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An alternative analysis of indirect tensile test results for evaluating fatigue characteristics of asphalt mixes

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HIGHLIGHTS

- Asphalt mixes shall be screened based on their fatigue resistance.
- Use of ITS test results for fatigue characterization may be the easiest.
- Fatigue index can discriminate the mixes based on the fatigue resistance.
- Fatigue index correlates well with SCB test results.

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ABSTRACT

Fatigue cracking is one of the major distresses responsible for the failure of asphalt pavements. The widely-accepted Superpave® volumetric mix design method does not consider screening the asphalt mixes based on their fatigue resistance. Based on a survey conducted in this study, it was found that many state Departments of Transportations (DOTs) do not perform a fatigue test during mix design, mainly due to lack of specialized equipment, trained personnel and consensus about the most appropriate test method. This present study was undertaken to suggest a simple, quick and effective fatigue test method and the corresponding data analysis procedure. It was found that the indirect tension test, which is usually conducted in the DOTs on a regular basis, can be used to characterize the fatigue resistance of asphalt mixes as well. A simplified data analysis approach has been proposed. The fatigue resistance of asphalt mixes can be determined by using a newly derived parameter called Fatigue Index (f_i). Fatigue resistance of five different asphalt mixes were evaluated using this new parameter, f_i. It was found that the f_i parameter were able to statistically discriminate five selected asphalt mixes with respect to their fatigue resistance. The effectiveness of the f_i parameter was verified by investigating its correlations with the results of the semi-circular bend and four-point beam fatigue test results.

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1. Introduction

Fatigue cracking is one of the most critical distresses responsible for the failure of asphalt pavements. Asphalt pavements experience fatigue cracking because of (i) excessive traffic load repetition, (ii) insufficient pavement structure, and (iii) use of fatigue prone asphalt mixes in the pavement layers [1,2]. However, the current Superpave® volumetric-based mix design method [30] hardly accounts for the fatigue behavior of asphalt mixes. On the other hand, asphalt mixes are becoming more complex with the increased use of reclaimed or recycled materials, modified binders, additives and warm mix technology; it is therefore very important to screen asphalt mixes based on their fatigue resistance for achieving the intended design life. The fatigue resistance of asphalt mix can be determined by conducting tests, such as, (i) Semi-Circular Bend (SCB) [3,4,1], (ii) Four-Point Beam Fatigue (BF) [5–8], (iii) Indirect Tension (IDT) [9,10,3], (iv) Cyclic Direct Tension (CDT) [11,12], (v) Disc-shaped Compact Tension (DCT) *(ASTM D 7313)* [13], and (vi) Overlay Tester (OT) [14,15]. In most cases, one specialized equipment and trained personnel are required for performing fatigue tests on asphalt mixes and also for analysing the test results.

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Several researchers compared the merits and demerits of different fatigue test methods. The National Cooperative Highway Research Program (NCHRP) project 9–57 [35] conducted a ruggedness test and inter-laboratory study to compare different fatigue tests. In this study, the OT, CDT and BF tests were suggested for the bottom up fatigue cracks and the SCB and IDT tests were suggested for the top-down fatigue cracks. Huang et al. [34] compared the SCB and IDT tests; this study suggested that the results from SCB and IDT test were fully comparable and convertible. Kim et al. [3] compared the fracture properties of asphalt mixes with the SCB and IDT test results, and concluded that SCB and IDT test results correlates well (R^2 = 0.65) for the laboratory produced mixes.

Even though several fatigue test methods are available at present, many state Departments of Transportation (DOTs) in United States of America (USA) do not have any guidelines to select the most appropriate fatigue test method for their prevailing conditions. The objective of this study is: (i) investigating the feasibility of using IDT test for characterizing the fatigue resistance of asphalt mixes, and then (ii) deriving a simple mechanistic data analysis procedure for characterizing the fatigue resistance.

In this study, first, a survey was conducted including different state DOTs to recognize the necessity of screening asphalt mixes during the mix design stage. It was found that fatigue cracking is a significant concern for many DOTs in USA. However, because of the complexities involved in the fatigue tests and the corresponding data analysis procedures, and most importantly lack of consensus about the most suitable fatigue test method, many DOTs often avoid screening asphalt mixes based on their fatigue resistance. Several DOTs are however in favour of adopting a fatigue test method provided the test and data analysis procedure is simple. Among the fatigue tests mentioned above, the IDT test is very easy to perform and usually conducted by the DOTs on a regular basis, but only as a means for determining the indirect tensile strength (ITS) of the asphalt mixes, as per AASHTO T 283 method [16]. However, the IDT test could not become a popular fatigue screening test method because of some limitations such as, (i) the ITS is not an indicator of fatigue resistance, (ii) IDT test is not able to properly discriminate mixes when fatigue resistance is evaluated with respect to only toughness Index (TI) (discussed later) [17,3], and (iii) requires a number of associated tests when fatigue resistance is evaluated with respect to dissipated creep strain energy [18]. In the present study, three different fatigue test methods were evaluated. It was found that the IDT test is the most easiest to perform. Since, IDT test is usually conducted at DOTs and paving agencies, an effort was made to derive a simplified data analysis procedure through which asphalt mixes can be screened based on their fatigue resistance using the IDT test data (load vs. deflection). A new parameter namely, Fatigue Index (f_i) was introduced. The feasibility of characterizing the fatigue resistance of asphalt mixes by using f_i were investigated by testing five different types of asphalt mixes. In order to see the applicability of the f_i on varieties of asphalt mixes (from brittle to ductile behavior), the asphalt mixes were selected in such a way that representative of very low, low, medium, high and very high fatigue resistant mixes were included in the study. It was found that the f_i was able to statistically discriminate the five asphalt mixes based on their fatigue resistances. Interestingly, good correlations were also found between the ITD, SCB and BF test results. Future studies are recommended for further verification of the effectiveness of the f_i concept. Nevertheless, this paper introduces an alternative approach for characterizing the fatigue resistance of asphalt mixes using a simple but most commonly performed test at DOTs. Upon further verification and field validation of this approach, DOTs can use their IDT test results to screen asphalt mixes with respect to the fatigue resistance as well.

2. Survey on fatigue test methods

The main purpose of conducting the survey in this study was to (i) recognize the necessity of screening asphalt mixes based on their fatigue resistance, and (ii) identify the DOT practices with regards to screening of asphalt mixes. The survey was conducted online, using www.surveymonkey.com. A total of forty-three engineers from twenty-three DOTs responded to this survey [19]. A large number of responders opined that fatigue crack is a critical distress. As shown in the Fig. 1a, 37.5% responders agreed that fatigue cracking is the most critical distress (Rank 1), while 25% responders consider fatigue cracking as the second most critical distress (Rank 2). The majority of the responders indicated that (i) excessive traffic load, (ii) insufficient pavement structure and (iii) most importantly the improper mix design (or material selection) are the main causes of fatigue cracking. However, as many as 92% responders expressed that they do not perform fatigue test for screening asphalt mixes (Fig. 1b), but a large number of them were in favor of conducting fatigue test. Many responders mentioned that unavailability of equipment, shortage of trained personnel, uncertainty about the most suitable test methods and specifications are the main reasons for not performing a fatigue test during the mix design stage. The survey could not yield a clear picture on the DOT's most preferred fatigue test method though. It could however recognize the fact that fatigue crack is a great concern and shall be addressed during the mix design stage, but through an easy-to-perform test.

3. Background of fatigue test methods

A brief summary about the IDT, SCB and BF test methods, which were considered in this study, is provided in this section. The test standards, specimen shapes and dimensions, loading patterns and tentative pass/fail criteria are provided in Table 1. Among the three tests, the IDT test has been in practice since long time; however, as mentioned earlier, IDT test data were not widely used for characterizing fatigue resistance of asphalt. The SCB test method for asphalt is relatively new and currently being investigated by several DOTs to verify the feasibility of using it for screening asphalt mixes. AASHTO TP-105 [20] and ASTM D8044 [21] are available for the SCB test method for characterizing the crack resistance of asphalt mixes at low (thermal crack resistance) and intermediate temperatures (fatigue crack resistance), respectively. For the intermediate temperature SCB test, states like Illinois [22] and Louisiana [3] have come up with their own test and data analysis procedures. The BF test [27] has been in practice for quite some time, but mostly in research studies.

3.1. Indirect tension (IDT) test

The IDT test is conducted by applying a monotonically increasing load at a 50 mm/minute rate along the diameter of a cylindrical specimen (Fig. 2a). In this study, the displacement was measured at the top of the specimen. A few researchers used the IDT test data to determine the toughness index (TI) to characterize the fatigue resistance of asphalt mixes [3,5,23]. The TI is determined by using the normalized ITS – strain curve. The normalized ITS value is obtained by normalizing the stress values with respect to the peak stress. Fig. 3a shows a typical normalized ITS – strain curve; this figure also illustrates the computational procedure for TI, which can be computed using the following equation.

$$TI = \frac{A_\varepsilon - A_P}{\varepsilon - \varepsilon_P} \quad (1)$$