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Investigation on fatigue damage of asphalt mixture with different air-voids using microstructural analysis

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HIGHLIGHTS

- The relationship between air-voids ratio and compactness is linear.
- Initial air-voids number and temperature have influence on cracks distress.
- The effect of air-voids complexity on fatigue damage is significant.

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ABSTRACT

Fatigue damage caused by vehicle loads is the main asphalt pavement distress, and it deteriorates the serviceability and strength seriously. In order to evaluate the fatigue damage of asphalt mixture under repeated load, microstructures were detected to investigate the morphology change of internal structures using Digital Image Processing (DIP). Field pavement named as ISAC test track was built, and cores were drilled to slice into test specimens with different air-voids that can reflect the real internal state of asphalt pavement. Fatigue properties were measured under temperature −10 °C, 0 °C and 10 °C respectively, the frequency of sinusoid load was 0.1 Hz, the minimum value was 0.035 MPa and maximum value was 0.5 MPa. Internal structures of asphalt mixture were scanned by X-ray Computed Tomography (XCT) device before and after fatigue damage, thus the relationship between microstructures and fatigue damage can be conducted. The results show that microstructural analysis can effectively determine the internal structure change of asphalt mixture. Charging compaction causes different air-voids distributions and morphologies, which have obvious influence on failure state of asphalt mixture. The effect of temperature and initial air-voids on fatigue performance is significant, and fatigue damage presents a linear relation with the complexity of air-voids. Methodology established in this paper provides an effective method for fatigue damage assessment.

1. Introduction

Asphalt mixture is a composite material that includes aggregates, air-voids and asphalt mastic, each microstructure has obvious influence on the performance. Air-voids are main structure component of asphalt pavement, and some functions such as drainage and noise reduction relate with air-voids significantly. However, air-voids can aggravate the fatigue damage under repeated load and reduce the strength of asphalt mixture, causing macro crack and some typical failures appear in asphalt pavement, such as rutting and bleeding. Therefore, air-void can be regarded as a defect of asphalt mixture. Although the gradation of asphalt mixture is a critical factor for air-voids morphology, the compaction affects the spatial distribution of air-voids in asphalt pavement as well. Due to the different compaction energies the asphalt pavement suffers, the air-voids must be changed along with the depth, result in different states in different parts of pavement. Thus the effect of air-voids on fatigue performance should be investigated to evaluate the properties of asphalt pavement.

In recently years, microstructure has become a prevalent research objective in pavement engineering, Digital Image Processing (DIP) base on the X-ray Computed Tomography (XCT) is generally used to analyze the failure mechanism and influencing factors of asphalt mixture. The development of pavement distress can be

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detected using the microstructure reconstructed by XCT images [1–6], and the presented literature shows that air-voids have obvious influence on the performance and durability of asphalt mixture [7]. Some researchers have certified the significant effect of air-voids on the failure of asphalt mixture, especially the mechanisms that air-voids affect the mechanical behavior of asphalt pavement are commonly involved base on the XCT scanning technology [8–11]. Coleri used XCT apparatus to scan the internal structure of asphalt pavement before and after high temperature deformation, then the air-voids change were measured and the effect of air-voids on rutting distress was evaluated [12,13], Sefidmazgi also analyzed the influence of microstructure on anti-deformation performance of asphalt mixture using XCT images and DIP [14]. Khan developed a 3D microstructure numerical model according to XCT data, the result shows that air-voids affect stress concentration and aggravate the pavement failure [15], besides, moisture damage of asphalt mixture was investigated as well [16]. In fact, air-voids are extended to form cracks distress commonly because of stress concentration, and the conclusion of presented research shows that air-voids have adverse influence on performance of asphalt mixture [17].

Furthermore, the air-voids distribution is uneven because of the different compaction energies during pavement construction. The components of asphalt mixture, especially the content of fine aggregates, determine the air-voids distribution [18]. Some microstructural characteristics of air-voids, such as the homogeneous of distribution state and discrete degree of morphology, can be analyzed by the XCT images and DIP [19–21]. However, most researchers study the asphalt mixture molded in laboratory, it is hard to reflect the real state of internal structure, and the investigations about the relationship between air-voids and fatigue damage are rare.

Through the XCT scanning, this paper establishes the relationship between compaction and air-voids of asphalt mixture drilled from pavement layers in different depths. Air-voids were extracted, and DIP was used to determine morphology and distribution. Meanwhile, the effect of air-voids on fatigue performance and change of internal microstructure after fatigue damage were detected as well.

2. Objective

The investigation was aimed at providing an effective method for a better understanding of the change of internal structure after fatigue damage and the influence of microstructure characteristics on fatigue performance. A comprehensive research was conducted in order to achieve the following objectives:

(1) Determining the relationship between pavement compaction and air-voids, and reconstructing the real distribution of air-voids in the asphalt mixture by DIP technology.
(2) Counting the damage state of asphalt mixture, such as crack quantity, crack sharp and crack area, before and after fatigue test, and evaluating the effect of different temperatures (−10 °C, 0 °C and 10 °C) and air-voids complexity on the fatigue performance of asphalt mixture.

3. Materials and methods

3.1. Laboratory design for material

Initially, a Stone Mastic Asphalt (SMA) mixture with a nominal maximum aggregate size (NMAS) of 12.5 mm and bitumen of 6.9% was prepared and named as SMA-11S. The NMAS is defined as one sieve size larger than the first sieve to retain more than 10% of the aggregates. The SMA-11S mixture was prepared using a PG 50/70 binder and diabase aggregates, Marshell method was used to determine the gradation of SMA-11S, the test temperature was 170 °C, the gradation of the diabase aggregates are shown in Fig. 1 and critical material parameters are listed in Table 1.

3.2. Test track construction, fatigue test and XCT scanning

In order to obtain the internal structure of real asphalt pavement, the field test track was built at Institute of Highway Engineering of RWTH Aachen University and named as ISAC test track. Diabase aggregates were mixed at temperature of 170 °C. A brief overview about the procedure of the test track construction, fatigue test and XCT scanning follows.

(1) A miniature paver was used to prepare the asphalt mixture, a heating part within the machine can keep the paving temperature higher than 150 °C. The length, width and thickness of the test track were 26 m, 1.2 m and 0.3 m respectively, as shown in Fig. 2(a).
(2) Dividing ISAC test track into three layers, each layer has the same depth of 0.1 m. Using a miniature roller compacted these layers respectively, as shown in Fig. 2(b). It must be note that the test track was composed of three layers, thickness of each layer was 0.1 m after compression, the lower layer of test track suffers more compaction energy, so compaction degree was greater than that of other layers. Test track determined in this paper can provide different asphalt mixtures which have different porosity rate, these asphalt mixture samples are the foundation for investigating the effect of compaction (air-voids) on the fatigue property.
(3) In order to obtain the internal structure of asphalt pavement, cylindrical cores were drilled at different sections of test track after maintenance, as shown in Fig. 2(c). Fig. 2(d) illustrates the cylindrical cores, which size were 150 mm in diameter and 300 mm in height.
(4) Each cylindrical core can be sliced into five test specimens which size were 40 mm in height and 100 mm in diameter according to the demand of FGSV-Nr.430 of Germany, and test specimens were numbered base on their corresponding initial depth in the test track, as shown in Fig. 2(e).
(5) The Universal Test Machine (UTM) was used to measure the fatigue performance of test specimens at test temperature of −10 °C, 0 °C and 10 °C in Fig. 2(f). The loading followed sinusoid mode that frequency was 0.1 Hz and stress control

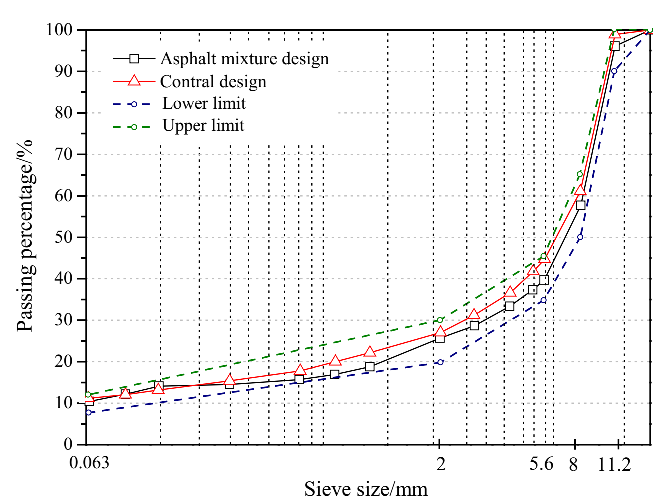

Fig. 1. Gradation of diabase aggregates of SMA-11S.