Construction and Building Materials 163 (2018) 901–911

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Influence of fibres on rheological properties and toughness of bituminous binder

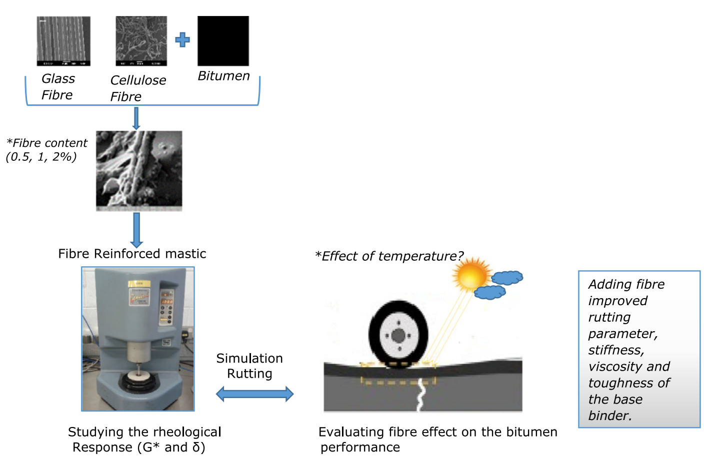
Monketh Mohammed *, Tony Parry, James (J.R.A.) Grenfell

Nottingham Transportation Engineering Center, University of Nottingham, UK

HIGHLIGHTS

- Fibre shape and microstructure will influence how fibres can reinforce bitumen.
- Fibre stiffening effect is more significant at low frequency and high temperature.
- Phase angle master curves of mastic showed different patterns from base binder.
- 2% fibre content led to significant increase in rutting parameters.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 16 February 2017
Received in revised form 7 August 2017
Accepted 22 December 2017

Keywords:
Glass fibre
Cellulose fibre
Fibre reinforced mastic
Rheology
Compatibility
Stiffness
Essential work of fracture
Toughness

ABSTRACT

Many studies have been made to examine different ways to modify bitumen and asphalt mixtures in response to increasing performance requirements. One of these is the use of additive materials and in this study, the potential of cellulose and glass fibres to modify the rheological properties of bitumen has been investigated. To achieve this, mixtures of bitumen with different contents of fibre were prepared and the properties of the bitumen and resulting modified binders were tested (penetration, softening point, viscosity and double edge notch tension test along with rheological testing in the dynamic shear rheometer). The experimental results demonstrated that adding fibres improves the rheological properties of bitumen across a range of loading frequencies and temperatures. Adding fibre reduced the penetration and increased the softening point and viscosity of bitumen implying improved rutting resistance of asphalt mixtures using these mastics. Finally this investigation established that adding fibre to bitumen improved its toughness, which could lead to improvement in asphalt fatigue performance. However, there are some limitations that are also discussed.

1. Introduction

This study examines the effect of the addition of fibres on some mechanical properties, and rheological properties of bituminous mastic. Fibres can significantly improve bitumen's penetration

* Corresponding author at: Nottingham Transportation Engineering Center, University of Nottingham, Nottingham NG7 2RD, UK.

E-mail addresses: evxmsmo@exmail.nottingham.ac.uk (M. Mohammed), evztp@exmail.nottingham.ac.uk (T. Parry), evzjg@exmail.nottingham.ac.uk (James (J.R.A.) Grenfell).

https://doi.org/10.1016/j.conbuildmat.2017.12.146
0950-0618/

and viscosity [1,2]. Seventy percent of bitumen is used in road construction as the binder mixed with aggregate and filler particles to form asphalt mixtures [3]. Bitumen is a viscoelastic material and it is well known that the mechanical behaviour of viscoelastic materials depend on loading time and temperature. The behaviour of bitumen plays a significant role in the performance and service life of flexible pavements.

The binder composed of fibres and bitumen works as the material that bonds an asphalt mixture together and is, therefore, an important part of that mixture. The properties of fibres (length, adhesion, absorption, swelling) and how they affect bitumen is complex. Fibres are added to bitumen to enhance its viscoelastic properties, for instance by improving the bitumen viscosity and stiffness [4,5]. Fibres are mainly used in stone matrix asphalt and gap graded mixtures to prevent the draining out of binder during mixing and compaction [6–8]. Fibres can reinforce the asphalt mastic through the three dimensional network they form and also through absorption of the asphalt binder and through adhesion in the mix [1,5]. Additionally, fibres have the potential to increase moisture resistance [9], fatigue resistance [10–12] and rutting resistance and creep compliance [13].

In this paper, fibre modified binder mastics were prepared with different fibre types (cellulose, 6 mm glass and 13 mm glass fibres). Cellulose fibres are natural fibres obtained most commonly from woody plants. Although glass fibres have desirable properties, such as low thermal expansion coefficient, high tensile modulus, high elastic recovery and high softening point, a literature review shows that their use has not been reported very often [14]. Experiments were conducted to evaluate the viscoelastic characteristics of the base bitumen and modified mastic with various fibre additions. These tests included penetration, softening point, viscosity, dynamic shear rheometer (DSR) and the double edge notch tension (DENT) test.

2. Experimental programme

2.1. Materials

The binder used in the experimental programme was a 40/60 penetration grade bitumen [15]. Three fibre types including two types of glass fibre and cellulose fibres were used as the additive to bitumen. Table 1 lists the basic properties of these fibres. Table 2 summarises the experimental programme. Three fibre concentrations of 0.5%, 1.0% and 2.0% by bitumen volume were selected. The glass fibres have two different lengths of 13 and 6 mm and diameter of 12 μm, which are termed glass-l and glass-s respectively. Micrographs of these three fibre types and the fibre reinforced bitumen are given in Figs. 1 and 2 respectively, using a scanning electron microscope (SEM). An SEM image of cellulose mastic is not included in this study because these fibres were difficult to identify and did not protrude from the faces of the mastic specimens in the same way as the glass fibre. This may be due to the dimensions and absorbent natural of cellulose fibre.

In Fig. 1, compared with the glass fibres, the cellulose fibre is much rougher. The cellulose fibre has a width of about 25 μm with length from 20 to 2500 μm, with irregular size and uneven surface texture and shows an irregularly shaped surface with interweaved branches. Glass fibres are produced with a uniform cylindrical shape and smooth surface texture. They are made up of bundles of individual fibres. Fig. 2 shows the formation of a network of fibres for a glass fibre reinforced mastic.

Table 2
Experimental programme.

Materials	Variables	Test methods	Test replicate
Bitumen 40/60	Fibre content 0.5% 1.0% 2.0%	Penetration test Softening point Brookfield viscosity	3 2 3
Fibre	Fibre type Glass-l Glass-s Cellulose	Dynamic shear rheometer Double edge notch tension test Scanning electronic microscopy	2 2 –

2.2. Experimental methods

Bitumen was placed in an oven at 160 °C for more than one hour to make it fluid enough for mixing. A specific experimental procedure was used to obtain homogeneous bitumen-fibre mastics. A Stuart mixer with a SS10 stirrer was used to apply a specific mixing speed (500 rpm) which prevented air bubbles forming in the bitumen-fibre mastic. Thermocouple probes were used to monitor the temperature throughout mixing by placing the probe directly inside the composite in the mixing vessel. Fibres were slowly added to the bitumen, while the mixing continued at constant speed to prevent the fibres from agglomerating. Bitumen-fibre mastics were mixed for one hour at 160 °C to produce homogeneous composites.

The penetration of the bitumen mixed with different fibres was measured with a STANHOPE-SETA penetrometer [15]. The penetration test was used to evaluate the hardness of the fibre reinforced bitumen mastic. Penetration is defined as the depth of penetration of a standard needle under a one hundred grams load after a five second loading time at a specified temperature and the penetration value expressed in units of 0.1 mm. The fibre reinforced binder samples were left for one hour in air and then placed in a water bath at 25 °C for one hour to equilibrate thermally before the penetration test.

Softening point (ring and ball) tests were conducted under standardised test conditions to determine the temperature at which a phase change occurs in the bitumen or mastics according to EN 1427 [16].

A standard rotational viscometer (Model LVDV-II+ PRD, Brookfield Engineering Inc.) was used to measure the viscosity of the fibre reinforced bitumen [17].

A Bohlin Gemini 200 (DSR) was used in this study for measuring the rheological properties of base and fibre reinforced bitumen. It has a torque range between 0.5 (μN·m) and 200 (mN·m). There is a sensor attached to the shaft to detect the movement of the measuring system [18]. Eleven testing frequencies ranging from 0.1 to

Table 1
Properties of fibres.

Fibre	Specific density (g/cm^3)	Length (μm)	Width (μm)	Modulus of elasticity at 23 °C (GPa)	Absorption value	Colour
Glass-l	2.58	13,000	12	80.3	–	White
Glass-s	2.58	6000	12	80.3	–	White
Cellulose	1.50	20–2500	25	–	High absorption and retention of liquid media (water binding capacity)	Grey