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Applicability of evaluation indices for asphalt and filler interaction ability

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HIGHLIGHTS

- $\triangle G^*$, *K-B-G**, *L-A-δ* and *K-B-δ* are used to study the asphalt and filler interaction.
- The asphalt-filler interaction ability increases with temperature increasing and decreases with loading frequency increasing.
- The *K-B-δ* has the most significant sensitivity followed by *L-A-δ*, $\triangle G^*$ and *K-B-G** sequentially.

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ABSTRACT

The asphalt and filler interaction plays a significant role on the performances of asphalt mixtures, and the asphalt and filler interaction ability can be evaluated by the rheological properties. In this paper, one kind of matrix asphalt binder and three kinds of fillers were selected to prepare asphalt mastics with different filler volume fractions respectively, and the dynamic shear rheological properties of asphalt mastics were measured to analyze the four evaluation indices of $\triangle G^*$, *K-B-G**, *L-A-δ* and *K-B-δ*. Results indicate that $\triangle G^*$ and *K-B-G** cannot represent the effects of temperature on asphalt and filler interaction ability. However, the two indices can reflect the effects of loading frequency on asphalt and filler interaction ability. *L-A-δ* and *K-B-δ* not only represent the effects of temperature on asphalt and filler interaction ability but also the effects of loading frequency on asphalt and filler interaction ability. The higher temperature is, the stronger asphalt and filler interaction ability is. But the higher loading frequency is, the worse asphalt and filler interaction ability is. And then the sensitivity analysis of evaluation indices was also conducted, and finding that the sensitivity from high to low is (1) *K-B-δ*, (2) *L-A-δ*, (3) $\triangle G^*$, and (4) *K-B-G**.

1. 1Introduction

Asphalt mixture consists of mineral aggregates of varying sizes, asphalt binder and air voids. And coarse and fine aggregates are coated by asphalt mastic which is formed by asphalt and filler interaction [1]. However, asphalt mastic constitutes the weakest phase in asphalt mixture and has significant effects on the overall road performances of asphalt mixture [2]. A great number of researches have demonstrated that the interaction between asphalt and filler can obviously influence constructability, oxidative aging, stiffness, fracture resistance and moisture susceptibility of asphalt mixture [3–5]. Therefore, deeply realizing the process of asphalt and filler interaction has great significance to improve the performance of asphalt mixture and reduce the occurrence of diseases effectively.

Originally, researchers applied the adhesion tests, including the boiling water test and static immersion test to evaluate the asphalt and filler interaction ability. However, these are all qualitative tests, and actually reflect the anti-striping property of asphalt-aggregate system in water, which is limited for the evaluation of the asphalt and filler interaction. Currently, researchers have reached a consensus that the asphalt and filler interaction is a complex process of physico-chemical interaction and related to various factors, such as acid-base property and surface characteristics of fillers, and the components and properties of asphalt binder [6–8]. According to the theory proposed by Л *A Repin tyuter* [9], the chemical components of asphalt will be rearranged and a layer of diffusion solvation membrane will be formed on the surface of fillers when the asphalt and filler interaction happens. And the asphalt within this film thickness is called “structure asphalt”, and the asphalt outside this film thickness is called “free asphalt”, as shown in Fig. 1. The change of relative proportions between “structure asphalt” and “free asphalt” can reflect the asphalt and

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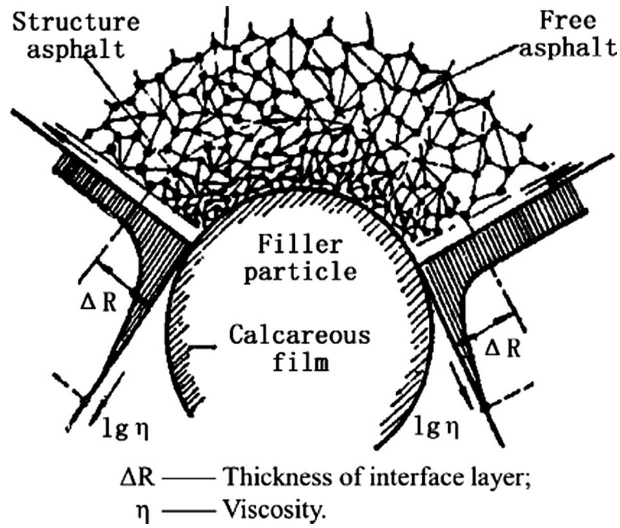

Fig. 1. Asphalt and filler interaction theory model schematic [10].

filler interaction ability. Thus, the asphalt and filler interaction ability can be quantitatively evaluated by the rheological properties of asphalt mastic.

In order to quantitatively evaluate and compare the asphalt and filler interaction ability, numerous rheology-based approaches have been adopted. Tan et al. [11] defined the complex viscosity coefficient $\triangle\eta^*$ for setting aside the effects of matrix asphalt binder on the rheological properties of asphalt mastic to evaluate asphalt and aggregate interaction ability. And yet the results show that the discrimination is not obvious for different asphalt binders and aggregates. Guo [12] evaluated asphalt and filler interaction ability by the intrinsic viscosity *[η]* which represents the interaction level of solid particle and liquid when the concentration is zero. These results indicate that the intrinsic viscosity *[η]* can reflect the irregularity and dispersion of mineral filler in asphalt mastic to some extent. But the intrinsic viscosity *[η]* sensitivity is not enough to estimate interaction ability of asphalt and filler. Unlike the complex viscosity η^*, others evaluated asphalt and filler interaction ability based on the other rheological parameters, such as phase angle δ and complex modulus G^*. Tan et al. [13] used *K-B-δ* and *L-A-δ* which were proposed by Ziegel [14] and Ibrarra [15] respectively to estimate asphalt and aggregate interaction ability. And the results reveal that *K-B-δ* and *L-A-δ* have higher sensitivity than the complex viscosity coefficient $\triangle\eta^*$. Tan et al. [16] subsequently analyzed the effects of internal factors on asphalt and filler interaction ability by the index *K-B-δ*. These results indicate that the contribution order of various influence factors on asphalt and filler interaction ability is resins and asphaltenes content > particle size of filler > silica content > filler concentration. Zhang et al. [17] measured the complex modulus of asphalt binder and mastic by Dynamic Shear Rheometer (DSR) to calculate the complex modulus coefficient $\triangle G^*$, *K-B-G** and Einstein coefficient K_E of Nielsen's model for evaluating asphalt and filler interaction ability. The results show that the three indices have good consistency for characterizing the asphalt and filler interaction ability, but the Einstein coefficient K_E is determined by non-linear regression fitting methods, and cannot compare the ability of asphalt and filler interaction between different filler concentrations.

The above studies show that the evaluation of asphalt and filler interaction ability based on rheological properties becomes a research hotspot, and some evaluation indices have been established. However, there is not only lacking applicability analysis for these indices, but also relatively little research has been conducted on the effects of temperature and loading frequency on asphalt and filler interaction at present.

2. Objective and scope

The objectives of this study are to validate the applicability of evaluation indices for asphalt and filler interaction and reveal the effects of temperature, loading frequency on asphalt and filler interaction ability. In order to achieve this goal, the two main elements are the following:

(1) To validate the applicability of evaluation indices based on rheological properties, such as $\triangle G^*$, *K-B-G**, *K-B-δ* and *L-A-δ* and the sensitivity of the four indices will be compared.
(2) To analyze the effects of temperature and loading frequency on the interaction ability between asphalt and filler respectively.

3. Experiments

3.1. Raw materials and specimen fabrication

The matrix asphalt binder, whose penetration grade is 70#, was used as base material. 70 means the penetration of the asphalt binder at 25 °C ranges from 60 to 80 (units in 0.1 mm) according to the Chinese specification, JTG F40-2004 [18]. The properties of asphalt binder were measured according to the test methods of the specification Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering, JTG E20-2011 [19]. And the property indices of asphalt binder are shown in Table.1. Limestone, Portland cement and hydrated lime were selected respectively as fillers to prepare asphalt mastics, and the properties of the fillers were measured by Mastersizer 3000. The property indices of three kinds of fillers are shown in Table 2.

According to the research conducted by Zhang et al. [17], the asphalt and filler interaction ability should be evaluated within the critical volume fraction. And the critical volume fractions of the three kinds of fillers are about 40%. Therefore, the filler volume fractions of 15% and 30% were selected to fabricate asphalt mastics in this study. These asphalt mastics were obtained by blending the matrix asphalt binder and fillers at different filler concentrations. The stirring time was 15 min at 1000 rpm speed.

3.2. Test methods

The temperature sweep test and frequency sweep test of matrix asphalt binder and mastics were conducted by DHR-1 DSR which is produced by TA. And the rheological parameters such as complex modulus G^* and phase angle δ of matrix asphalt binder and mastic were measured. The temperatures, loading frequencies and loading modes for different tests are summarized in Table 3.

3.3. Evaluation indices for asphalt and filler interaction ability

3.3.1 ΔG^*

Generally, the complex modulus G^* can indirectly reflect the asphalt and filler interaction ability. In order to set aside the effects of asphalt binder on the rheological properties of asphalt mastic, the complex modulus of asphalt mastic are made in normalization processing, and defined as the complex modulus coefficient $\triangle G^*$, as shown in Eq. (1) [20].

$$\Delta G^* = (G_c^* - G_m^*)/G_m^* \tag{1}$$

where, $\triangle G^*$ is the complex modulus coefficient; G^*_c is the complex modulus of asphalt mastic (kPa); G^*_m is the complex modulus of