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Damage Evolution and Crack Propagation in Semicircular Bending Asphalt Mixture Specimens**

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ABSTRACT The damage and fracture behaviors of semicircular bending (SCB) asphalt mixture specimens with different orientation notches are experimentally and numerically investigated. In the numerical simulations, asphalt mixture is modeled as a two-phase material, namely a mix of coarse aggregates and asphalt mastic, and the mechanical behavior of asphalt mastic is characterized with the damage constitutive model and the damage-based fracture criterion. Some SCB experiments are performed on the asphalt mixture specimens with different orientation notches to validate the numerical method. Finally, the effects of notch orientation and aggregate distribution on crack path, damage distribution, and the load vs. displacement relation are numerically evaluated.

KEY WORDS semicircular bending, heterogeneous model, damage, notch orientation

I. Introduction

Asphalt pavements are widely used in airfield runway, urban street and high-grade highway due to their many advantages[1]. In China, however, a number of distresses occurred in pavements with the rapid increment in traffic volume in recent years, and cracking has become one of the main distress modes. In order to enhance the cracking resistance of pavement, it is significant to investigate the damage evolution and fracture mechanism of asphalt mixture.

Numerical simulation can largely reduce laboratory costs and exhibit field evolution process, so the finite element method (FEM) as well as the extended finite element method (XFEM)[2,3] have been frequently adopted to simulate cracking in asphalt mixture in recent years. However, asphalt mixture is a particulate composite, in which a rigid skeleton of aggregate particles is held together by soft asphalt matrix. The traditional homogeneous models tend to neglect heterogeneity of asphalt mixture, and thus always give some predictions of unrealistically smooth crack paths and unreliable load-carrying capacities. Therefore, the computational models with component and microstructure information are more attractive than the homogeneous ones. In order to cover the heterogeneity effect, asphalt mixture was generally modeled as a composite of coarse aggregate and asphalt mastic composed of asphaltic binder, fine aggregates, and entrained air voids with the numerical image processing method (NIPM) and the parameterization modeling method (PMM). In the NIPM, a high-resolution digital camera[4] or an X-ray computed tomography[5] is used to generate reliable and persuasive geometric models of

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asphalt mixture with realistic aggregate shape, gradation and distribution. However, the NIPM has disadvantages such as being time-consuming, expensive and dependent on the laboratory specimens. Therefore, the laboratory-independent and computer-aided method, namely the PMM, was developed[6]. In this method, asphalt mixture is treated as a mix of coarse aggregates and asphalt mastic, and aggregate particles are generally simulated with balls or ellipsoids and polygons or polyhedrons according to the given gradation. By combining the PMM with the discrete or finite element method, several researchers have successfully conducted the fracture research on asphalt mixture. For instance, Yin et al.[7] developed the random aggregate generation and packing algorithm (RAGPA) and successfully simulated the fracture behaviors of uniaxial tensile asphalt mixture specimens. Based on the RAGPA, Zeng et al.[8] simulated the damage evolution and crack propagation behaviors of three-point bending asphalt mixture beams.

Asphalt mixture is temperature dependent. It is viscoelastic at high temperature but elastic at low temperature. Viscoelastic fracture is very complex because the energy dissipation in the material includes damage dissipation and viscous dissipation, and the latter is usually much greater than the former[9–12]. Fortunately, fracture in asphalt pavements mainly occurs at low temperature. It is noted that asphalt mixture generally exhibits evident postpeak softening behavior in a fracture process because numerous microcracks initiate and develop before the macrocrack is formed[13]. Accordingly, an appropriate fracture constitutive model is very important for describing the discrete microcrack evolution. As one of the most important separation models, the cohesive zone model (CZM) was extensively used as the fracture criterion in numerical simulation of fracture behavior of asphalt mixture[14,15]. In general, highly concentrated stress near a crack or notch tip will result in damage. The CZM can realistically simulate the initiation and growth process of micro-crack, but cannot quantitatively exhibit the damage distribution and evolution in a damaged structure. The above literature indicates that little work has been done to reveal the performance deterioration and damage evolution of cracked asphalt mixture.

Continuum damage mechanics (CDM) introduces damage as an internal variable to explicitly characterize the local loss of material integrity[16], so the analysis based on CDM can show damage degree and distribution at different crack growth stages. In recent years, CDM has been used for the description of nonlinear behavior of asphalt mixture, such as Zhao[17], Uzan[18], Underwood and Kim[19], and so on. Zeng et al.[8] characterized the physical degeneration of asphalt mastic in fracture processes using the damage constitutive model with experimentally determined parameters, and successfully simulated damage evolution and crack propagation in the three-point bending pre-cracked asphalt mixture beams.

Many laboratory tests, including the three- or four-point bending test[20,21], the disk-shaped compact tension test[22–24], the indirect tension test[25,26], and the semicircular bending (SCB) test[27,28], were utilized to investigate various fracture modes of asphalt mixture. The SCB test is practically more attractive than other tests because of its relatively simple testing configuration, easy specimen preparation, and applicability for mode I and mixed mode fracture. With the help of SCB tests, Ameri et al.[29] experimentally observed the mode I and mixed mode crack propagations, Li and Marasteanu[30] evaluated the effects of aggregate gradation and temperature on fracture work, and Aliha et al.[31] investigated the effect of asphalt characteristic on the mixed mode fracture toughness at low temperature.

In this paper, in order to better understand the damage evolution and crack growth of SCB pre-notched asphalt mixture samples, the RAGPA[7,15] is combined with CDM to build two-dimensional (2D) microstructural models based on the given aggregate gradation. A series of experiments and numerical simulations are performed to investigate the effects of notch orientation and aggregate distribution on the fracture behavior.

II. Material Model

2.1. Damage constitutive model for asphalt mastic

Asphalt mixture consists of three distinct components, asphalt binder, aggregates and air voids. In numerical modeling of asphalt mixture with component and internal structure information, for simplicity, aggregates are divided into two parts, namely coarse and fine aggregates, according to the cut-off size of 2.36 mm proposed by Bandyopadhyaya et al.[32]. Numerous fine aggregates are combined with asphalt binder and air voids in the asphalt mastic. As a result, asphalt mixture is treated as a two-phase composite with coarse aggregates embedded in the asphalt mastic matrix[33].