Construction and Building Materials 126 (2016) 785–799

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

# Influences by air voids on fatigue life of asphalt mixture based on discrete element method

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## HIGHLIGHTS

- Virtual modeling was built to predict fatigue life of asphalt mixture.
- Larger air void content leads to worse fatigue life of asphalt mixture.
- Non-uniform distribution of air voids affects fatigue life of asphalt mixture.
- Interconnected air voids with big size are harmful to fatigue durability.

## ARTICLE INFO

*Article history:*
Received 22 May 2016
Received in revised form 5 September 2016
Accepted 17 September 2016

*Keywords:*
Asphalt mixture
Fatigue life
Virtual test
PFC3D
Air voids

## ABSTRACT

The paper studied the impacts of different air void parameters on the fatigue life of asphalt mixture based on discrete element method (DEM). By using discrete element software PFC3D (Particle Flow Code in Three Dimensions), virtual three-dimensional fatigue test was built according to the laboratory four-point bending beam fatigue test with stress-controlled loading mode. And the feasibility of virtual fatigue test was confirmed by laboratory testing data. Based on virtual fatigue test, the influences by content, distribution, size and orientation of air voids on the fatigue life of asphalt mixture were evaluated. It is found that, higher air void content leads to lower fatigue life of asphalt mixture especially when the air void content exceeds the designed air void content of asphalt mixture, interconnected air voids with bigger size is more harmful to the fatigue life of asphalt mixture than the independent air voids with smaller size especially when the orientation of air voids is parallel to the fatigue loading direction, and the non-distribution of air voids within asphalt mixture specimen also has important influences on the fatigue life of asphalt mixture especially for the variation of the air void distribution within the central-bottom section of asphalt mixture specimen. Thus, to guarantee the fatigue durability of asphalt mixture, it is important to improve the content, distribution and microstructure of air voids within asphalt mixture.

## 1. Introduction

Fatigue cracking is one of the main damages of asphalt pavement and its failure mechanism is very complicated [1,2]. Road workers have been always focusing on the researches of fatigue performance of asphalt pavement. Currently, fatigue life of asphalt mixture is mainly measured through laboratory fatigue test. However, due to the heterogeneity of asphalt mixture and the complex artificial interferences, it is difficult to control the variability of laboratory tests. Meanwhile, most of the laboratory test can only obtain the macro-property of asphalt mixture but cannot depict the micro-mechanical response of asphalt mixture which is more helpful to understand the fatigue behavior of asphalt mixture. Previous studies have proved that it is more reasonable to analyze the cracking properties and mechanism of asphalt mixture based on heterogeneous microstructure [3–5].

Discrete element method was put forward by Cundall et al. in geotechnical engineering field [6]. It was initially use to analyze the mechanical properties of rock and soil from mesoscopic aspect. In recent 20 years, discrete element method, as a new numerical simulation method, has been extensively applied in road engineering due to its well applicability for solving problems related to non-continuous medium and large deformation of materials

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http://dx.doi.org/10.1016/j.conbuildmat.2016.09.045
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[7–9]. Buttlar et al. divided multiple disk units into "clump" by adopting two-dimensional (2D) discrete element method to simulate indirect tensile behavior of asphalt mixture [10]. Collop et al. performed uniaxial compressive creep test simulation for asphalt mixture based on elastic contacting model by adopting discrete element method [11]. You et al. established 2D and 3D discrete element model to simulate dynamic modulus test of asphalt mixture by adopting image processing technology and 3D digital generation technology to predict the dynamic modulus of asphalt mixture and observe the stress–strain response during dynamic modulus test [12,13]. Zhang et al. conducted a series of studies on the rutting resistance of asphalt mixture based on discrete element method. They put forward a three dimensional generation algorithm to simulate aggregates with irregular shape, established virtual triaxial compression tests to predict the resilient modulus of graded aggregates and the dynamic modulus of asphalt mixture, analyzed the rutting deformation and resistance of asphalt mixture by tracking the trajectories of aggregates of asphalt mixture under vehicle load, and performed 3D virtual shear test for asphalt mixture to analyze the influence of aggregate shape on the shear property of asphalt mixture [14–16]. Yang et al. simulated the bending beam fracture test by adopting discrete element method, and analyzed the healing property of asphalt mixture by using bond healing model [17]. Yang and Jin et al. established a database for aggregates with various shapes and angularities during three-dimensional discrete element modeling [18,19]. Ma Tao et al. built virtual creep test and wheel tracking test for asphalt mixture, evaluated the effects of air voids on the creep behavior of asphalt mixture, and analyzed the micromechanical response of coarse aggregates during rutting of asphalt mixture [20–22]. Chen et al. also conducted a series of studies about the test simulation for asphalt mixture. Based on three-dimensional discrete element modeling, they evaluated the influences of size and non-deformability of aggregates on the interlocking property of aggregates skeleton, built a derivation formula transforming the three-dimensional volume gradation of asphalt mixture to two-dimensional quantity gradation based on probability theory, studied the dynamic loading response and cracking behaviors of asphalt mixture, and conducted simulation of splitting test to predict the low-temperature properties of asphalt mixture under −10 °C and 15 °C [23–25].

This study focused on the influences of different parameters related to air voids on the fatigue life of asphalt mixture. Discrete element method and PFC3D were used to build three-dimensional digital specimen and virtual fatigue test for asphalt mixture based on real asphalt mixture and laboratory four-point bending beam test with stress-controlled loading mode. And the influences of air void content, size of single air void, orientation of air voids and distribution of air voids on the fatigue life of asphalt mixture were evaluated.

## 2. Experimental

### 2.1. Materials

Asphalt mixture with nominal maximum aggregate size of 13.2 mm (AC13) and asphalt mortar with maximum aggregate size of 2.36 mm were prepared for laboratory test. The basic properties of neat asphalt, aggregates and mineral fillers are shown in Tables 1 and 2. The designed gradation of AC13 mixture is shown in Table 3 and the designed asphalt content is 4.9%. According to the designed AC13 asphalt mixture, asphalt mortar composed of asphalt binder and fine aggregates smaller than 2.36 mm (including mineral fillers) were prepared. Since the asphalt mortar is consisted of asphalt and fine aggregates, based on the asphalt content and gradation of asphalt mixture, the asphalt content of asphalt mortar, which is the weight ratio of asphalt to the total weight of asphalt and fine aggregates (including fillers), was determined to be 11% and its gradation is shown in Table 4.

### 2.2. Laboratory tests

In this study, the laboratory fatigue test named as four-point bending beam test was used as the basis for DEM modeling of virtual fatigue test. Since viscoelasticity is one of the essential properties of asphalt mixture, viscoelastic property was considered during DEM modeling. Based on previous studies [9,20,24], the

**Table 1**
Basic properties of neat asphalt.

| Test items | 25 °C penetration/0.1 mm | 15 °C ductility/cm | Softening point/°C | 135 °C viscosity/mPa.s | Apparent specific gravity |
|---|---|---|---|---|---|
| Test values | 68 | >100 | 49 | 41 | 1.029 |

**Table 2**
Basic properties of aggregates and fillers.

| Test items | Apparent specific gravity | | | | | LA Abrasion loss/% | Absorption/% | Sand equivalent/% |
|---|---|---|---|---|---|---|---|---|
| Test values | 9.5–16 mm | 4.75–9.5 mm | 2.36–4.75 mm | 0–2.36 mm | Filler | 10 | 0.52 | 89.5 |
| | 2.832 | 2.825 | 2.818 | 2.711 | 2.721 | | | |

**Table 3**
Gradation of AC13.

| Sieving size/mm | 16 | 13.2 | 9.5 | 4.75 | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---|---|---|---|---|---|---|---|---|---|---|
| Passing ratio/% | 100 | 95 | 79.7 | 49.8 | 37.6 | 26.4 | 17.1 | 9.8 | 7.2 | 6.6 |

**Table 4**
Gradation of asphalt mortar.

| Sieving size/mm | 2.36 | 1.18 | 0.6 | 0.3 | 0.15 | 0.075 |
|---|---|---|---|---|---|---|
| Passing ratio/% | 100 | 70.2 | 45.4 | 26.1 | 19.1 | 17.6 |