

Stone mastic asphalt: assessing the effect of cellulose fibre additives

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- Currently, in the UK, there is considerable interest in the fact that a German bituminous surfacing mixture known as stone mastic asphalt may possess levels of in-service performance that resist the growing incidence of premature failure experienced by traditional materials such as hot rolled asphalt. A high stone content grading requires the use of a stabilizing additive to ensure long-term performance. The most common type of additive is cellulose fibre. This paper assesses the effect that the addition of differing types of this fibre has on measurable bituminous mix properties.

Keywords: roads & highways; pavement design; strength & testing of materials

Introduction

Traditionally, the most common type of surfacing for motorways and other main roads in the UK has been hot rolled asphalt (HRA).¹ However, in recent years its expectation to perform has been severely tested due to hot summers and ever-increasing volumes of heavy traffic. Permanent deformation has become a serious problem. In response, there has been the recent introduction of Clause 943 HRA² designed to resist this problem by the incorporation of modified binders and inclusion of sands and fillers with which there has been little long-term experience.

2. Elsewhere in Europe, the problem of permanent deformation has existed for many years. During the 1960s and 1970s, the use of studded tyres and high binder content surfacing mixes in Germany resulted in unacceptable levels of rutting. Research into this performance problem resulted in the development of stone mastic asphalt (SMA). Although the use of studded tyres was banned in 1975, the use of SMA has continued because practical experience and observation has shown it to perform better than traditional mixes.

3. Resistance to permanent deformation was obtained by a stable gap-graded aggregate skeleton structure with voids filled with a mastic mortar of bitumen, crushed sand and filler. To maintain a durable material, it has been found that SMA requires a stabilizing additive. This is required for a number of

reasons, for example to prevent drainage of bitumen off the coarse aggregate grading, to increase the thickness of the bitumen coating to reduce the effects of oxidation and ageing, and to improve cohesiveness of the mixture.

4. A number of different additives may be used including fibre-, polymer- and silica-based types. This paper details research carried out at the University of Ulster into understanding the role played by the most common type, that is, cellulose fibre, and how its addition to SMA affects mix performance as measured in the laboratory.

Specification of stone mastic asphalt

5. SMA may be classified as a hot bituminous mixture containing a high percentage of high quality coarse gap-graded aggregate, a high bitumen content of 6–7% with an additive to minimize binder drainage. The coarse aggregate creates a close, interlocked skeletal structure that helps to dissipate impact to underlying layers. It also provides resistance to wear and permanent deformation. A lack of medium-sized aggregate particles results in a rougher surface texture, increasing skid resistance and noise absorption. In general terms, a well-designed SMA should have the following properties

- (a) high stability, rutting and deformation resistance
- (b) good frictional properties
- (c) increased durability and anti-ageing properties
- (d) reduced water spray
- (e) reduced traffic noise
- (f) mix homogeneity.

6. In Germany, three grades of SMA may be used: 0–11 mm, 0–8 mm and 0–5 mm. The grading limits shown in Table 1 are taken from the German regulations of the ZTV Asphalt Stb96.³ SMA has now gained world wide acceptance. In the UK it is steadily being considered and used as an alternative surfacing mix to traditional HRA. A report published by the Transport Research Laboratory⁴ described an evaluation of SMA arising out of the importance of identifying European mixes that could be adopted in the UK. Road trials and wheel-tracking testing highlighted the

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Table 1. Summary of German SMA specification (modified 1996)

Stone mastic grade	0/11S	0/8S	0/8	0/5
Aggregates	High quality crushed rock, quarry sand, additional filler			
Sieve size: mm	% by weight			
> 11.2	≤ 10	—	—	—
> 8	≥ 40	≤ 10	≤ 10	—
> 5	60–70	≥ 55	50–70	≤ 10
> 2	75–80	75–80	70–80	60–70
< 0.09	9–13	10–13	10–13	10–13
Quarry sand—natural sand ratio	≥ 1:1			
Bitumen type: penetration	B65	B65	B80	B80
Bitumen content	6.5–7.5	7.0–7.5		7.2–8.0
Stabilizer content in mix: % by weight	0.3–1.5			
Void content of Marshall specimen compacted at 135°C: % by volume	3.0–4.0		2.0–4.0	
Layer thickness: mm	35–40	30–40	25–35	15–25
Layer void content: % by volume	≤ 6.0			

ability of SMA to withstand permanent deformation and meet UK surface texture requirements. The report included a draft clause specification for wearing course SMA. A summary of the draft clause is given in Table 2.

Stabilizing additives for SMA mixtures

7. Both the German and UK specifications specify a stabilizing additive. Table 3 shows the different types of additive used in

Germany. Because of its low price and, given the lowest bidding price concept, it can be seen that cellulose fibre dominates the German market. Trials and practical experience have also shown cellulose fibre to be used in preference to other additives because it is easy to handle, temperature inert, has the best effect in reducing binder drainage and causes no health or recycling problems.

8. Addition of cellulose fibre to SMA does not chemically modify the bitumen used;

Table 2. Summary of draft British SMA specification.⁴ PSV, polish stone value; TFV; ten percent fines value; AAV, aggregate abrasion value; FI, flakiness value

Coarse aggregate	PSV > 45, or as specified in Appendix 7/1 TFV > 180 kN, or as specified in Appendix 7/1 AAV < 12, or as specified in Appendix 7/1 FI < 30%, or as specified in Appendix 7/1	
Fine aggregate	To comply with Clause 901 and comprise crushed rock, crushed slag or crushed gravel fines, which may be blended with not more than 50% natural sand	
Added filler	Hydrated lime, crushed limestone, Portland cement and shall be > 2% by mass of total aggregate	
Aggregate grading	% by mass of total aggregate passing	
Sieve size: mm	14 mm SMA	10 mm SMA
20	100	—
14	90–100	100
10	35–60	90–100
6.3	23–35	30–50
2.36	18–30	22–32
0.075	8–13	8–13
Bitumen type	Modified binder—base binder 50, 100 or 200 pen 50 or 100 pen bitumen with a stabilizing additive	
Bitumen content	6.5–7.5	6.5–7.0
Stabilizer content in mix: % mass of total mix	> 0.3	
Binder drainage of loose mix	> 0.3% by total mass of mix according to method given in Clause 939	
Air void content of mix	2.0–4.0	

Table 3. Market share of SMA additives in Germany⁵

Type of additive	Market share in Germany: %
Cellulose fibre: Arbocel, Technocel	>90
Mineral fibre: Inorphil	<4
Polymer—SBS, SBP, EVA: Styrelf, Cariphalt, Olexobit, Vestoplast	<5
Silica: Sipernat	<1

rather, it enhances performance of the finished product by allowing the use of higher bitumen contents that tend to thicken and bulk the aggregate coating. The three-dimensional structure of cellulose fibre assists the bitumen to maintain a high viscosity and avoid binder drainage during storing, transportation and laying. The thicker coating of bitumen around each stone also reduces long-term oxidation, ageing and moisture penetration.

9. As cellulose fibre is fine in size and bulky, its addition during mixing requires special equipment and procedures. In response, cellulose fibre may be supplied in two basic ways: as loose fibre, contained in small plastic bags convenient for batch mixing; or it may be added during mixing by suitably modified plant. It may also be mixed with bitumen creating a pelletized form that may be easily handled and added during mixing.

10. While it is generally accepted that a polymer additive may substantially improve mix performance, cellulose fibre is typically regarded as having only a marginal improvement on the performance of SMA during its lifetime. However, given the different types and forms of cellulose fibre now available, this assumption needs validation. In terms of in-service performance, a number of important questions need to be addressed, including the following.

- (a) Do all types of cellulose fibre react with bitumen in a similar manner?
- (b) Do differing types of cellulose fibre become evenly distributed throughout the mix?
- (c) Can the benefit of cellulose fibre addition to SMA be quantified in the laboratory?

11. These basic questions have prompted research at the University of Ulster into determining the effect of cellulose fibre addition on the performance of SMA as measured in the laboratory. The remainder of the paper summarizes work carried out using three types of cellulose fibre currently available in the UK. The fibres were

- (a) loose cellulose fibre A, 0.025–2.5 mm length
- (b) loose cellulose fibre B, 0.025–1.6 mm length
- (c) a pelletized compound of 66% cellulose fibre and 33% bitumen.

Laboratory investigation of cellulose fibre additives in SMA

12. The laboratory investigation carried out was based on determining the effect that varying amounts of cellulose fibre had on a standard SMA using a range of test methods currently used in the UK to determine basic bituminous mixture properties. The investigation considered the following

- (a) manufacture of SMA test samples for investigation
- (b) determination of bitumen drainage using the Schellenberg binder drainage test
- (c) determination of Marshall stability and flow characteristics
- (d) determination of SMA mixture cohesiveness using the Cantabro test
- (e) determination of SMA mixture stiffness using the indirect tensile stiffness modulus test method
- (f) determination of SMA mixture resistance to permanent deformation using a modified indirect tensile fatigue test method

Manufacture of SMA test samples for investigation

13. An SMA mix grading (UUJSMA) was prepared based on both the German 0/11S and British 14 mm specification requirements.⁴ The grading curve limits of UUJSMA are shown in Fig. 1. Test samples were prepared using Marshall compaction apparatus as specified in the German specification. The mixing temperature was 170°C with compaction carried out at 135°C using 50 blows of the hammer on each side of the sample. The different types of cellu-

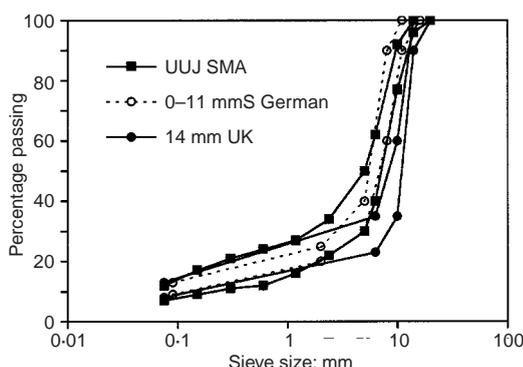


Fig. 1. SMA grading curves

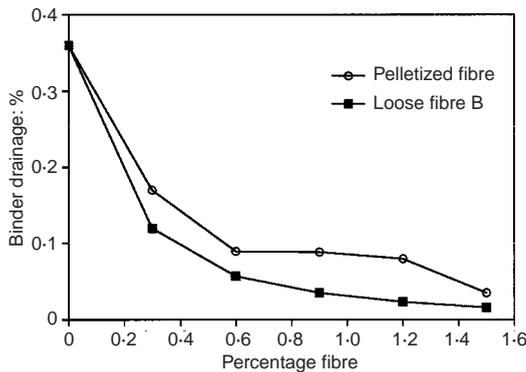


Fig. 2. Schellenberg binder drainage test data

lose fibre were added in varying proportions ranging from 0.3% to 1.2%.

Determination of binder drainage using the Schellenberg binder drainage test

14. This method was developed by the Schellenberg Laboratory in Germany to determine whether an unacceptable amount of bitumen drains from an SMA mixture.⁵ It was used to determine whether the different types of cellulose fibre had a similar effect on reducing bitumen drainage. The test entailed taking 1000 g of the SMA mix at 135°C and placing it into an 850 ml glass beaker which was then placed in an oven at 170°C for 1 h, after which the hot mix was poured out. By weighing the SMA mix before and after, the loss in weight gives the amount of bitumen that has drained off the aggregate particles. The results obtained are shown in Fig. 2. In Germany, a limit of >0.3% bitumen drainage is considered bad, <0.3% acceptable and <0.2% good. It can be seen that without the use of cellulose fibre there was 0.36% binder drainage. By the addition of just 0.3% of both fibres, binder drainage had reduced to 0.17% and 0.12% for the pelletized and loose fibres respectively. With increasing amounts of fibre, the loose fibre consistently gave lower values of binder drainage.

Determination of Marshall stability and flow characteristics

15. In Germany, the use of Marshall stability and flow is regarded as misleading and not suitable for the evaluation of an SMA mixture.⁶ Nevertheless, stability and flow characteristics were determined using the standard UUJ SMA mix and increasing amounts of cellulose fibre. Fig. 3 shows the results obtained for the pelletized fibre. It can be seen that there was a small increase in stability from 4.42 kN for 0% fibre to 4.79 kN for 1.5% fibre. The addition of fibre increased flow from 3.5 mm to 4.66 mm.

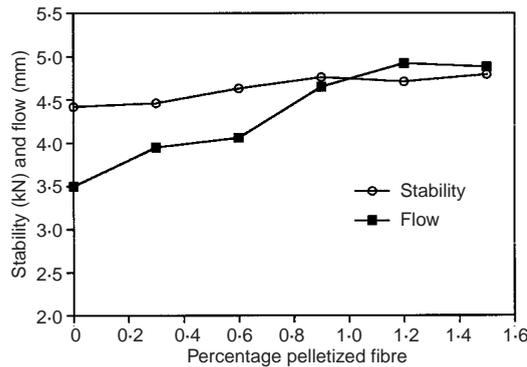


Fig. 3. Plot of Marshall stability and flow data with percentage of pelletized fibre

16. Although the data indicate that the addition of fibre affects stability and flow characteristics, its measurable influence is not great. The authors agree that the Marshall method of bituminous mix assessment is not suitable for predicting the effect of cellulose fibre addition on SMA mixture properties.

Determination of SMA mixture cohesiveness using the Cantabro test

17. The Cantabro test was developed in Spain to determine the cohesiveness of porous asphalt (PA) mixtures. Compacted test samples were tested to determine the effect of fibre addition on SMA mixture cohesiveness. The method used was based on that currently under consideration by the Comité de Normalisation (CEN) for assessing PA mixtures.⁷

18. Single Marshall moulds were placed in a Los Angeles drum and rotated. The percentage particle loss was determined every 50 rotations up to a total of 500 rotations. The test was repeated three times for each percentage of cellulose fibre additive. The results obtained for a pelletized fibre and a loose fibre are shown in Fig. 4. This plots the mass loss

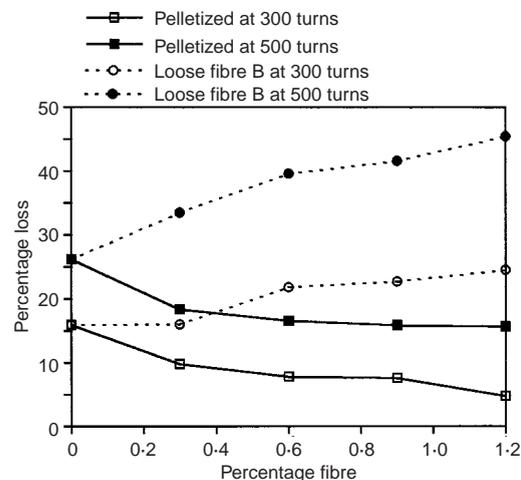


Fig. 4. Comparison of Cantabro data for two types of cellulose fibre

after 300 turns and after 500 turns against the amount of fibre additive. It can be seen that there was a noticeable difference in results for the two types of fibre. Addition of 0.3% pelletized cellulose fibre reduced Cantabro loss from 15.9% to 9.8% after 300 turns. This implies that addition of this type of pelletized cellulose fibre improved cohesiveness of the SMA mixture, making it more durable to the disintegrating forces acting inside the Los Angeles drum. Further addition of pelletized fibre continued to reduce particle loss.

19. In contrast, the addition of loose cellulose fibre had the opposite effect and caused particle loss to increase. This type of loose cellulose fibre may be absorbing excess bitumen, creating an increasingly 'dry' mix which could account for the increasing loss experienced during testing. Further addition of loose fibre continued to result in greater amounts of particle loss.

Determination of SMA mixture stiffness using the indirect tensile stiffness modulus test method

20. Mixture stiffness is now a recognized method of assessing bituminous materials in the UK. To determine whether addition of cellulose fibre affected mix stiffness, test samples were subjected to the indirect tensile stiffness modulus test (ITSM) using the Nottingham asphalt tester.⁸ The standard test conditions of 20°C and application of five load pulses were used. The results obtained for differing additions of a pelletized fibre and two types of loose cellulose fibre are shown in Fig. 5. For the two types of loose fibre, ITSM stiffness increased until an optimum addition of fibre, after which it decreased. In terms of maximum stiffness, the optimum addition of loose fibre was dependent upon the fibre, that is, 1% for loose fibre A and 0.6% for loose fibre B. Stiffness also increased with addition of pelletized fibre; however, an optimum value had not been reached at 1.5%.

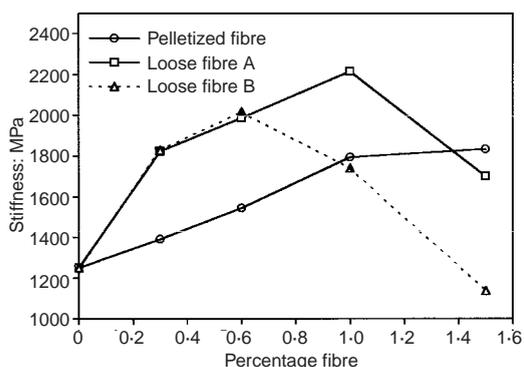


Fig. 5. Effect of cellulose fibre addition on SMA mixture ITSM stiffness

Determination of SMA mixture resistance to permanent deformation using the indirect tensile fatigue test method

21. Creating a mix with resistance to permanent deformation was one of the aims of the original development that resulted in SMA. In any bituminous material, application of a load causes a very small amount of deformation. After its removal, this loading causes a certain amount of irrecoverable deformation that will eventually result in a rut. Numerous factors need to be considered. With regard to the UK, these include the recent warmer-than-average summers, increasing amounts of traffic, increasing channelization and lane width reduction, a slowing of vehicle speeds due to congestion, and a reliance on high binder content HRA as the main type of surfacing material. The net result has been the premature rutting of many highway surfacings in the past few years.

22. A modified version of the indirect tensile fatigue test⁹ was used to determine what effect the addition of cellulose fibre would have on the resistance of SMA to this type of deformation. In this method, repeated load pulses are applied to a test sample. These generate indirect tensile stresses and strains eventually causing a crack to form. In this investigation, the number of load pulses required to cause an 8 mm deformation has been used to indicate the effect of fibre addition on SMA mixture performance. A greater number of load pulses represents greater resistance to permanent deformation. The test temperature was 20°C with a test stress of 300 kPa applied until an 8 mm deformation formed.

23. Figure 6 plots the number of load pulses required to cause an 8 mm deformation in test samples containing a pelletized cellulose fibre and two types of loose cellulose fibre. Similar to the ITSM data, there was an optimum addition for both types of loose fibre

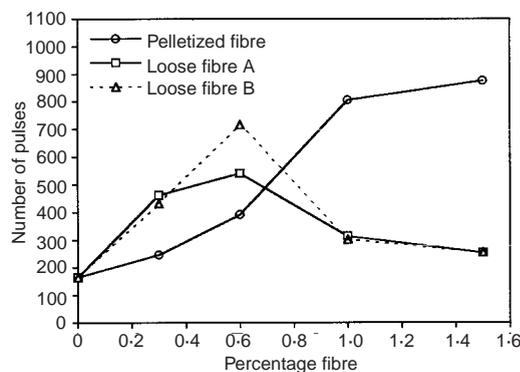


Fig. 6. Effect of cellulose fibre addition on the number of load pulses to cause 8 mm deformation during the ITFT test

after which resistance to permanent deformation decreased. An optimum for the addition of pelletized fibre was not reached within the range 0–1.5%. Continued addition of pelletized fibre improved the performance of the SMA mixture.

Conclusions

24. The investigation reported in this paper set out to determine whether the addition of differing types of cellulose fibre had any effect on the performance of SMA mixtures using a range of common laboratory-based test methods. Based on the results obtained, it may be possible to reach the following conclusions.

- (a) The addition of differing types of cellulose fibre affects the performance of laboratory-prepared SMA test samples.
- (b) The type of cellulose fibre, whether loose or pelletized, has been shown to affect the performance of laboratory-prepared SMA samples in differing ways.
- (c) Both types of cellulose fibre were shown to prevent binder drainage from an SMA mixture.
- (d) The use of Marshall stability and flow values was found to be of limited use in showing the effect of cellulose fibre addition to SMA mixtures.
- (e) The addition of loose cellulose fibre to an SMA mixture increased particle loss as shown by the Cantabro test. While required to reduce bitumen drainage, this suggests that the addition of excess loose cellulose fibre may produce a 'dry' mix that may have future durability problems. In contrast, the addition of pelletized cellulose fibre was shown to improve resistance to particle loss within the range of fibre additions assessed.
- (f) The addition of loose cellulose fibre increased ITSM stiffness until an optimum amount, above which stiffness decreased quite rapidly. Again, this shows the importance of close control in the addition of this type of cellulose fibre to SMA. The addition of pelletized fibre was shown to improve mix stiffness within the range assessed.
- (g) There appears to be an optimum amount of loose cellulose fibre addition in terms of SMA resistance to permanent deformation. The addition of pelletized fibre was shown

to improve resistance to permanent deformation within the range assessed.

25. The investigation has shown that the addition of cellulose fibre to SMA mixtures may affect performance in ways not being considered at present. While the addition of small amounts (0.3%) will reduce binder drainage, greater additions may affect in-service properties such as cohesiveness, stiffness and resistance to permanent deformation in unexpected ways which need to be considered should prediction of in-service performance be the aim.

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