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Effects by property homogeneity of aggregate skeleton on creep performance of asphalt concrete

Xunhao Ding [a], Tao Ma [a,*], Weiguang Zhang [a], Deyu Zhang [b], Teng Yin [a]

[a] School of Transportation, Southeast University, 2 Sipailou, Nanjing, Jiangsu 210096, China
[b] School of Civil Engineering and Architecture, Nanjing Institute of Technology, Nanjing 211167, China

HIGHLIGHTS

- Two different asphalt concretes were prepared and modeled by PFC3D.
- Property homogeneity of aggregate skeleton was described in PFC3D.
- Virtual creep tests of asphalt concrete were simulated and carried out.
- Impacts by homogeneity variation of aggregate skeleton were evaluated.

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ABSTRACT

Since the aggregate skeleton of asphalt concrete is mainly formed by the coarse aggregates and it has important influences on the creep performance of asphalt concretes, this paper evaluated the property homogeneity of coarse aggregate skeleton on the creep performance of different asphalt concretes. Two different asphalt concretes with the same maximum nominal size of 13 mm but different gradation types, which are dense-graded Superpave asphalt concrete (SUP13) and gap-graded stone matrix asphalt concrete (SMA13) were prepared and evaluated. The particle flow code in three dimensions (PFC3D), which is a software based on discrete element method (DEM), was used for the discrete element modeling of asphalt concrete and the numerical simulation of laboratory creep test for asphalt concrete. The property homogeneity variation of aggregate skeleton was considered to follow Weibull distribution during DEM modeling. Based on the numerical analysis for different asphalt concretes, the influences by property homogeneity of aggregate skeleton on the macro creep performance of asphalt concrete and the distribution of micromechanical contacting forces within asphalt concrete were analyzed. It is found that the property homogeneity variation of aggregate skeleton generate obvious impacts on the creep performance of asphalt concrete through affecting the micromechanical contacting forces within asphalt concrete. And the property homogeneity variation of aggregate skeleton causes more obvious influence on the creep performance of asphalt concrete with stronger aggregate skeleton. Thus, improving the property homogeneity of aggregate skeleton is a benefic method to promote the creep performance of asphalt concrete, especially for the gap-graded asphalt concrete.

1. Introduction

Creep is one of the essential characters of asphalt binder especially at high temperatures and under heavy traffic loading [1–3]. The creep deformation of asphalt concrete under repeated loadings is one of the most important reasons for the generation of rut depth [4–6]. Therefore, improving the creep performance could be a potential way to obtain asphalt concrete with improved rutting resistance. Many laboratory tests and field observations have been designed and conducted to evaluate the creep performance of asphalt concrete and asphalt pavement [7–12]. It is believed that the homogeneity of the asphalt concrete plays an important role in influencing its performance and the property homogeneity is attributed to its inner components, including the mechanical and morphological characteristics of the void, asphalt binder and aggregates respectively. Tests conducted by Peng and Sun indicted that as the nominal maximum aggregate size increased, the homogeneity of asphalt mixture becomes worse. Moreover, the content of the aggregates retained on 4.75 mm sieve was a key impact fac-

* Corresponding author.
E-mail address: matao@seu.edu.cn (T. Ma).

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tor on the homogeneity of asphalt mixture, which should be paid attention to [13]. Aggregate types were also factors contributed to the homogeneity of asphalt mixture, which was found by Peng and Sun as well [14]. Dubois et al. evaluated the homogeneity of asphalt mixture by the gramma-ray measurement and concluded that the compaction process would influence the void homogeneity of asphalt mixture, thus an improved compaction method was proposed by respecting geometry criteria for the samples and was recommended for practical use [15]. Similar studies for the other impact factors on the homogeneity of asphalt mixture were shown by many researchers [16–18]. However, it is hard for the experimental measures to reveal the inner mechanism of asphalt concrete and the homogeneity influences on its performance from micromechanical view.

The discrete element method (DEM), which is a numerical method developed by Cundall to analyze particulate system by modeling the translational and rational behavior of particles based on Newton's second law, provides a promising way to solve the previous problems with experimental tests [19]. It is proved that, by using appropriate inter-particle contacts, DEM can well character the mechanical behavior of rocks, soils and asphalt concretes from micromechanical view [20,21]. For the last decades, a type of software based on DEM have been designed and developed. Among which, the particle flow code in two and three dimensions (PFC2D/3D) is one of the most commonly adopted DEM codes for asphalt concrete analysis due to its high computation efficiency and flexible human-computer interaction [22–27].

Based on combination of image-based technology and DEM modeling, You et al. rebuilt the microstructures of asphalt concrete and predicted the modulus of asphalt concrete based on numerical simulation tests [28]. Khattak et al. built DEM model for carbon nanofiber modified asphalt concrete based on imaging techniques and predicted the stress-strain behavior, dynamic modulus and strength of asphalt concrete based on numerical simulation tests [29]. Liu et al. investigated the micro viscoelastic models for asphalt concrete during DEM modeling to characterize the viscoelastic behavior of asphalt concrete [30]. Based on building of DEM models for granular mixes, Dongdi et al. analyzed the influences of grain shape and angularity on property of granular mixes [31]. Chen et al. conducted micromechanical modeling for asphalt concrete and analyzed its fracture resistance and behavior by using user-defined DEM method [32]. Chen et al. conducted numerical simulation of compaction process for asphalt concrete and analyzed the air void distribution within asphalt concrete as well as its influence on the property of asphalt concrete [33]. Zhang et al. developed algorithms to generate irregular aggregates for asphalt concrete during DEM modeling and investigate the effect of coarse-aggregate morphology on shear property of asphalt concrete [34,35]. Based on Zhang's researches, Hou et al. conducted three-dimensional DEM modeling as well as loading simulation for asphalt concrete and investigated the moving path of aggregates under traffic loading [36]. Chen et al. built two-dimensional and three-dimensional random aggregates structures for asphalt concrete, performed two-dimensional and three-dimensional numerical simulation testing for asphalt concrete, and predicted the thermal conductivity of asphalt concrete with heterogeneous microstructure [37,38]. Through discrete element modeling, Yang et al. evaluated the healing effect of asphalt concretes by using of bonding-healing model and numerical simulation of bending beam fracture test, they also built a sphere growth model based on realistic aggregate shapes to describe the mesostructure for stone based materials [39,40].

In this paper, the particle flow code in three dimensions (PFC3D) was applied to perform DEM modeling for asphalt concrete. Weibull distribution was used to characterize the property homogeneity (elastic property actually in this study) of aggregate skeleton in asphalt concrete and was actualized by user-defined procedure during DEM modeling. The influences by the property homogeneity of aggregate skeleton on the creep performance of asphalt concrete were also analyzed based on numerical creep test.

2. Experimental

2.1. Experimental materials

Two mixes, including dense-graded Superpave asphalt concrete (SUP13) and stone matrix asphalt concrete (SMA13) were prepared in the laboratory. The maximum nominal size (NMAS) for both mixtures is 13 mm. The design gradations for SUP13 and SMA13 are shown in Fig. 1. It is seen that the percentage passing of 4.75 mm of SMA 13 was much lower than that of SUP13. This indicates that the content of coarse aggregates in SMA13 is higher than SUP13 which indicate SMA13 has stronger aggregate skeleton than SUP13.

2.2. Experimental tests

In laboratory, the creep test was utilized to assist the DEM modeling of asphalt concrete and the built of numerical simulation creep test. In the DEM model, the designed asphalt concretes were separated into two parts consisting of coarse aggregates with size larger than 2.36 mm, as well as asphalt mortar, which is composed of asphalt binder, and fine aggregates. The laboratory uniaxial static creep tests were conducted at 60 °C for both asphalt mortar and asphalt concrete to determine the viscoelastic parameters for asphalt mortar and verify the validity of built numerical simulation creep test for asphalt concrete. The applied axial stress were 0.07 MPa and 0.7Mpa for the asphalt mortar and asphalt concrete respectively with a total 300 s loading. Fig. 2 shows the illustrations of SPT test and the test samples for asphalt mortar and asphalt concrete.

3. Discrete element numerical simulation

3.1. Numerical simulation of asphalt concrete

The coarse aggregates, asphalt mortar and air voids were modeled separately in the DEM model for asphalt concrete. The generation of asphalt concrete in the DEM is elaborated in Fig. 3. As shown in Fig. 3(a), the numerical simulation used the same sample size as that used for laboratory test, with 150 mm in height and 100 mm in diameter. The model was generated and fulfilled with

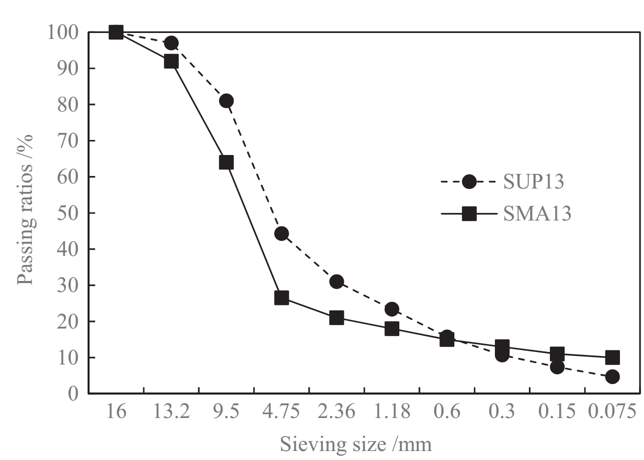

Fig. 1. Gradations for SUP13 and SMA13.