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Quantitative test technology study on the mesoscopic strength parameters of the mineral aggregate contact surface of bituminous-stabilized macadam

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HIGHLIGHTS

- The failure forms of contact surface include adhesion failure and cohesion failure.
- The microscopic strength parameters of contact surface include R_t, R_a and R_c
- Cohesion strength has nothing to do with the thickness of the oil film.
- Adhesion strength has relationship with temperature and oil film thickness.
- Achieve quantitative test of microscopic strength parameters of contact surface.

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ABSTRACT

Quantitative test technology on the mesoscopic strength parameters of the mineral aggregate contact surface of bituminous-stabilized macadam was studied. On the basis of the failure mechanism of the mineral aggregate contact surface, the HC-40 hydraulic force measurement device and the self-designed test die were used to apply tensile load on the contact surface of the mineral aggregate. The total tensile strength R_t of the mineral aggregate contact surface was calculated. The total tensile strength R_t was compared with the splitting strength R_T of the AM-20 Semi-Open-Graded bituminous-stabilized macadam mixture under different conditions. A corresponding calculation method was used to determine the adhesion strength R_a between the aggregates and bitumen, as well as the cohesion strength R_c of the bitumen binder itself. The results show that despite the small difference in numerical value between the total tensile strength R_t of the mineral aggregate contact surface and the splitting strength R_T of the mixture, the variation law is consistent. The method of calculation adopted in the present study can provide the quantitative test for the adhesion strength R_a and the cohesion strength R_c at different states. The mesoscopic parameters of the mineral aggregate contact surface can directly affect the macroscopic strength parameters of the mixture. The test can promote the study on crack resistance and raveling resistance abilities of bituminous-stabilized macadam mixtures.

1. Introduction

Bituminous-stabilized macadam is a kind of flexible structure material. It has better pavement performance compared with cement stabilized macadam, for example, when used as a stress-releasing layer, this material can effectively reduce the stress concentration on pavement structures and can greatly retard the occurrence of reflective cracks on pavement [1]. As the material of bituminous macadam base is similar to pavement materials, the interlayer bonds are firm, the moduli are similar in numerical value, and the stress and deformation are more coordinated. Pavements made from bitumen macadam base can have long service lives compared with traditional semi-rigid base asphalt pavement used in China. For semi-rigid base asphalt pavement, the crack will occur in a short time, but when the semi-rigid base was substituted by bitumen-stabilized macadam, the service lives of the pavement increases. Thus, bituminous-stabilized macadam has a good application prospect [2].

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The main disadvantages of bitumen-stabilized macadam used on road structures are crack and raveling [3]. The sub-layer material and the sub-grade are vulnerable to certain degree of vertical deformation that can directly lead to bending of the base materials, which then causes cracks [4,5]. At the same time, vehicle load vibration and low temperature soaking condition can also result in a series of raveling that causes loss of stability of road structure [6].

The crack and raveling disadvantages of bituminous-stabilized macadam always occur on the mineral aggregate contact surface. Hence, confirming the strength characteristics of the contact surface is important in the study of the crack and raveling resistance abilities of the mixture. Current study shows that the adhesion strength between mineral aggregates and bitumen has significant influence on the macroscopic pavement performance of the mixture and that water reduces the adhesion and cohesion effects [7–9]. Using an anti-stripping material is an effective method to improve the adhesion strength between mineral aggregates and bitumen. At present, three main kinds of anti-stripping materials are available: the inorganic class of anti-stripping agents, metal saponated substances, and the polyamide kind of polymer materials. The most effective kind of anti-stripping material depends on the accurate assessment of the adhesion effect between the aggregates and bitumen [10,11].

Mesoscopic strength parameter test of mineral aggregate contact surface is a new research field. At present, adhesion test between asphalt and aggregate is one of its aspects. The Standard Test Methods of Bitumen and Bituminous Mixtures for Highway Engineering of China adopts the water-boiling method to test the adhesion of aggregates and bitumen. However, it has some defects [12]. At the same time, some scholars have been developing a study on a test method for adhesion based on the basic theory of adhesive work. Due to the limitation of the method itself, however, developing a quantitative test for the adhesion between aggregates and bitumen in more states is difficult [13–15].

Damage to the mineral aggregate contact surface has two forms: the adhesion failure by which bitumen is stripped from the mineral aggregate interface, and the cohesion failure by which cracks occur in the bitumen mixture itself [16]. Hence, the quantitative test of adhesion and cohesion strength of the mineral aggregate contact surface is an important research subject [17]. Through a quantitative-testing technology on mesoscopic strength parameters of mineral aggregate contact surface, we can make an objective evaluation of the adhesion effect of different bitumens and aggregates and of the enhancement effect of adopting different kinds of anti-stripping measures. In particular, it is important in the relevant research on the crack and raveling resistance performances of bituminous-stabilized macadam mixtures.

2. Current methods for adhesion assessment

2.1. Water-boiling method

The water-boiling method is the most direct way to inspect the adhesion between bitumen and a coarse aggregate that is larger than 13.2 mm. The mineral aggregate wrapped with bitumen film is immersed in slightly boiling water for 3 min. Then, it is removed from the water and the degree of stripping of the bitumen film is observed. The grades of adhesion is assessed according to Table 1.

However, the water-boiling method has two main defects. On one hand, the testing skill is difficult to master, because determining and mastering the slight boiling condition of water vary from one person to another. On the other, the stripping area of bitumen is determined through visual inspection, which is difficult to estimate and which experimental results are more subjective.

2.2. Test method based on adhesive work

Adhesion work can be defined as the external power exerted when two phases are separated into independent ones. High adhesion work indicates greater power required to separate and to form new surfaces, as well as better adhesion between materials. The adhesion work between an aggregate and asphalt is W_{SL}. Combining adhesion work with the Young Equation, the basic relationship between adhesion work and interface tension of a material can be expressed as:

$$W_{SL} = \gamma_{LG}(1 + \cos\theta) \tag{1}$$

where W_{SL} is the adhesion work; γ_{LG} is the interface tension between asphalt and air; and θ is the angle formed by the aggregate–asphalt interface [18].

By testing the bitumen surface tension and the angel, the adhesive work can be calculated. According to the numerical value of the adhesive work, the adhesion effect can be determined [19,20]. The test method has clear theoretical meaning. However, bitumen surface tension is difficult to determine during the actual test process at thermal melt condition, and the test is limited by the performance of the surface tension instrument. At the same time, the parameters of adhesive work are determined at the thermal melt state, which temperature is about 160 °C. The adhesion effect corresponds to high temperature condition. The failure condition of the aggregate contact surface is rather complicated, and the probability of failure is higher at low temperature. Hence, evaluating the adhesion effect at low temperature, with adhesive work, can inevitably result in large error.

3. Forms of failure in aggregate contact surface

Panjin70# bitumen, SBS-modified bitumen, and rubber-modified bitumen were chosen for the preparation of the AM-20 Semi-Open-Graded bitumen stabilized macadam mixture. The high speed shearing machine was used to prepare the rubber-modified bitumen and the proportion of the rubber modifier is 6%. The technical parameters of the three kinds of bitumen are listed in Table 2, and the gradation characteristics of AM-20 are listed in Table 3. The aggregates with regular shapes were selected among the bitumen-stabilized macadams. Bitumen was dissolved in C_2HCl_3. The aggregates were dried, and the mass loss was weighed. The thickness of the bitumen film can be calculated according to the surface area of the mineral aggregate. The corresponding relationship between bitumen–aggregate ratio and the bitumen film thickness of the aggregate contact surface is shown in Fig. 1. The

Table 1
Grades of bitumen adhesion.

The stripping phenomenon of bitumen after experiment	Grades of bitumen adhesion
Bitumen film completely preserved, the percentage of stripping area is almost 0	5
Thickness of bitumen film was uneven, the percentage of stripping area is less than 10	4
Bitumen film almost retained in the aggregate surface, the percentage of stripping area is less than 30	3
Partial of bitumen film retained in the aggregate surface, the percentage of stripping area is more than 30	2
The aggregate almost naked, all of the bitumen floated on the water surface	1