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CONSTITUTIVE MODELING AND EXPERIMENTAL INVESTIGATION OF RATE-DEPENDENT COMPRESSION-TENSION ASYMMETRY OF ASPHALT MATRIX

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ABSTRACT

This research presents an experimental and numerical approach to study the mechanics of asphalt matrix, a crucial component in asphalt concrete. Understanding its response is essential to guide the new designs in advanced asphalt concrete. The dynamic mechanical analysis (DMA) is used to execute a variety of quasi-static and dynamic tests under tension and compression. Uniaxial tests reveal a remarkable rate-dependent compression-tension (C-T) asymmetry of the asphalt matrix in terms of stiffness and strength. The creep rupture envelop is derived by performing creep tests at different stress levels. Amplitude and frequency sweep tests and fatigue-recovery test are performed to explore the fatigue response. A user-material visco-elasto-plastic-damageable (VEPD) model is developed to simulate the asphalt via finite element method (FEM).

Keywords: asphalt matrix, visco-elasto-plastic-damageable model, compression-tension asymmetry, DMA, FEM.

INTRODUCTION

Asphalt concrete is the most widely used material for pavements. Asphalt matrix, containing asphalt binder, fine aggregates and filler, is a visco-elasto-plastic material, whose mechanical behavior is highly non-linear. The study of the rheological properties of asphalt matrix is important for improving the mix design of asphalt concrete. Since asphalt pavement undergoes repetitive traffic loads under different climatic conditions, it is important to understand the C-T asymmetric behavior and failure mechanism of asphalt materials. The development of an experimental, mathematical and simulation framework is the key to predict and improve the material performance.

METHODOLOGY

(1) A total of six tests (three quasi-static and three dynamic tests) have been conducted using DMA under tension and compression (see Figure 1). (2) A three-dimensional VEPD constitutive model is proposed, which provides rate-dependency on stiffness and strength and describe progressive degradation and failure. (3) The model and the material parameter identification strategy are implemented using the FEM code ABAQUS via user-defined material subroutines (V)UMAT.

RESULTS OVERVIEW

Uniaxial tests reveal a remarkable C-T asymmetry of the asphalt matrix (see Figure 1). The strength and stiffness can be 5 and 3 times, respectively, larger under compression than in tension. Both properties are rate-dependent, albeit stiffness and peak stress in compression are more sensitive than in tension. The creep rupture envelop is derived by performing creep tests at different stress levels. The creep-recovery tests show that compared to the recoverable strain, the permanent strain is far more sensitive to the creep stress. Amplitude and frequency sweep tests and fatigue-recovery test are performed to explore dynamic properties of asphalt matrix.

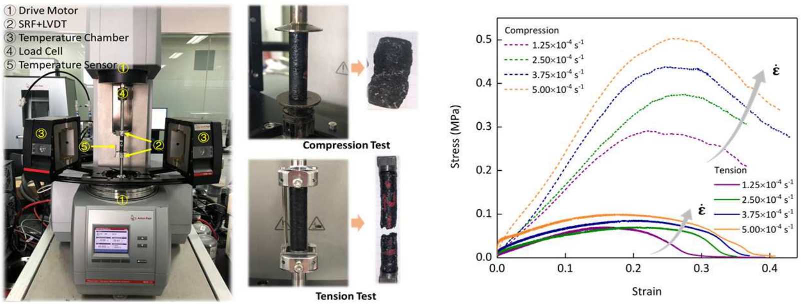

Fig. 1 – Test setup of DMA (left) stress-strain curves at different strain rates (right).

Figure 2(left) shows the rheological representation of the constitutive model for asphalt matrix. This model consists of a pressure dependent elasto-plastic model connected in parallel to a series of Maxwell branches that provide the visco-elastic response. All these elements are coupled to a continuum damage model. This model can capture the rate-dependent asymmetric response of the plastic yielding and fracture under tension and compression (see Figure 2).

The required material properties of this model are identified from the DMA results using an in-house improved multidimensional Nelder-Mead gradient-less algorithm integrated in the FEM framework. This algorithm allows for multiple user-defined and physical-based constrains leading to efficiently solve highly non-linear functions.

The strain-rate effect and the loading paths are studied using FE models that simulate the tensile and compressive tests in the same way as the real experiment, as shown in Figure 2(center).

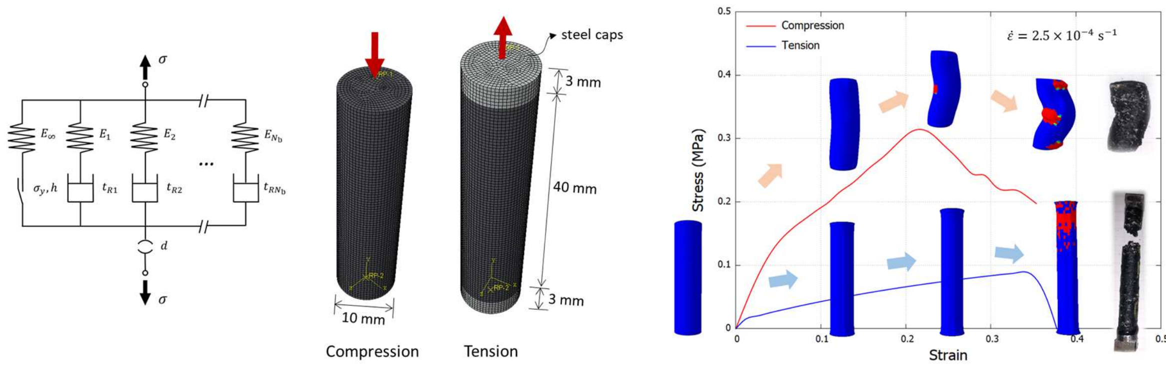

Fig. 2 – VEPD model (left) FE models (center) C-T asymmetric stress-strain curves (right).

The present VEPD model proves to contain the most relevant mechanical features to understand the experimental observations: a rate-independent plastic model coupled with visco-elastic elements can capture the rate-dependent asymmetry, and the additional damage coupling allows for predicting the progressive failure, as it is shown in Figure 2 (right). The DMA test results provide consistent data sets facilitating the identification of the model parameters.