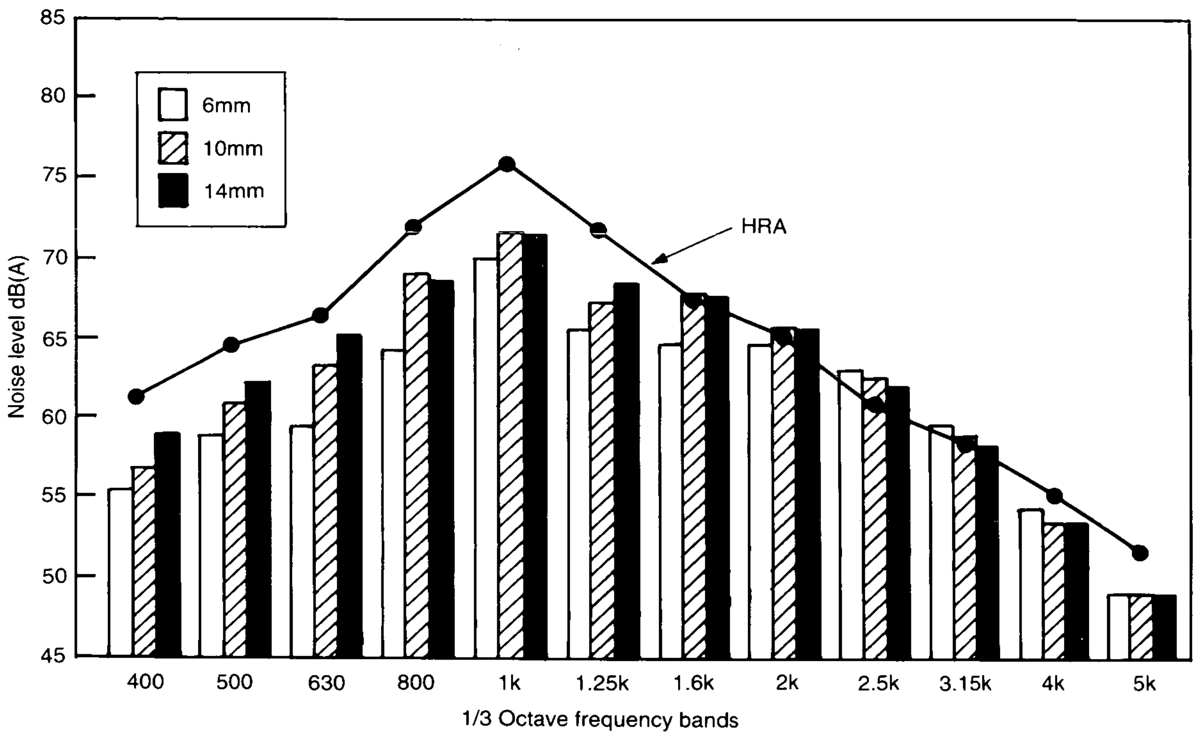

Fig. 4 Comparison of coast-by noise levels

This Figure shows how the sound energy is distributed over the frequency range most sensitive to the human ear. It shows that over the frequency range 400 Hz to 1.25 kHz the SMA generates lower tyre noise levels compared to a HRA surface. At higher frequencies the differences are small.

The dB(A) scale is a useful indicator of subjective noisiness, however it is generally recognised that a more sophisticated measure of loudness in sones has advantages over the dB(A) scale. The sone measure, established by Zwicker (1985), models the way the human hearing system responds to sounds and takes into account its ability to mask the effect of sound at one frequency by sounds at other frequencies. The loudness values for the tyre generated noise, given in Table 11, indicate that SMA surfaces are between 12 and 24 percent quieter than HRA and that this reduction is dependent on the aggregate stone size of the SMA and to some extent on vehicle speed. As the stone size increases the difference in the loudness between HRA and SMA reduces as previously indicated on the dB(A) scale.

TABLE 11

Average Maximum Loudness Level

Surface Type	Average Maximum Coast-by Loudness Level (sone) 70 km/h	90 km/h
6mm SMA	23.7 (24%)	29.8 (22%)
10mm SMA	25.8 (17%)	32.7 (14%)
14mm SMA	26.7 (14%)	33.5 (12%)
HRA Average	31.2	38.1

The results demonstrate the potential benefits in noise and loudness reduction that SMA surfaces may achieve compared with traditional surfaces. For high speed traffic the dominant noise source, particularly for light vehicles is from tyre/surface noise. Reductions in noise levels of the order of 3 dB(A) is comparable to the effect of a 50 percent reduction in traffic flow.

8. ADAPTION FOR THE UK

It should be stressed that measurements carried out on the examples of SMA laid for the demonstration trial can only give a very broad indication of typical properties of the material. Nevertheless, the trial confirmed that the SMA has good potential as a wearing course material in the UK, it appears to have some advantages over HRA. It is very resistant to rutting and experience elsewhere has demonstrated that it also resists cracking, and it provides a good riding quality surface. Furthermore it can be laid as a thin layer and it reduces traffic noise, which is becoming a more desirable property in an increasingly environmentally aware society. On the other hand SMA does cost more, it is estimated to be between 15 and 20 percent more expensive than HRA wearing course.

UK aggregate sizes differ from those in countries where SMA is used, and therefore SMA gradings would need to adapted to suit the UK sieve sizes. The trial, however, demonstrated that this will not be a problem. SMA does use a higher proportion of good quality fully crushed aggregates compared to HRA. This could be a disadvantage in regions where stone has to be imported, and here HRA, which often has a high content of local sand, may retain an advantage.

In the design process it is necessary to demonstrate that the binder and aggregate do not segregate during mixing, storage, transport and laying. The Schellenberg binder drainage test is most frequently used. Currently a binder drainage test developed by Daines (1992) is used, in the design of porous asphalt. It is not desirable to have two separate binder drainage tests in use in the UK and therefore it would be worth considering the test developed by Daines for both materials.

The investigation described in this report shows that SMA has considerable potential and should be considered for use in the UK. However more experience is required before it can be specified with confidence. It is recommended that the material is introduced on a trial basis until confidence is fully established over a range of contractual conditions using a range of ingredients. Both SMA and porous asphalt are gap-graded materials whose performance depends on a very stable stone skeleton. Consequently there may be value in experimenting with compositions intermediate between these two materials to produce good texture and durability. A draft specification has been prepared by the Road Engineering and Environmental Division of the Highways Agency (Appendix A) and trial lengths of SMA should be included in several trunk road resurfacing contracts. The monitoring of these trials would lead to the development of a specification and provide more information on the materials surface characteristics, particularly its skidding resistance in the longer term.

9. CONCLUSIONS

This investigation included one full-scale trial with the supporting laboratory based studies as well as an assessment of experience of SMA in other countries. The following conclusions can be drawn from this evaluation:-

1. SMA can be designed, produced and laid successfully by UK contractors using existing plant. The trial demonstrated clearly the feasibility of using SMA in the UK. Furthermore with a careful choice of aggregate size and grading SMA has the potential to meet UK surface texture requirements, to be laid as a thin layer, and it generates less tyre noise. Experience in countries that have adopted SMA has shown it to be very durable.

2. From the successful trial, it can be concluded that the material could be used in carefully monitored road trials to build up experience before considering it for general use.

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APPENDIX A: DRAFT CLAUSE STONE MASTIC ASPHALT WEARING COURSE

A.1 INTRODUCTION

Stone mastic asphalt is a gap-graded mixture with about 70 - 80 percent stone content, 6 - 7 percent of binder, 8 - 12 percent respectively of filler and bitumen and about 0.3 percent fibres or similar modifier. The design parameters are set to ensure a mixture which will be durable when compacted in layers of 25 - 40 mm thickness.

The high stone content of the mixture forms a skeleton-type structure offering high resistance to deformation. The fibres or modifier act to prevent binder drainage during manufacture, transportation and laying. The mixture is very durable and rut resistant and provides a medium level of surface texture.

Trials are in progress to evaluate the mixture, the objectives of which are to monitor aspects of durability, economics of production, skidding resistance and noise levels. The specification clauses given below should only be used as an indication as to the expected requirements. They will be subject to revision and amendment as on-going research and monitoring of the trial areas continues. References to other clauses refer to the Specification for Highway Works (August 1993).

This specification has been prepared by the Highways Agency. Comments and enquiries should be directed to:

The Head of Division
Road Engineering and Environmental Division
Highways Agency
St Christopher House, Southwark Street
London, SE1 OTE

SPECIFICATION CLAUSE

A.2 GENERAL

A.2.1

Stone mastic asphalt shall comply with the general requirements of BS 4987 for coated macadam, the Specification for Highways Works and the specific requirements of the following sub-Clauses.

A.3 MATERIALS

A.3.1 AGGREGATES AND FILLER

A.3.1.1

Coarse aggregate shall be crushed rock or crushed slag complying with Clause 901.

A.3.1.2

When tested in accordance with the procedures of BS 812, the coarse aggregate shall additionally have the following properties:

Polished Stone Value - not less than 45, or as specified in Appendix 7/1.

Ten Percent Fines Value - not less than 180 kN when tested in a dry condition, or as specified in Appendix 7/1.

Maximum Aggregate Abrasion Value - not more than 12, or as specified in Appendix 7/1.

Maximum Flakiness Index - for the coarse aggregate only, 30 percent, or as specified in Appendix 7/1.

A.3.1.3

Fine aggregate shall comply with Clause 901 and shall comprise crushed rock, crushed slag or crushed gravel fines, which may be blended with not more than 50 percent natural sand.

A.3.1.4

Added filler shall be hydrated lime, crushed limestone or Portland Cement, in accordance with the requirements of BS 594 : Part 1 and shall be at least 2 percent by mass of total aggregate.

A.3.2 BINDER

A.3.2.1

Unless specified otherwise in Appendix 7/1, either a modified binder or, alternatively, bitumen with a stabilising additive, shall be used, at the choice of the Contractor. Modifiers include any material added to or blended with the base bitumen.

A.3.2.2

Bitumen shall comply with BS 3690 : Part 1 and shall have a nominal penetration of 50 or 100, unless specified otherwise in Appendix 7/1.

A.3.2.3

If a modified binder is used, the base bitumen, before modification, shall comply with BS 3690 : Part 1, and shall have a nominal penetration of 50 or 100 or 200, unless specified otherwise in Appendix 7/1.

A.3.2.4

The choice of bitumen grade or type of modified binder shall be notified to the Engineer before the commencement of work.

A.3.3 STABILISING ADDITIVE OR MODIFIED BINDERS

A.3.3.1

When bitumen complying with BS 3690 : Part 1 is used as the binder, at least 0.3 percent by mass of total mixture of stabilising additive shall be used to ensure binder drainage does not occur during transport and handling. Stabilising additives shall be cellulose or mineral or other suitable fibre.

A.3.3.2

Proposals to use a bitumen and stabilising additive, or a modified binder, shall be submitted to the Engineer, complete with all details, including binder drainage test results, manufacturer's recommendations for addition or means of incorporating any stabilising additives or modifiers, homogeneously, without segregation, into the mix.

A.3.3.3

Before agreeing the use of an additive or modified bitumen, the Engineer shall be satisfied it has proved satisfactory in use under circumstances, similar to the Contract, elsewhere or that it has undergone appropriate performance trials. For the purpose of this sub-clause, documented evidence of use and trials of the additive or modifier, in any member country of the European Union, will be acceptable.

Where information on use or trials is inadequate or lacking, in the opinion of the Engineer, trials may be required to be undertaken before agreeing the use of the additive or modifier.

A.4 MIXTURE

A.4.1

The target aggregate grading and target binder content proposed by the Contractor shall fall within the envelope formed by the limits given in Table A1, unless agreed otherwise by the Engineer before the commencement of work.

Adjustments may be required to the above binder content ranges to account for the varying density of slag aggregates should these be used.

A.4.2

The Contractor shall demonstrate the properties of the proposed mixture, at the target composition, by preparing loose mixture and compacted specimens in accordance with the general requirements of BS 598 : Part 107. The loose mixture and compacted specimens shall comply with the requirements of Clause 4.3 and 4.5 below.

A.4.3

When tested at the target composition, the loose mixture shall demonstrate not more than 0.3 percent binder drainage, by total mass of mixture, at a temperature of 175°C. The test shall be carried out using the apparatus and general principles stated in Clause 939. The drainage shall be calculated as:

$$\text{Binder drainage} = [(W_2 - W_1)/(1100 + B)] \times 100\%$$

where B is the initial mass of binder in the mixture, W_1 and W_2 are the mass of tray and foil before testing and tray and foil and drained binder after testing and the mass of combined aggregate before addition of binder was 1100 gm, all as stated in Clause 939.

TABLE A1

Aggregate Grading and Binder Content

BS SIEVE SIZE mm	Per Cent by mass of total aggregate passing Nominal Size 14 mm	10 mm
20	100	
14	90 - 100	100
10	35 - 60	90 - 100
6.3	23 - 35	30 - 50
2.36	18 - 30	22 - 32
75 micron	8 - 13	8 - 13
Binder % by mass	6.5 - 7.5	6.5 - 7.0

A.4.4

Three compacted specimens shall be manufactured at the target composition and the air void contents of these shall be measured by the procedure described in ASTM D 3203 (or DD XYZ - Methods for determination of maximum density of bituminous mixtures), using:

(a) the maximum density of the mixture, obtained using the theoretical maximum specific gravity of the loose mixture, determined in accordance with ASTM D 2041 and converted to relative density using the appropriate correction factor.

(b) the bulk density of the specimen, determined in accordance with BS 598 : Part 104 : Clause 4, as the bulk density required by ASTM D 3203, except the specimens shall not be coated in wax.

A.4.5

At the target composition, the air void content of the mixture shall be within the range 2 - 4%.

A.5 MIXING

A.5.1

Stone mastic asphalt shall be mixed in accordance with the requirements of BS 4987 : Part 1, such that an homogeneous mixture of aggregate, filler, bitumen and, when used, additive, is produced at a temperature of 150 - 190 degrees C. At the time of mixing, the coarse aggregate shall be in a surface dry condition.

A.6 TRANSPORTATION

A.6.1

Stone mastic asphalt shall be transported to site in double-sheeted or tented and sealed ridge sheeted insulated vehicles.

A.6.2

To facilitate discharge of stone mastic asphalt, the floor of the vehicle may be coated in accordance with the requirements of BS 598 Clause 4.3. When a coating is used then, prior to loading, the body shall be tipped to its fullest extent, with the tailboard open, to ensure drainage of any excess. The floor of the vehicle shall be free from adherent bituminous materials or other contaminants.

A.7 SURFACE PREPARATION

A.7.1

Existing surfaces shall be prepared in accordance with the requirements of BS 4987 and the Series 700. Tack coat shall be K1-40 cationic bitumen emulsion complying with BS 434 : Part 1. It shall be spray-applied at a rate of 0.3 - 0.5 L/m^2 to completely cover the surface and shall be allowed to completely break before the stone mastic asphalt is laid.

A.7.2

Where necessary, or when required by the Engineer, existing surfaces shall be regulated in accordance with the requirements of Clause 907.

A.7.3

Unless raised prior to surfacing, iron-work and reflecting road studs shall be located for lifting and relaying after completion of surfacing works. Gullies shall be covered prior to surfacing.

A.8 LAYING

A.8.1

Unless required otherwise, stone mastic asphalt shall be laid and compacted in accordance with the requirements of Clause 901, to the thickness stated in Appendix 7/1.

A.9 COMPACTION

A.9.1

Stone mastic asphalt shall be compacted immediately, to practical refusal, using at least two steel-wheeled rollers, with a minimum mass of 6 tonne, per paver. One roller shall be a tandem drum roller.

A.9.2

The tandem drum roller shall operate directly behind the paver, while the other roller shall be used for completion of rolling and the removal of all roller marks.

A.10 SURFACE TEXTURE

A.10.1

When stated in Appendix 7/1, the texture depth of the surfacing shall be in accordance with the requirements of Clause 921 after compaction.

A.11 COMPLIANCE OF MIXTURE

A.11.1

The agreed mixture shall be that obtained following completion of mixture design and the agreement of a target binder content and target aggregate grading for the mixture.

NOTE FOR GUIDANCE: The agreed mixture is that obtained after the Contractor demonstrates a mixture which complies with the above requirements, and then proposes that mixture to the Engineer for agreement.

A.11.2

When sampled and tested in accordance with the procedures of BS 598 : Parts 100, 101 and 102, the approved aggregate grading limits for compliance purposes shall be those obtained by applying the tolerances given in Table A2 to the grading of the agreed mixture. The grading curve of the aggregates shall not vary from the low limit on one size of sieve to the high limit on the adjacent size or sieve or vice-versa.

A.11.3

When tested in accordance with the methods of BS 598, the sampling and testing tolerance for binder content shall be ± 0.6.

A.12 DETAILS TO BE SUPPLIED

A.12.1

The Contractor shall supply all the details required in this Clause to the Engineer before commencement of work under this Clause and when requested during the work.

A.12.2

The Contractor shall supply the Engineer with test certificates stating the properties of the materials used. Samples of emulsion tack coat, modified or unmodified bitumen, additive or mixed bituminous materials from the pavement surface or other suitable sampling point shall also be supplied to the Engineer by the Contractor when so instructed by the Engineer.

TABLE A2

Tolerances for Aggregate Grading 14 mm and 10 mm size

BS Test Sieve	Tolerances for aggregate grading in percent by mass of aggregate passing BS test sieve
14 mm	±5
10 mm	±10
6.3 mm	±8
2.36 mm	±7
75 micron	±2

Note : Application of the above tolerances to the target grading may result in limits outside those permitted by the appropriate envelope in Table 1. This is acceptable.

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