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Mechanical characterization of a bituminous mix under quasi-static and high-strain rate loading

Srinivasan Arjun Tekalur [a], Arun Shukla [b,*], Martin Sadd [b], K. Wayne Lee [c]

[a] Mechanical Engineering Department, Michigan State University, East Lansing, MI 48824, USA
[b] Department of Mechanical Engineering and Applied Mechanics, University of Rhode Island, Kingston, RI 02881, USA
[c] Department of Civil Engineering, University of Rhode Island, Kingston, RI 02881, USA

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ABSTRACT

There are various methods to determine the compressive and tensile strength of asphalt concrete under static loading conditions and most studies on asphalt strength and fracture have been conducted under such loading conditions. However, pavement materials also have to withstand a wide variety of loading and temperature conditions which may vary from quasi-static to high-strain rate impact, and pavement breakdown may occur due to fracture and/or fatigue failure. In the present study, a bituminous mix with 30% RAP has been characterized under quasi-static (10^{-3}–10^{-4} strain/s) and high-strain rate (200–700 strain/s) regimes. The experimental studies have been performed to better understand the compressive, tensile and fracture response of bituminous mixes. Split Hopkinson pressure bar (SHPB) and its modifications were used for high-strain rate characterization of this bituminous mixture. It was observed that the mechanical properties of the hot mix asphalt (HMA) changed significantly under high-strain rate testing. Also, the failure mechanisms observed under the high-strain rate loading were found to be considerably different from those obtained in static testing, where failure of binder was a predominant mechanism. It was observed that high-strain rate loading caused trans-aggregate failures in the specimens; in addition to failure of the binder.

1. Introduction

An extensive experimental investigation is presented to describe the fundamental mechanical and fracture properties of a bituminous mix containing 30% reclaimed asphalt pavement (RAP). Estimation of strength and load carrying capacity of pavement material is important to predict the life and service capability of the roadway. Various standard tests have been practiced in the industrial and research community to predict the performance of asphalt concrete. From the early 1990s, there has been a considerable effort to follow a mechanistic design procedure for mix design and performance prediction. This research effort has aimed at such a characterization using a bituminous mix with 30% RAP which is the maximum allowed level in the state of Rhode Island. Quasi-static and high-strain rate behavior under uniaxial compression, indirect tension and fracture toughness were studied and are reported in subsequent sections of this paper. The significance of the high-strain rate study comes from the fact that pavement materials are often subjected to various high-strain rate and impact loading conditions during service. Such cases may arise from a scenario whereby sizeable objects may be dropped on to structural pavement systems or from explosive devices. Other high rates of loading could come from high-speed traffic and accidents. Material behavior of pavement structure under high-strain rate loading needs to be understood to be able to facilitate better design principles. High-strain rate mechanical behavior of bituminous materials has received little attention due to inherent difficulty in testing and interpretation of results. Venkatram [14] performed studies on high-strain rate fracture behavior of binders. There exists considerable work on high-strain rate properties of cement concrete (Gomez et al. [6]), but literature on similar studies on asphalt concrete is scarce. The current work presents an initial study into the high-strain rate properties of a HMA concrete in three fundamental regimes of failure, namely, compression, tension and fracture.

2. Materials

Material studied in the present research was hot mix asphalt (HMA), commonly used for pavement binder course in Rhode Island. Asphalt cement with Performance Grade (PG) 64-22 was used as binder. The coarse aggregates were obtained from stone stockpiles with maximum sizes 19 mm (0.75 in.), 12.7 mm (0.5 in.) and 9.5 mm (0.375 in.) and the fine aggregate used was sand. RAP was obtained from two stockpiles with maximum sizes 19 mm (0.75 in.) and 9.5 mm (0.375 in.). The Marshall mix design procedure was adopted for determining the mix optimum binder content (OBC). The gradation chart of the mix used in the study is shown in Fig. 1. It may be noted that the aggregate gradation also meets the Superpave specification. The OBC was found to be 5.4% and is used to prepare HMA specimens.

* Corresponding author. Tel.: +1 401 874 2283; fax: +1 401 874 2355.
E-mail address: shuklaa@egr.uri.edu (A. Shukla).

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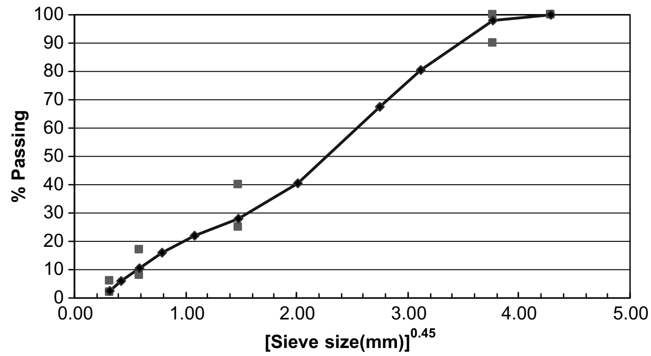

Fig. 1. Gradation chart of the mix used in the present study.

3. Experimental approach

3.1. High-strain rate testing – split Hopkinson pressure bar

The Hopkinson bar technique was first developed in 19th century and has been used for high-strain rate material characterization. A conventional split Hopkinson pressure bar or the Kolsky bar consists of a striker bar, an incident bar and a transmitter bar, as illustrated in Fig. 2. The specimen under study is sandwiched between the incident and transmitter bar. The striker bar is launched at a predefined velocity towards the incident bar. This impact generates a compressive incident stress pulse which travels towards the specimen. The amplitude of the stress pulse is a function of the velocity of the striker bar, and its period is approximately equal to twice the travel time of the wave in the striker bar. This wave, upon reaching the incident bar–specimen interface, gets partly reflected back and partly transmitted into the specimen depending on the impedance and area mismatch between the specimen and the bar. From one-dimensional wave theory, it has been established that the amplitude of the transmitted pulse is related to the stress in the specimen and the amplitude of the reflected pulse is related to the strain rate in the specimen. Thus upon integrating the reflected pulse, the strain in the specimen can be determined. The specimen can be subjected to a wide range of strain rates by employing striker bars of various lengths. Performing one-dimensional wave analysis on the strain signal obtained from the incident and transmitted bars, we can obtain the stress–strain profile in the specimen as given below.

The average strain in the specimen, ε_s, is then given by

$$\varepsilon_s = \frac{c_o}{l_s}\int_0^t (\varepsilon_i - \varepsilon_r - \varepsilon_t)dt \tag{1}$$

where l_s is the original length of the specimen and $c_0 = \sqrt{(E/\rho)}$, is the wave speed in the bar, and ρ is the mass density of the bar material. The loads at the two interfaces are given by

$$P_2(t) = A_b E_b \varepsilon_t(t) \tag{2}$$

$$P_1(t) = A_b E_b[\varepsilon_i(t) + \varepsilon_r(t)] \tag{3}$$

where A_b is the cross-sectional area and E_b is the modulus of elasticity of the pressure bars. Now, an important assumption is made that wave propagation effects within a short specimen may be neglected, thus $P_1 = P_2$. Hence

$$\varepsilon_s(t) = \frac{-2c_o}{l_s}\int_0^t \varepsilon_r dt \tag{4}$$

The average stress in the specimen is given by

$$\sigma_s = E_b \frac{A_b}{A_s}\varepsilon_t \tag{5}$$

where A_s is the cross-sectional area of the specimen. Enough consideration was given to avoid frictional effects.

3.2. Compressive behavior

3.2.1. Quasi-static

Compression testing was done on an Instron universal testing machine and the procedure outlined in ASTM D1074 was followed. A crosshead movement of 51 mm/min (2 in./min) was maintained. To avoid friction between the sample and the crosshead, a thin layer of talc was applied. The standard cylindrical specimen was adopted for this study as prescribed in ASTM D1074. The specimen blank had a diameter of 101.6 mm (4 in.) and a height of 101.6 mm. A Marshall standard mold was unavailable for such a size. Hence, special molds were machined and manual compaction was adopted while preparing the samples for compression testing. The amount of compaction needed for the specimen was obtained by trial and error approach by comparing the volumetric properties of each attempt to the standard Marshall specimen. It was found that 80 blows at each end were required to produce the compression samples. Subsequently compression samples were made using the same. Results from three typical experiments on the quasi-static compression tests are plotted in Fig. 3. The stress–strain slope of all the tests was almost equal, and the average peak stress was 3.55 MPa at a corresponding strain of approximately 0.015.

3.2.2. High-strain rate

The high-strain rate compression tests were performed on the split Hopkinson pressure bar facility in the Dynamic Photomechanics Laboratory at the University of Rhode Island. These experiments were performed on an SHPB apparatus with 50.8 mm (2 in.) diameter bars. A thin layer of lubricant was used at the interface of the specimen and bars to minimize the friction effects. The strain–time history recorded by axial strain gages were demodulated using Ectron 563F signal conditioners, and were subsequently recorded on a LeCroy 8025 data acquisition system. These signals were post processed using an in-house MATLAB program. The specimen

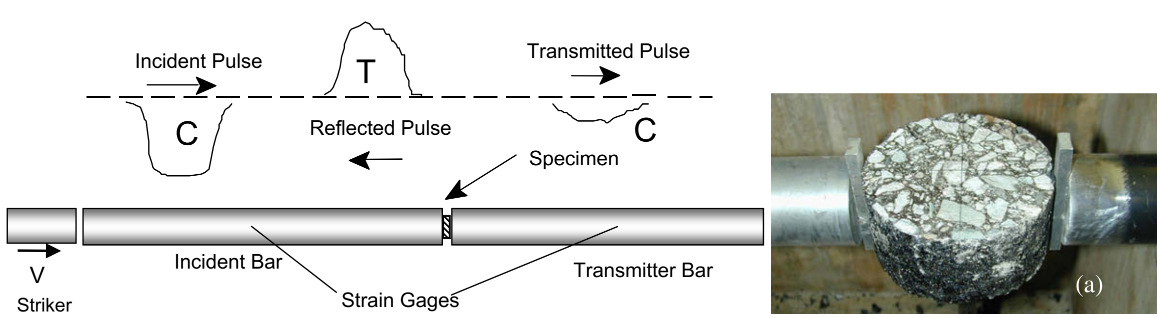

Fig. 2. Schematic of the SHPB apparatus and typical pulses obtained in testing (a) specimen configuration for dynamic IDT testing.