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A MICROMECHANICAL FRAMEWORK WITH AGGREGATE-MASTIC INTERFACE EFFECT FOR PREDICTING UNIAXIAL COMPRESSION CREEP OF ASPHALT MIXTURE**

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ABSTRACT According to the elastic-viscoelastic correspondence principle, an elastic micromechanical framework taking the inclusion-matrix interface effect into account is extended for predicting viscoelastic properties of asphalt mixture, which is simply treated as elastic coarse aggregate inclusions periodically and isotropically embedded in a viscoelastic asphalt mastic matrix. The Burgers model is adopted for characterizing the matrix mechanical behavior, so that the homogenized relaxation modulus of asphalt mixture in compression creep is derived. After a series of uniaxial compression creep tests are performed on asphalt mastic in different temperature and stress conditions in order to determine the matrix constitutive parameters, the framework presented is validated by comparison with the experiment, and then some predictions of uniaxial compression creep behavior of asphalt mixture in different temperature and stress conditions are given.

KEY WORDS asphalt mixture, micromechanics, elastic-viscoelastic correspondence principle, compression creep

I. INTRODUCTION

Asphalt mixture is widely used in pavement engineering because of its advantages, such as high strength, and smooth and comfortable drive made possible. In recent years, however, numbers of distressful happenings, including crack, rut, layer segregation, etc, have taken place in asphalt pavements with the increase in traffic volume and heavy vehicle percentage, reducing the service capacity of asphalt pavement. Investigation of mechanical behaviors of asphalt mixture is very important for distress control, and design and life prediction of asphalt pavement[1–3].

It is well known that asphalt mixture is a heterogeneous materialthat can be described as a particle reinforced composite consisting of at least two phases: aggregates in a high volume fraction and asphalt binder. Aggregates are solid inclusions of different sizes, irregular shapes, and random locations. As a matrix, asphalt binder is a typical thermoviscous material in most loading conditions. Both of them directly and significantly influence the performance of mixture. Because of the wide diversity of asphalt content, aggregate type, gradation, distribution, etc, the mechanical properties of asphalt mixture are very complicated. Therefore, it is important to construct a micromechanical constitutive model con-

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taining the component and microstructure information with micromechanical approaches to predicting the mechanical properties of asphalt mixture[4,5]. Li and Metcalf[6] proposed a two-step approach to predict the asphalt mixture modulus based on a two-phase micromechanical model. In their approach, asphalt mixture was thought to consist of a large spherical aggregate particle and a spherical shell of fine aggregate-filler-binder mixture surrounding it as the matrix. The fine aggregate-filler-binder mixture is further represented by the two-phase model, which treats fine aggregates as a spherical inclusion and filler-binder mixture as the matrix. Utilizing the two-step approach, the asphalt mixture modulus can be predicted via the volumetric fraction of aggregate, the Poisson's ratios and the moduli of aggregate and filler-binder mixture. Shashidhar and Romero[7] called the fine aggregate-filler-binder mixture asphalt mastic, which consists of fine aggregates and asphalt binder. Bandyopadhyaya et al.[8] suggested 2.36 mm as the cutoff size between coarse and fine aggregates, the fine aggregates size 2.36 mm and below being combined with asphalt binder as asphalt mastic.

The micromechanics methods played important roles in the viscoelastic or viscoplastic properties prediction of composites[9] and were recently applied to asphalt mixture. Luo and Lytton[10] reported an inverse analysis scheme with the self-consistent method to back-estimate aggregate properties when measured binder and mixture properties are available. Kim[11] evaluated the role of aggregates in stiffening asphalt mixtures and pointed out that the micromechanical scheme tends to slightly underestimate the stiffness of asphalt mixture. However, the aggregate-mastic interface effect was not considered in these schemes, although the bonding condition of interfaces between inclusions and matrix is one of the important factors for controlling the displacement/stress field and influencing the overall properties of composites[12–14]. Of the two kinds of interface model used to simulate the interface effects in composites and polycrystalline materials[15–17], one is the mathematical interface model including the linear-spring interface model and the interface stress model, in which displacement and stress discontinuities are assumed to exist in the interface. Using the linear-spring interface model to simulate the imperfect interface bonding, Hashin[15] investigated the effective elastic properties and the thermal expansion coefficients of particle-reinforced composite materials. Nix and Gao[16] evaluated the effect of interface stress on the overall mechanical properties of various metal multilayers with the interface stress model. Duan et al.[18] pointed out that the linear-spring interface model is suitable for approximating a thin and soft interphase rather than the interface stress model for a thin and stiff interphase, and presented a unified theoretical framework to predict the effective modulus of multiphase composites containing spherical particles or cylindrical fibers with various interface effects. The other is the interphase model introduced by Walpole[19], in which the inclusion-matrix interface is described as an interphase layer with a certain depth and mechanical properties different from the inhomogeneity and matrix. It was frequently used for property prediction and damage analysis of nanocrystalline materials[17] and composites[20–22].

In this paper, according to the replacement method proposed by Hashin[23], aggregates are replaced by the equivalent aggregates with a common content and the aggregate-mastic interface is depicted by the linear-spring model. According tothe elastic-viscoelastic correspondence principle, micromechanical approaches can be extended from elastic to viscoelastic multiphase problems[24], so that the generalized self-consistent model[18,25] can be used to predict the effective properties of asphalt mixture. The paper is arranged as follows. Firstly, a micromechanical framework with inclusion-matrix interface effect is extended to predict the viscoelastic behavior of asphalt mixture by invoking the elastic–viscoelastic correspondence principle in §II. Then asphalt mastic is characterized with the Burgers model, and its constitutive parameters are determined through the uniaxial compressive creep experiments under different stress and temperature conditions in §III. Thirdly, the viscoelastic creep behaviors of asphalt mixture under different stresses and temperatures are predicted and compared with the experiment results of asphalt mixture in §IV. Finally, some conclusions are given in §V.

II. A MICROMECHANICAL FRAMEWORK WITH AGGREGATE-MASTIC INTERFACE EFFECT FOR ASPHALT MIXTURE

In this section, a micromechanical framework with aggregate-mastic interface effect will be constructed for viscoelastic behavior prediction of asphalt mixture by extending the elastic micromechanical framework with inclusion-matrix interface effect[26] on the basis of the elastic-viscoelastic correspon-