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Laboratory evaluation of fatigue characteristics of recycled asphalt mixture

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Abstract

This paper presents the results of a laboratory study of evaluating the fatigue characteristics of hot-mix asphalt (HMA) mixtures using different testing methods. In this study, the fatigue performance of HMA mixtures was evaluated with the Superpave indirect tension (IDT) tests and beam fatigue test. The HMA mixtures containing 0%, 10%, 20%, and 30% of recycled asphalt pavement (RAP) were plant prepared with one source of aggregate, limestone, and one type of binder, PG 64–22. The fatigue properties tested included indirect tensile strength (ITS), failure strain, toughness index (TI), resilient modulus, $DCSE_f$, energy ratio, plateau value, and load cycles to failure. The results from this study indicated that both Superpave IDT and beam fatigue tests agreed with each other in ranking the fatigue resistance of mixtures when proper procedures were followed.

Keywords: Hot-mix asphalt; Fatigue; Dissipated energy; Indirect tensile strength

1. Introduction

Fatigue cracking is one of the three major distresses (fatigue cracking, low temperature cracking, and rutting) of flexible pavements. Fatigue cracking is mainly caused by repeated traffic loading and it can lead to significant reduction in the serviceability of flexible pavements. The cracking resistance of hot-mix asphalt (HMA) mixtures is directly related to the fatigue performance of flexible pavements. Therefore, the laboratory characterization of the fatigue behavior of HMA mixtures has been a topic of intensive study for many years.

Many laboratory testing methods are available to characterize the fatigue behavior of HMA mixtures. Probably the one that possesses the most similar stress condition to HMA field mixtures under traffic loading is the repeated flexural test (also called beam fatigue test) [1]. This test was developed under SHRP-A-003A to evaluate the fatigue response of HMA mixtures and to summarize what is known about the factors that influence pavement life using a third point loading. The flexural beam fatigue test was later modified in SHRP-A-404 to improve its simplicity and reliability.

This test uses a digitally controlled, pneumatic beam fatigue equipment, which subjects a beam specimen under repeated stress or strain controlled loading, which is applied at the center of the beam until failure occurs. The failure of the flexural fatigue test can be defined as a 50% reduction in initial stiffness, which is measured from the center point of the beam after 50th load cycle [1].

Recently, a new way to determine the failure of the flexural fatigue test was proposed by Carpenter et al. based on the dissipated energy [2–4]. In this new method, the ratio of dissipated energy change (RDEC) is defined as a ratio of the change in dissipated energy between two neighboring cycles divided by the dissipated energy of the first cycle. A plateau value (PV), or the nearly constant value of RDEC, can be determined and it represents a period where there is a constant percent of input energy being turned

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into damage. This PV can be used to characterize the fatigue life of HMA mixtures. For a strain-controlled test, the lower the PV, the longer the fatigue life for a specific HMA mixture [4].

Since the 1970s, fracture mechanics theory has been used to analyze the fatigue behavior in HMA mixtures [5]. In recent years, comprehensive laboratory and field studies were conducted by Roque et al. at the University of Florida to characterize the crack growth rate of HMA mixtures using the Superpave indirect tension (IDT) tests [6–8]. They used the three Superpave IDT tests (IDT strength test, resilient modulus test, and creep test) and developed a viscoelastic fracture mechanics-based crack growth law for HMA mixtures. In addition, they introduced two thresholds, the dissipated creep strain energy (DCSE) limit and the fracture energy (FE) limit, to account for the crack development and propagation in HMA mixtures. When these two thresholds are not exceeded, only healable micro-damage occurs. Non-healable macro-damage appears unless one of the thresholds is exceeded. This suggests that the higher the values of DCSE or FE, the longer the fatigue life of HMA mixtures [7].

In addition to the traditional fatigue approach and fracture mechanics approach, damage mechanics is also applied to HMA mixtures to characterize their fatigue behavior. Kim et al. developed a fatigue model for HMA mixtures using the elastic–viscoelastic correspondence principle and continuum damage mechanics [9,10]. This model has been successfully used to predict the fatigue life of HMA mixtures with multiple rest periods based on the material's viscoelastic properties, loading conditions, and damage and micro-damage healing characteristics.

The objective of this study was to evaluate and compare the fatigue performance of HMA mixtures based on the results of different laboratory fatigue testing. In this study, HMA mixtures were plant prepared with one source of coarse aggregate (limestone), four percentages of recycled asphalt pavement (RAP) (0%, 10%, 20%, and 30%), and one asphalt binder (PG 64–22). The fatigue properties of HMA mixtures were evaluated using the Superpave IDT tests and beam fatigue test.

2. Laboratory experiments

2.1. Materials

One type of asphalt binder, PG 64–22, was chosen in the study. Its properties are presented in Table 1.

The coarse aggregates selected in this study were crushed limestone with a nominal maximum size of 12.5 mm. The fine aggregates consisted of No. 10 screenings, natural sand, and manufactured sand. Their gradations and other properties are presented in Table 2. All the aggregate properties meet the specification of the Tennessee Department of Transportation (TDOT) [11].

The RAP used in this study was screened through the No. 4 sieve (4.75 mm) to acquire a consistent gradation that was comparable to the fine aggregate. RAP gradation was determined on the bare aggregate after the binder was extracted from RAP, as shown in Fig. 1. The asphalt content of RAP was 5.5% and its maximum specific gravity (G_{mm}) was 2.412.

Table 1
Asphalt binder properties

Binder status	Binder test		Test results	Specification
Original binder	Rotational viscosity at 135 °C, Pa · s		0.52	3 Pa · s max
	DSR, $G^*/\sin\delta$, kPa	70 °C	0.78	1.00 kPa min
		64 °C	1.63	
RTFO aged binder	DSR, $G^*/\sin\delta$, kPa	70 °C	1.66	2.20 kPa min
		64 °C	3.54	
PAV aged binder	DSR, $G^*\sin\delta$ MPa, 25 °C		3725	5000 kPa max
	BBR creep stiffness S, MPa		238	300.0 MPa max
	BBR creep slope, m value		0.310	0.300 min
PG grading			64–22	

Table 2
Properties of aggregates

Sieve size	Limestone D-rock	No. 10 screening	Natural sand	Manufactured sand
5/8″	100%	100%	100%	100%
1/2″	97%	100%	100%	100%
3/8″	70%	100%	100%	100%
#4	21%	92%	98%	99%
#8	7%	61%	93%	82%
#30	4%	29%	63%	28%
#50	3%	21%	13%	17%
#100	2.0%	20.0%	2.0%	9.0%
#200	1.8%	16.0%	1.0%	5.0%
G_{sb}	2.524	2.424	2.501	2.476

Note: G_{sb} – bulk specific gravity of aggregate.

2.2. Mixture design

The Marshall mix design procedure was employed to design the control mixture. For the HMA mixtures, 50% limestone D-rock, 15% No. 10 screenings, 25% natural

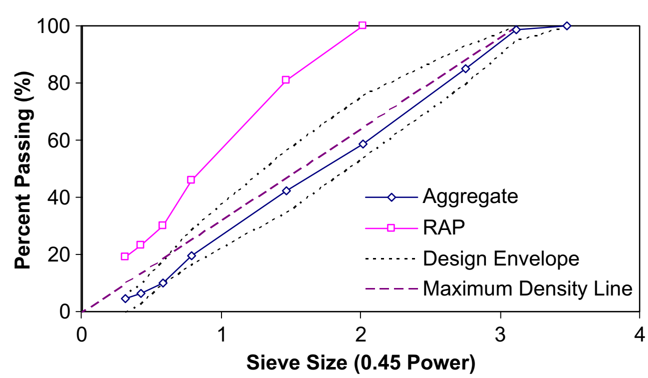

Fig. 1. Aggregate and RAP gradations.