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A model for the quantitative relationship between temperature and microstructure of Styrene–Butadiene–Styrene modified asphalt

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HIGHLIGHTS

- Coefficient of variation was used as a new quantitative index to feature the distribution of SBS polymer in virgin asphalt.
- The microstructure index of SBS modified asphalt shows an exponential relationship with temperature.
- Temperature sensitivity of SBS modified asphalt with different content of SBS can be expressed by a universal model.

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ABSTRACT

This paper presents a new method to characterize the change of microstructure of Styrene–Butadiene–Styrene (SBS) modified asphalt when temperature changes. MATLAB was employed to process microscopic images and to extract feature index of distribution of polymer modifier under different temperature. The coefficient of standard deviation V_σ was appointed as the feature index. By non-linear fitting, the relationship between V_σ of 3.5% SBS modified asphalt and temperature was proved to be in accordance with an exponential equation. The equation shows that when temperature drops, the feature index V_σ increases. The variation tendency of V_σ means congregation happens in SBS with dropping of temperature, leading to its poorer distribution homogeneity. Furthermore, the absolute value of variation rate of V_σ increases with the drop of temperature, which means the congregation rate of SBS becomes greater under lower temperature. In the last part of this paper, a universal model was put forward after analyzing modified asphalt with different SBS contents. This study lays a foundation for new methods to evaluate the temperature characteristics of SBS modified asphalt.

1. Introduction

Styrene–Butadiene–Styrene (SBS) is a widely used macromolecule modification material, especially effective in improving low temperature plasticity and high temperature stability of base asphalt, so it is an important research subject in the area of asphalt material [1]. However, SBS polymer differs from base asphalt in molecular weight, density, and chemical nature. Therefore, the compatibility of the two is poor and they are likely to separate. In this way the modification effect is lowered [2].

Among factors that have influence on performance of SBS modified asphalt, temperature is the relatively crucial one. Separation and ageing of stored modified asphalt exhibit a complicated variation with storage temperature. The separation softening point difference decreases with the storage temperature lower than 120 °C and then increases with temperature beyond 120 °C [3].

Commonly temperature sensitivity indexes are employed to evaluate temperature characteristics [4] such as PI (Penetration Index), PVN (Penetration Viscosity Number), VTS (Viscosity Temperature Susceptibility), and CI (Class Index) [5–7]. Some researchers use VTS as temperature susceptibility index of SBS modified asphalt [4]. In their research, the influence of type and dosage of modifier on PI and VTS of modified asphalt was investigated. Yet a unified standard was still not put forward to evaluate temperature characteristic of SBS modified asphalt. To propose a quantitative index of SBS modified asphalt and a model for the relationship between the index and temperature is highly meaningful for research and practical application of SBS modified asphalt.

The development of technology of analyzing microscopic images has stimulated a large number of researchers to study the performance of SBS modified asphalt through microstructure. In an image produced by a fluorescent scope, the compatibility of

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different SBS and asphalt can be observed [8]. Phase segregation before and after storage is also visible [9]. Though microstructure is closely related to performance [10] and is even considered decisively influential [11], current methods have not established quantitative relationship between them. The model which can quantitatively depict variation of microstructure with temperature is especially important. Therefore, this paper aims at putting forward a model to express the relationship between a microstructure index and temperature, which serves as foundation for evaluation of temperature characteristic.

In the first step, a number of images of microstructure of SBS modified asphalt were produced by a fluorescence microscope. These images were processed by MATLAB to enhance their resolution of the two phases, SBS and asphalt. Then a quantitative index which was established on the base of the distribution feature was extracted from the images. At last, the model for relationship between the quantitative index and temperature was established. Change of SBS modified asphalt with temperature could be analyzed through the model.

2. Materials and methods

2.1. Materials

2.1.1. Base asphalt

The base asphalt used in this study is Donghai No. AH-70 paving asphalt. The physical properties of this asphalt are shown in Table 1.

2.1.2. SBS modifier

Branched modifier was chosen in this study to modify base asphalt. The property is presented in Table 2. The dosage of modifier added to base asphalt was 3.5% by weight.

2.1.3. Stabilizer

It is necessary to add stabilizer into the mixture, because the architecture of SBS modified asphalt is not stable. Stabilizer can increase interfacial energy of polymers and conglutination of SBS asphalt. In this study, Doctor LF-5 stabilizer was used with a content of 0.3%. The stabilizer is purchased from Shanghai Doctor Asphalt Technology Co., Ltd., which has three main functions-increasing the softening point of modified asphalt by at least 10 °C; decreasing the adding amount of SBS; improving anti-separation property of mixture.

2.2. Experiment method

2.2.1. Preparation of microscopic images

Specimens of SBS modified asphalt were prepared with a high speed sheering instrument in the key laboratory of school of transportation engineering, Tongji University. Referring to the temperature at which modified asphalt is usually prepared and stored in practical use, SBS modified asphalt in this study was cooled down in air from 170 °C to 30 °C. At fixed temperature with interval of 20 °C, some asphalt was taken from the center of the sample and rapidly frozen to below zero to stabilize the microstructure. Then slices of specimens for the fluorescent scope were rapidly prepared and observed [12]. In strict accordance with standard collection method of digital images for a fluorescent scope, digital images of microstructure of specimen titled A170 to A30 were obtained. The serial numbers of the images represent the temperature at which the modified asphalt was prepared, e.g., the 'A170' image shows it is the image of binder prepared at 170 °C and quickly frozen. The original images of branched SBS modified asphalt are shown in Fig. 1.

2.2.2. Processing of microscopic images

The original images were processed with MATLAB. They were converted into binary images which only contained two pixel value, 0 and 1. The exported images are shown in Fig. 2.

Table 1
Properties of base asphalt.

Properties	Testing results
Softening point (°C)	57
Penetration, d mm, 100 g, 5 s, 25 °C	61.8
Ductility, cm, 5 cm/min, 5 °C	0.5
Rotary viscosity, MPa s, 135 °C	493.8

Table 2
Property of SBS modifier.

Properties	Branched
Block ratio (S/B)	30/70
Oil-extended content, %	0
Volatile contents, %, ⩽	0.50
Tensile strength at break, MPa, ⩽	12.0
300% tensile modulus, MPa, ⩽	1.7
Elongation at break, %, ⩽	600
Residual deformation, %, ⩽	40
Shore hardness, A	82 ± 7

3. Results and discussion

3.1. Extraction of microstructure feature index for SBS modified asphalt

In Fig. 2, it is obvious that SBS modifier, or the white portion, congregated when temperature became lower. In order to demonstrate the difference mathematically, the images were partitioned into small pieces of the same size with MATLAB. For every image, the number of pixels SBS occupied in every piece was counted and statistical frequency was calculated. Next, for every binary image, mean pixel number, μ, and variance, σ^2, were obtained. The values of μ and σ^2 for all the images are listed in Table 3.

When two sets of data are to be compared, standard deviation can be directly used to make a comparison of them once they have the same unit and mean. However, if they have different unit or mean, standard deviation cannot be employed to contrast the dispersion levels of them. The appropriate index is the coefficient of standard deviation, the ratio of standard deviation to mean. The coefficient of standard deviation analyzes data from a relative point of view.

Table 3 shows that the images have different means, so coefficient of standard deviation have to be used to contrast the images. Values of coefficient of standard deviation are listed in Table 4.

3.2. A model for the relationship between microstructure index and temperature for SBS modified asphalt

Coefficient of standard deviation V_σ was chosen as feature index of microstructure. The values of the index under different temperature read from Table 4 were fitted into a curve. The curve fitted is shown in Fig. 3.

As is shown in Fig. 3, an exponential model can be used to express the relationship between microstructure feature index and temperature for the studied sample of SBS modified asphalt, that is

$$V_\sigma = 4.9459\exp(-0.013T) \tag{1}$$

where V_σ coefficient of standard deviation, and T = temperature in °C.

3.2.1. Discussion on the model

Firstly, the goodness of fit, R^2 = 0.9566, and the data points distribute around the curve evenly and tightly. It shows that the chosen equation is suitable to represent the temperature characteristic of 3.5% SBS modified asphalt.

Secondly, in Eq. (1), taking derivatives of T, we get

$$\dot{V}_\sigma = -0.0643\exp(-0.013T) \tag{2}$$

$\dot{V}_\sigma$ represents the variation rate of V_σ with T.

It is found that

$$\dot{V}_\sigma < 0 \tag{3}$$