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Characterization and testing of fibre-modified bitumen composites

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The binding of cellulose fibres to bitumen compared to polyester, mineral and glass fibres is presented. The surface characteristics of fibres were analysed using scanning electron micrographs and BET techniques. The results of elongation tests, softness, hardening and elasticity of the fibre–bitumen composites are shown. The influence of fibres in asphalt paving materials and mixtures used on roads is evaluated.

1. Introduction

Fibre–bitumen composites are rather new solutions in asphalt pavement technology, although many earlier applications with fibres have been reported. These are the use of fibres in cement concretes [1, 2] and in lightweight structures [3]. A composite is, however, a well-known term which means a material or a structure which, when processed from its original components using some extra component, is often better than that of the original components alone. In the fibre–bitumen composites, bitumen can be called the matrix material, the characteristics of which are changed by using fibres in this matrix as stabilizing additives.

The most common fibre type in bitumen blends is a cellulose fibre. Originally, the German "Splittmastixasphalt" paving mixture [4, 5] was stabilized with a cellulose fibre or with a mineral fibre. Fibres such as glass and steel have also been proved in road pavements but their use has been limited [6, 7]. Rather good laboratory results in the USA were also obtained when using a synthetic polyester fibre in reinforcing the asphalt paving mixtures [8].

In practice, the cellulose fibre has proved to be one of the most suitable fibres as a stabilizer in asphalt paving composites. For this reason, the characteristics of the cellulose fibre-modified bitumen blends have been compared with other fibres in this article.

2. Characteristics of materials

2.1. Bitumen

The bitumen in these studies was refined from Arabian Heavy crude and was a traditional quality on a penetration level 120 measured by the ASTM D 5–73 penetration test for road bitumens.

2.2. Fibre qualities

The fibres were common trade qualities or special national alternatives produced for the research. Some characteristics of the fibres are shown in Table I.

TABLE I Fibre contents found in asphalt blends

Fibre no.	Quality	Characteristics
2	Cellulose	Based on selected unbleached and mechanical spruce cellulose fibres, fibre length max. 5 mm, average 1.1 mm
7	Mineral	Based on limestone and diabase, fibre length 0.2–2 mm
8	Glass	Based on C-glass, common fibre lengths 1 or 2–5 mm
6	Polyester	Synthetic fibre, fibre length 6 mm

2.3. Microstructures and specific surface areas

The scanning electron micrograph of the cellulose fibre 2, which is the most frequently used quality, is shown in Fig. 1. The microstructures of different fibres were analysed see also [9]. Cellulose fibres are ribbon type, porous and their cross-section is flat. Part of the filaments has been broken due to tearing, thus increasing their surface area.

When the specific surface area was analysed by the sc BET techniques [10], the result for cellulose fibre 2 was very large, 2.6 $m^2\ g^{-1}$. With a different cellulose

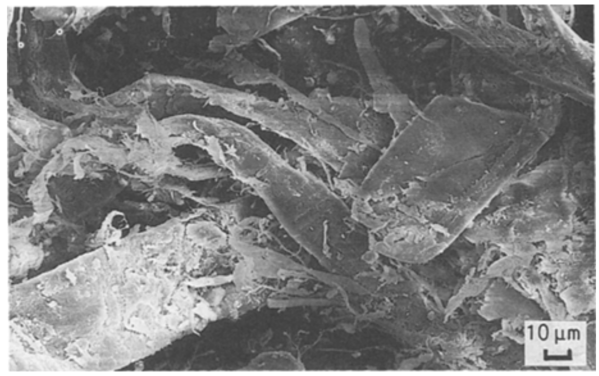

Figure 1 Scanning electron micrograph of a cellulose fibre.

fibre 3, which is not a commercial quality, the surface area was also large, 1.5 $m^2 g^{-1}$. Compared to mineral, glass or synthetic fibres (PES), the surface areas of the cellulose fibres can be even ten-fold. These characteristics of the commercial cellulose fibres, explain the efficiency of the fibre to bind more bitumen.

Fig. 1 also shows that the cellulose fibres can obviously form a network in three directions in the bitumen, which also prevents bitumen from flowing out of the blend.

The microstructure of a mineral and a glass fibre differs from the structure of the cellulose fibres. The cross-section of these fibres is quite round and their surface is smooth and the surface area much smaller. The surface areas were analysed by BET techniques [10] for the mineral fibre 7 and glass 8 which are both commercial qualities. The results were only 0.1 and 0.2 m^2g^{-1}.

The microstructure of a commercial, synthetic polyester, fibre 6 is shown in Fig. 2.

A polyester fibre, like mineral and glass fibres, is also round, not flat or torn like the cellulose fibre shown in Fig. 1. The approximate surface area of the polyester fibre, calculated and counted microscopically from a certain weight of fibres, is also rather low, 0.2 $m^2 g^{-1}$.

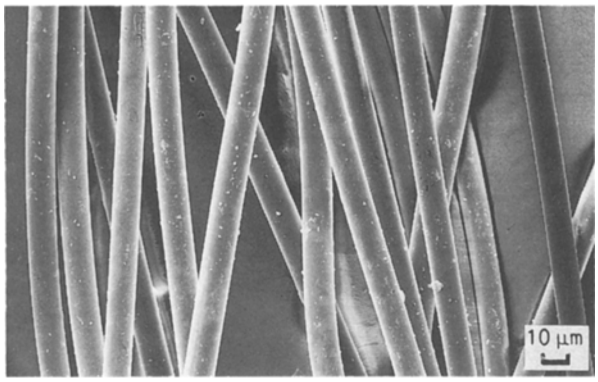

Figure 2 Micro-structure of a commercial polyester fibre.

3. Experimental procedure

3.1. Measuring of the binding effect

In the mixing and binding test, 3 g of each fibre were mixed with 5, 10, 15, 20 and 25 g hot bitumen. The blends were mixed well and spread onto the round filter paper for visual estimation, see Fig. 3. In this test, the highest binding effect was achieved by the cellulose fibre and was 17.5 g bitumen to 3 g fibre. The lowest value was obtained with the mineral fibre; only 5 g bitumen to 3 g fibre. The stabilization of bitumen with fibre was increased in the order cellulose > glass > polyester > mineral. This estimated order corresponds to the surface areas of the fibres. The result can be utilized in determining the correct bitumen content of an asphalt paving mixture.

3.2. Elongation tests

A force–elongation test, shown in Fig. 4, was performed. The forces were registered by two small strain gauges. The velocity of the strain was 50 mm min^{-1} and the testing temperature was + 7 °C.

Figure 3 Evaluation of the binding of the fibres to bitumen. (a) Cellulose fibre 2, (b) glass 8.

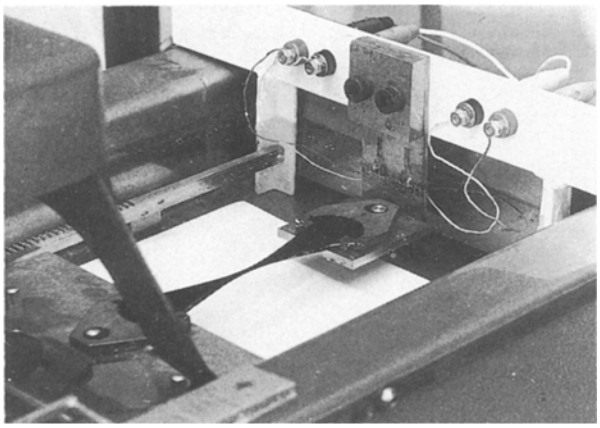

Figure 4 Testing arrangements for the force–strain test.

3.3. Viscosity

For Brookfield viscosities (Fig. 5), an automatic model HBTDV-II was used, which measures the variation of viscosity values with different rotating times of suitable spindels. The fibre–bitumen blends were so stiff at 60 °C that only a few values could be registered exactly.

3.4. Elastic recovery

Elastic recoveries of fibre–bitumen blends were analysed using a rotating elasticity test for modified bitumens [11]. In this test a steel staff was immersed in the hot, modified bituminous material, after which the staff was turned through 180 °. The elasticity after the torsion is calculated from the formula

$$E\,(\%) = (\alpha/180°)100 \quad (1)$$

where α is the recovered angle after torsion.

3.5. Softening point

The softening point test was based on an ASTM standard ball and ring test, D 2398-76. Owing to the use of fibres in the blends, larger mould rings, diameter 50 mm, were used. This modified test is also called the Wilhelm test.

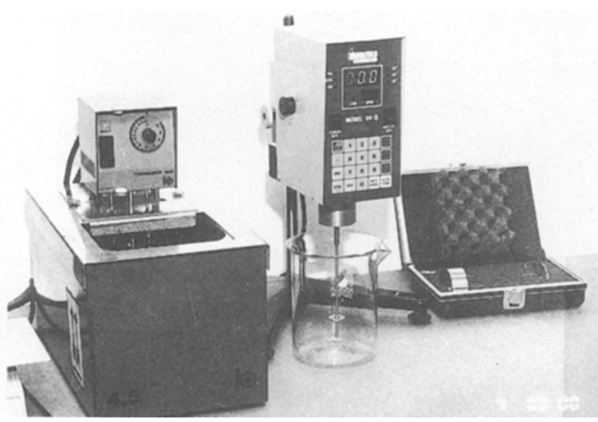

Figure 5 Testing arrangements for Brookfield viscosities.

4. Results

The force–elongation results are presented in Figs 6 and 7 and in Table II.

The results of viscosity measurements, hardening ratios, elastic recoveries and softening points are shown in Figs 8–11. The effect of the elastic recovery

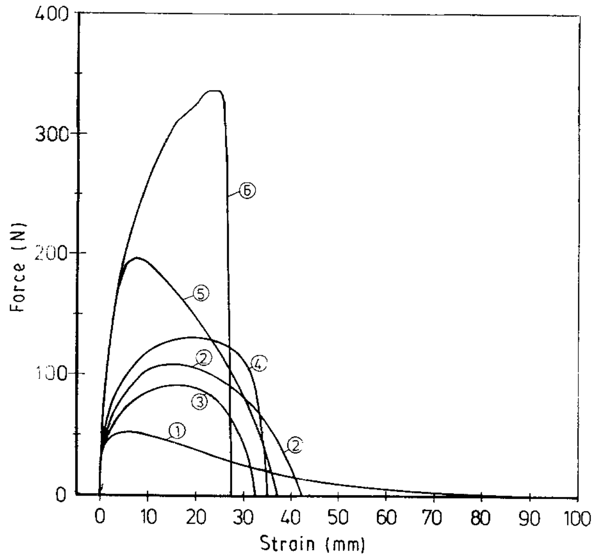

Figure 6 Strain (elongation) test curves of different fibre bitumen blends at 7 ± 1 °C. Test no.: 1, bitumen B-120 AH; 2, cellulose fibre 1; 3, cellulose fibre 2; 4, cellulose fibre 3; 5, mineral fibre M-P; 6, polyester fibre.

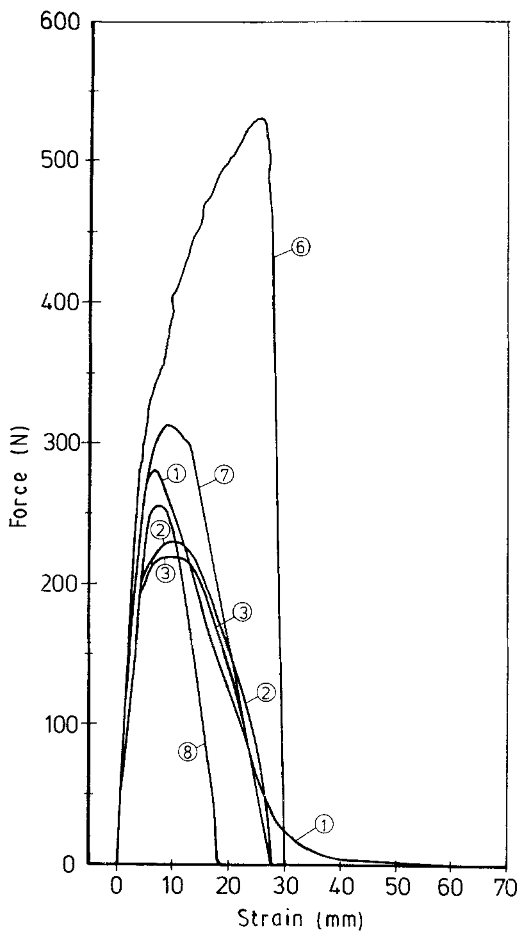

Figure 7 Strain (elongation) curves of the different fibre bitumen composites measured after cooling the blends at − 10 °C before normal straining at 7 ± 1 °C. Test no.: 1, bitumen B-120 AH; 2, cellulose fibre 1; 3, cellulose fibre 2; 6, polyester fibre; 7, mineral fibre M-D2; 8, glass fibre L-W.

TABLE II Test results of the elongation tests of the different fibre–bitumen blends

	Sample	Amount (wt %)		Amount (vol %)		Max. force (N)		Strain in max. (mm)		Breaking strain (mm)		Total energy (N mm)	
No.	Temperature (°C)	7 °C	− 10 °C	7 °C	− 10 °C	7 °C	− 10 °C	7 °C	− 10 °C	7 °C	− 10 °C	7 °C	− 10 °C
1	Bitumen	–	–	–	–	52	280	8	7	–	62	17.1	35.8
2	Cellulose 1	5.0	5.0	3.4	3.4	108	230	15	10	42	27	25.0	37.8
3	Cellulose 2	5.0	5.0	3.4	3.4	92	220	16	8	32	27	17.0	32.8
4	Cellulose 3	5.0	–	3.4	–	130	–	17	–	35	–	30.0	–
5	Mineral M-P	5.0	–	1.8	–	196	–	8	–	37	–	34.0	–
6	Polyester	5.0	4.6	3.6	3.4	335	530	22	26	27	30	54.4	99.5
7	Mineral M-D2	–	4.0	–	1.4	–	314	–	8	–	27	–	44.3
8	Glass L-W	–	4.0	–	1.7	–	256	–	7	–	18	–	26.9

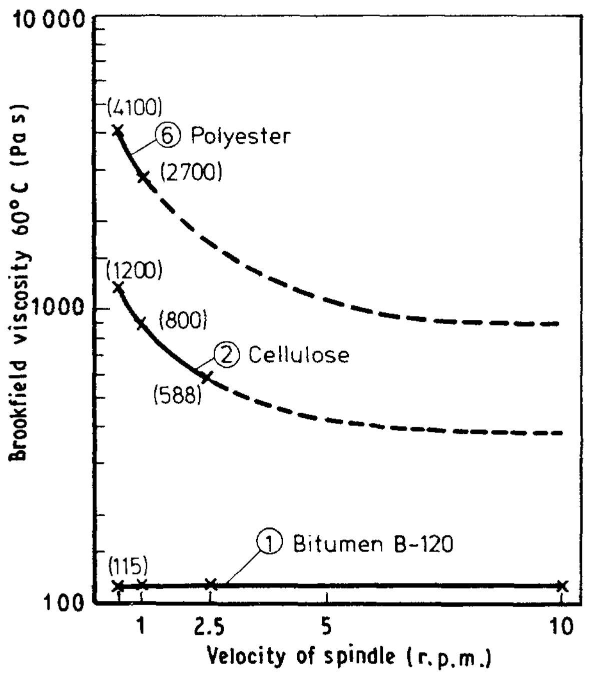

Figure 8 Comparison of viscosity values. 2.5 wt % fibre. (——) Apparatus value, (– – –) approximated curve.

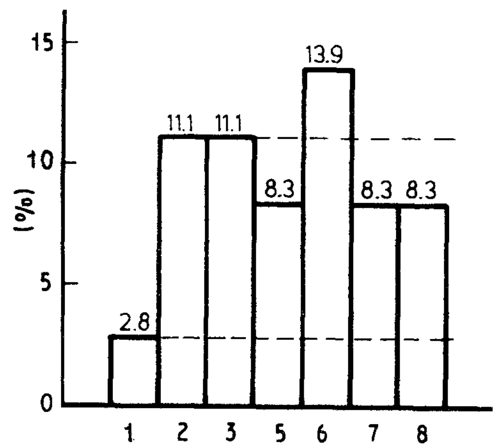

Figure 10 Elastic recoveries at 25 °C of the different fibre modified bitumens. For Test nos, see Fig. 9.

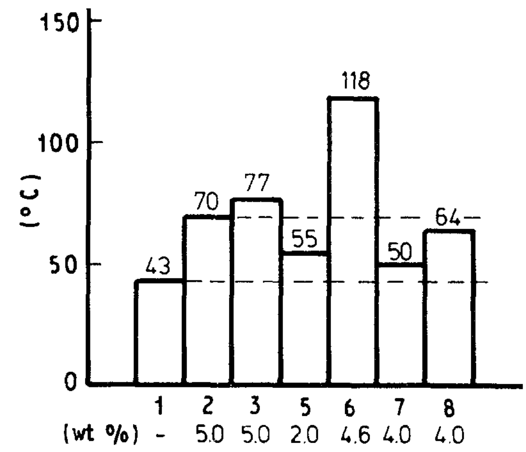

Figure 11 Softening points (Wilhelm) of the different fibre-modified bitumens. For Test nos, see Fig. 9.

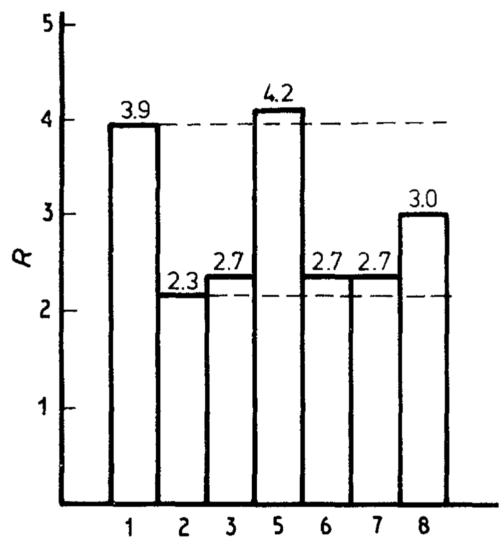

Figure 9 Hardening ratios, *R*, for different fibre–bitumen mixtures. R = (viscosity 60 °C Pas A TFOT/viscosity 60 °C Pas B TFOT). Test no.: 1, B-120 AH; 2, cellulose A; 3, cellulose R; 5, mineral P; 6, polyester D; 7, mineral D2; 8, glass W.

characteristics of the blends on the wearing of the modified asphalt paving mixtures is presented in Fig. 12. In these tests, a special laboratory-wearing device shown in [9], was used in analysing the wear characteristics of the fibre-modified asphalt paving mixtures.

The hardening ratio of a modified material is based on the formula

$$R = V_{\mathrm{A\,TFOT}}/V_{\mathrm{B\,TFOT}} \qquad (2)$$

where $V_{\mathrm{A\,TFOT}}$ means the viscosity of a blend after the

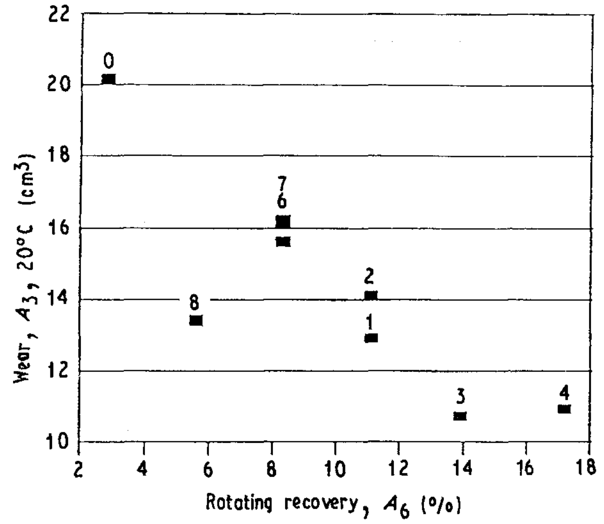

Figure 12 The relationship between the wear of fibre-modified asphalt pavements and the elastic recoveries of the same fibre-modified bitumens. SMACC 16: 0, B-120 AH; 1, cellulose A; 2, cellulose R; 3, PES; 4, nylon; 6, glass W; 7, mineral D2; 8, glass A3.

thin film oven test (TFOT) and $V_{\mathrm{B\,TFOT}}$ means the same value before the test. This ageing test for bitumens was carried out by keeping the thin bitumen layers at 163 °C in a heat box for 5 h. The test is based on specification ASTM D 1754-76. The results show the ageing characteristics of the modified materials.

In Fig. 12 the linear correlation was based on the equation

$$A_3 = -0.59\,A_6 + 20.09 \qquad (3)$$

where A_3 is the wear of Splittmastic asphalt pavement at -20 °C and A_6 is the elastic recovery of a fibre-modified bitumen. The correlation factor, r, in this regression analysis was relatively good, -0.85. Therefore, by using elastic fibres in bitumen, the wear resistance of an asphalt pavement can also be increased.

5. Conclusions

The fibres were characterized in bitumen mixtures by their binding and stabilizing effect. The following conclusions could be drawn from the results.

1. The specific surface areas of the fibres were increased in the order cellulose fibre > glass > polyester > mineral. Approximately, if 0.3 wt % cellulose fibre was blended with a bituminous paving mixture, the corresponding value of other researched fibres was increased to 0.5 wt %.

2. Compared to pure bitumen, the length of the strain with fibres was decreased. Certain differences were also seen in the form of the straining curves between different fibres. The highest straining strength with a rather good yielding effect was obtained with the polyester fibre–modified bitumens.

3. Bitumen could be effectively reinforced by the polyester fibre.

4. The good stabilizing effect of cellulose fibres in bitumen could also be explained on the basis of elongation properties. The blends with cellulose fibres had a rather flat straining curve, where the length of elongation at maximum force was very broad, 15–17 mm. Bitumen was effectively retained in the three-dimensional network and in the micropores of the cellulose fibres during elongation.

5. Cellulose and mineral fibres behave rather similarly in bitumen if their fibre–bitumen ratios are comparable. A difference was found between the elongation of a glass fibre blend and others, when the testing temperature was decreased. Glass fibres had both the lowest elongation at break, 18 mm and the lowest straining energy, 26.9 N mm.

6. Bitumen can be stiffened using fibres, giving very high viscosities for the fibre–modified bitumen composites.

7. All the main fibres gave a lower hardening ratio than a pure bitumen during ageing.

8. All fibre–bitumen composites also exhibited more elasticity after torsion than pure bitumen.

9. The softening points of the composites were increased from the traditional level of 43 °C to 50–118 °C.

10. Based on a correlation study directed towards practical application, it could be shown that if the elasticity of a composite is increased, a better cold resistance for the pavement surfaces in wear can also be obtained.

For road purposes, such as the use of "Splitt-mastixasphalt" which is very rich in bitumen, the cellulose fibre–modified bitumens are very good because cellulose fibres have a very high efficiency at binding bitumen.

If a reinforcement of a fibre–bitumen composite at a higher strength level is needed, polyester fibre can be used.

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