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Study on the correlation between aggregate skeleton characteristics and rutting performance of asphalt mixture

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HIGHLIGHTS

- An optimized multilevel mixing method was applied to obtain 3 mixtures with increasing strength.
- The number of contact points and inclination of aggregates can be used as the steady-state indicator.
- The number of contact points should be controlled to obtain better mixture performance.
- The dynamic stability estimation model could distinguish the influence of asphalt for mixtures.

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ABSTRACT

While the rutting performance of asphalt mixture is largely affected by the skeleton characteristics of the aggregate, the relationship between skeleton formation and rutting performance is not adequately understood. This study experimentally investigates the whole process of asphalt mixture skeleton formation by employing multilevel mixing gradation design method and digital image processing technology on three mixtures. The strength formation process of the mixture is analyzed by performing a laboratory test to establish the dynamic stability estimation model. Results indicate that a small discontinuity in gradation is helpful to enhance the density of the mixture even though skeleton formation and skeleton embedding are not necessarily correlated. With successive mixing of finer aggregate particles, the void ratio and Voids in the Mineral Aggregate (VMA) of the mixture were decreased continually but the stability and dynamic stability were increased. The number of contact points increased firstly and then decreased, and the inclination angle decreased monotonically. The number of contact points should be controlled within a reasonable range during the gradation design. However, a small initial inclination of aggregates possesses a higher dynamic stability. The estimation model proposed in this study could distinguish the influence of the asphalt type for mixtures with the same initial skeleton characteristics.

1. Introduction

Dense skeleton asphalt mixture (DSAM) is a kind of road paving material composed of coarse aggregate to form skeleton and fine material to fill voids [1–4], and has good stability in high temperature environment. With an increase in the proportion of heavy duty traffic in China, DSAM had been considered as a superb pavement material for heavy duty traffic in recent years [5–7]. Currently, most research on the skeleton structure of paving material is mainly based on the description of dense skeleton structure in the 'SMA mixing proportion design method' proposed by Federal Highway Administration (FHWA) and the National Asphalt Pavement Association (NAPA) of the US. According to an empirical formula [8,9], the concept that $VCA_{mix} < VCA_{DRC}$ is taken as an indicator of coarse aggregate skeleton. Among them, VAC refers to the ratio of voids between coarse aggregate skeletons to the total volume, VCA_{DRC} refers to the VCA of coarse aggregate skeletons obtained by the dry tamping method, and VCA_{mix} refers to the VCA of asphalt mixture specimen obtained by Marshall molding method. However, VCA is one of the macroscopic indicators to characterize the whole structure of asphalt mixture. Even when the skeleton structure of coarse aggregate is defined, correlation between the microstructure of asphalt mixture and the distribution of coarse aggregate inside the asphalt mixture cannot be

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judged by VCA. Therefore, the effect of the combination of coarse aggregates on the steady-state of the skeleton is not clear yet and should be investigated.

1.1. Skeleton state of asphalt mixture

The steady state of the skeleton of asphalt mixture is one of the main factors affecting its resistance to deformation. Li [10,11] described the steady-state behavior of the skeleton from the perspective of particle slip shear based on a custom-designed asphalt mixture slag shear test device. The experimental study verified the steady state creep mechanism of the mixture and proposed that the steady-state creep mechanism of asphalt mixture belonged to the diffusion creep controlled by the mineral interface dislocation mechanism. Therefore, the deformation of the mixture is an external manifestation of the accumulation of slipping of all the particles. Li proposed slip energy index (SEI) obtained by aggregate slip shear deformation test as the shear parameters for asphalt mixtures. Zheng [12] studied the mechanical properties of a loose-state hot asphalt mixture during molding process and described the steady-state migration process of the mixture skeleton with the visco-elastic-plastic parameters. Wei [13] used a rotary compaction device to study the compaction characteristics of mixtures with different gradations, and evaluated the stability of skeleton of different materials based on compaction performance. Sun [14] demonstrated the anti-deformation ability of the aggregate skeleton of the asphalt mixture by a rutting test, and proposed a method of characterizing the stability of the skeleton based on the contact force between aggregates and the fractal dimension of gradations. Ma [15] built a three-dimensional discrete element model to characterize various ingredients and their micromechanical properties within an asphalt mixture. The study revealed that the movement of coarse aggregates can weaken the stability of the aggregate skeleton; if the aggregate skeleton cannot bear the increasing contact force, the instability failure of the aggregate skeleton can result in severe rutting deformation of the asphalt mixture. Therefore, the steady state of the skeleton is the main factor affecting the response of the material to the external load. However, current research on the steady-state behavior of the skeleton is mainly aimed at characterizing single-sized aggregate or contrasting between different sizes. Few studies exist on the steady-state transition of the skeleton.

1.2. The multilevel mixing method

Multilevel mixing method, originally proposed by Lees [16], aims to maximize the density of a mix. After years of development, the multilevel mixing method is regarded based on the dense skeleton as the basic concept and maximum density of mixture as the design objectives [10–12]. Wang [17,18] optimized this design method so that it can be used for the design of skeletal asphalt mixes. The aggregate gradation is designed through several stages of blending of coarse and fine aggregates to obtain the optimum ratio of mineral aggregates by maximizing mixture density.

2. Test design

We adopt an optimized multilevel mixing method and employs digital image processing technology to observe the whole process of asphalt mixture skeleton formation. Mixture performances test under each mixing stage were conducted to analyze the strength development process of the mixture. The skeleton feature in different mixing stages is observed via analyzing the number of contact points and the inclination of coarse aggregates. And the steady-state of skeleton is observed from unstable equilibrium state to metastable equilibrium state and to stable equilibrium state. Based on these observations, the skeleton parameters affecting the rutting performance of the mixture and the reasonable range of these parameters are analyzed and summarized.

2.1. Test materials

The aggregates used in this test were granite and the asphalt was 70# paving grade asphalt. All the technical indicators of test material were conformed to the requirements in "Technical specification for construction of highway asphalt pavement" [28]. The test results are shown in Table 1, Tables 2 and 3.

2.2. Gradation design

Based on the classification of coarse and fine aggregates commonly used [19,20], the boundary of coarse and fine aggregates of asphalt mixture in this study was 2.36 mm for maximum nominal particle size of 13.2 mm. Therefore, the gradation design with multilevel mixing method aimed at utilizing 13.2 mm–2.36 mm aggregates to form the skeleton of mixture. Dry tamping test was used to obtain the density and void ratio of the mineral mixtures and to determine the optimal ratio of different sizes of aggregates with Gaussian fitting. There were three mixing stages in this gradation design: the first stage comprised mixing 13.2 mm aggregate with 9.5 mm aggregate, the second stage comprised mixing the 13.2 mm + 9.5 mm aggregates blend from the first stage with 4.75 mm aggregate, and the third stage involved mixing the blend of "coarse aggregate" (13.2 mm + 9.5 mm + 4.75 mm) with 2.36 mm aggregate. Fig. 1 shows the results of the Gaussian fitting for the aggregate in the third mixing stage.

Table 1
Properties of coarse aggregate.

Test indicators	Requirements	Test result	Test method
Crushing value/%	≤26	16	T0316
Los Angeles abrasion value/%	≤28	22	T0317
Water absorption/%	≤2	0.13	T0304
Apparent relative density/(g/cm^3)	≥2.6	2.778	T0304
Content of partials <0.075 mm/%	≤1	0.5	T0310
Elongated and flaky particles content/%	<15	10	T0312

Table 2
Properties of fine aggregate.

Test indicators	Requirements	Test result	Test method
Ruggedness/%	≥12	10	T0340
Sand equivalent/%	≥60	65	T0334
Mud content/%	≤3	1.4	T0333
Apparent relative density/(g/cm^3)	≥2.5	2.557	T0328
Elongated and flaky particles content/%	<15	8	T0312

Table 3
Properties of 70# asphalt.

Test indicators	Requirements	Test result	Test method
Penetration (25 °C, 100 g, 5 s)/ 0.1 mm	60–80	68	T0604-2011
Penetration index	−1.5 to +1.0	0.1	T0604-2011
Ductility (5°C, 5 cm/min)/cm	≥15	62.8	T0605-2011
Softening Point/°C	≥46	50	T0606-2011