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An experimentally-based viscoelastic behavior of asphalt mastic at high temperatures

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HIGHLIGHTS

- The filler shows no obvious effect on the temperature sensitivity of the mastic.
- The creep characteristic of base asphalt mastic can be modeled by the Maxwell model.
- The creep characteristic of SBS modified asphalt mastic can be modeled by the Burgers model.
- The relaxation characteristics of base asphalt binder and modified asphalt mastics can be modeled by the Burgers model.

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ABSTRACT

Mastic properties play important role in the performance of asphalt concrete, especially for high temperature performance. The objective of this paper was to describe the viscoelastic behavior of asphalt mastic at high temperatures and determine the regression constants of the models. Two different asphalt binders namely AS-70 base asphalt binder and SBS modified asphalt binder were selected to mix with the mineral filler. For each asphalt binder, asphalt mastic samples were prepared at five different mass percentages, as 0.6, 0.9, 1.2, 1.5 and 1.8. The viscosity and rheological properties were tested under different temperatures using Brookfield RVDV-III rotating viscosimeter and Dynamic Shear Rheometer (DSR). The test results indicated that, for the modified asphalt mastic, increasing mineral filler content in the mastic caused a significant increase in the viscosity, while the effects were not significant on the base asphalt mastic. The filler showed no obvious effect on the temperature sensitivity of the mastic. The creep characteristic of base asphalt mastic can be modeled by the Maxwell model. The Burgers model was the most appropriate to model the creep characteristic for the modified asphalt mastic. The relaxation function of Burgers model can successfully fit relaxation behavior of the mastic.

1. Introduction

1.1. Scope of research

Asphalt concrete is commonly used in highways and airport pavements as a surface layer. It has some advantages for pavement compared with rigid pavement, but asphalt concrete exhibited viscoelastic behavior at high temperatures [1]. The filler-asphalt mastic in asphalt concrete is known to affect the viscoelastic behavior of asphalt pavement [2]. It is the 'real' binder in asphalt concrete and is the mainly contributions for viscoelastic behavior. The objective of the work described in this paper was to describe the viscoelastic behavior of asphalt mastic (base asphalt mastic, SBS modified asphalt mastic) at high temperatures. The parameters of the viscoelastic model of asphalt mastic were determined by regression analysis at high temperatures.

In this study, two different asphalt binders (base asphalt binder and SBS modified asphalt binder) were blended with diorite filler to make mastics at five different concentrations by weight. The mastic samples were tested using Dynamic Shear Rheometer (DSR) to determining high temperature performance. The classical models were used to model the viscoelastic behavior of asphalt mastic. The regression constants of the models were determined by regression analysis.

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1.2. Literature review

Permanent deformation is a common failure of asphalt pavement at high temperatures. It shows up as rutting in the wheel path caused by repeated traffic loading during hot season [3]. The main reason of permanent deformation is viscoelastic behavior of asphalt concrete at high temperatures. The contributions for viscoelastic behavior of asphalt concrete is asphalt mastic. The asphalt mastic is the combination of asphalt binder and mineral filler smaller than 0.075 mm [4]. Mastic is the "real" binder in asphalt concrete. It has been demonstrated that the performance of mastic can significantly influence the performance of asphalt concrete.

Some researchers investigated the viscoelastic behavior of the mastic. Jiménez et al. [5] tested several mastics with five different fillers and three types of asphalt binders at different concentrations by DSR. It evaluated the effect of filler nature and content on the rheological characterization of asphalt mastics. Kim and Little [6] reported that micromechanical and rheology-based models of asphalt mastic to assess the effect of limestone and hydrated lime on the viscoelastic behavior of the asphalt mastic using the DSR. Results indicated that micromechanical models showed good agreement with measured data when the ratio was small. The rheological model can predict the stiffening effect of limestone filler when the percent added up to 25% by volume. Underwood and Kim [7] evaluated the nonlinear viscoelastic behavior of asphalt mastic in the laboratory. It indicated that the response functions of mastic were strain-level dependent and proposed a thermodynamics based constitutive equation. Liao and Chen [8] analyzed the zero shear viscosities of asphalt and asphalt mastics with three different contents of limestone filler on the basis of two viscosity measurement techniques using a DSR.

Other researchers focused on the temperature dependence performance. Cheng et al. [9] investigated the relationship between properties of fillers and performances of asphalt mastic, the Grey relational analysis method was used to determine the correlation degree. Results indicated that the specific surface area was suggested to be the most important property on high and medium temperature performance. Kong et al. [10] used the surface and interface theory to access the high temperature performance of mastic. Some relationships between contact angle and softening point and rutting factor were discovered. Bautista et al. [11] reported that effect of dosage, physical properties and chemical composition of 15 CCP on the stiffness, phase angle and rutting behavior of asphalt mastic. The results indicated that a strong physical and chemical interaction between the CCP and asphalt binder were discovered. Dan et al. [12] investigated the low temperatures performance of asphalt mortars and focused on the effects of the mesoscopic characteristics of mineral powder fillers. The results showed that mesoscopic characteristics of mineral powder fillers had a significant effect on the low-temperature cohesive strengths of asphalt mastic. Wang et al. [13] also tested the low temperature performance of mastic, but they focused on the effect of the basalt fiber on mastic at low temperatures. Fatigue cracking is one of the primary distresses of flexible pavements. Some researchers investigated the fatigue of mastic to discover the mechanism of fatigue cracking. Underwood [14] proposed a continuum damage model for asphalt cement and asphalt mastic. Liao et al. [15] evaluated the fatigue performance of mastic containing different types of filler. Martono et al. [16] reported that the testing geometry on the fatigue performance of mastic using parallel plate (PP) geometry and torsion cylinder (TC) geometry. It indicated that TC had better repeatability than PP. Some other materials were added in the mastic to evaluate the performance of mastic, such as rejuvenators [17], fly ash [18], recycled asphalt material [19], warm-mix additives [20]. The interaction between asphalt binder and filler were difficult and it can influence the performance of mastic. The microstructure of mastic was reported including physic-chemical interactions [21], some micromechanical model [22–24].

In China some researchers investigated the performance of mastic focused on the viscosity and the performance of mixture containing different mastic [25,26]. As a review of the literature suggests, some researchers focused on the effect of different filler, different additives on high and low temperature performance.

2. Materials and experiment procedure

2.1. Materials

2.1.1. Asphalt binder

Two asphalt binders were used in this study, they were: AS-70 base asphalt binder (penetration grade 60/80) and SBS modified asphalt binder. SBS modified asphalt binder was produced with a concentration of 4.0% SBS (by weight of base binder). The properties were tested in the laboratory according to Chinese National Standards [27] and the results were presented in Table 1.

2.1.2. Filler

Diorite filler was selected to prepare asphalt mastics in this experiment. The selected diorite filler was traditional filler used in the construction of asphalt pavement, which was obtained from local quarry in Gansu Province. The properties were tested in the laboratory according to Chinese National Standards [28] and the results were shown in Table 2.

2.2. Asphalt mastic preparation

Asphalt mastics were prepared in laboratory which made by AS-70 base asphalt binder with diorite filler and SBS modified asphalt binder with diorite filler, respectively. Asphalt binders were heated in an oven at 145 °C for base asphalt binder and 175 °C for SBS modified asphalt binder. Diorite filler was also dried for one hour in an oven at 160 °C before being used in the testing. After being heated, the heated filler was added to the heated asphalt binder at three or four times to avoid the incorporation of excess air into the blender. At the same time, a glass rod was used to stir the mixture until a homogeneous mixture was obtained. Sample preparation cannot be done until bubbles were eliminated from the asphalt mastic.

In the viscosity test, the filler was chosen the ratio of 0.6, 0.9, 1.2, 1.5 and 1.8 by weight of asphalt binder for AS-70 base asphalt binder and for SBS modified asphalt binder [29]. Previous studies reported on the optimal contents of asphalt mastic in asphalt mixture ranged from 1.07 to 1.45 [30]. Following these recommendations, the filler was chosen the ratio of 0.9, 1.2 and 1.5 by weight of asphalt binder to testing the creep and relaxation behavior of asphalt mastic.

In order to facilitate the expression in the later, SBS modified asphalt binder was referred as S, AS-70 base asphalt binder was referred as A and the diorite filler was referred as D. For example,

Table 1
Properties of the base asphalt binder and SBS modified asphalt binder.

Test properties	Test results	
	AS-70	SBS modified asphalt
Penetration (25 °C, 100 g, 5 s)/(0.1 mm)	63.7	41.8
Ductility (15 °C, 5 cm/min)/(cm)	>150	21.2
Softening point (TR&B)/(°C)	52.3	89
Density (25 °C)/(g/cm3)	1.023	1.057