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Comparison of fracture test standards for a super pave dense-graded hot mix asphalt

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ABSTRACT

The objective of this work is to compare the semi-circular bend (SCB) and disk-compact tension (DCT) fracture tests for asphalt-aggregate mixtures. Fracture tests are performed. Statistical analysis, digital image correlation, and 3D scans show that the SCB tests measure a low fracture resistance with a high coefficient of variation due to stress concentrations and plasticity developing at the anvil contact point. The DCT test is found to measure a high fracture resistance with a low coefficient of variation. The DCT tests is determined to provide a superior measurement of fracture resistance. Evidence concerning the physical problems with SCB is provided.

1. Introduction

The accumulation of cracks in HMA layers is often due to damage induced by repeated traffic loading and climatic effects: defined as *fatigue cracking* [1]. The cracking of HMA layers is one of the predominate forms of distress observed in flexible pavements, that significantly reduce service life [2]. An HMA overlay must have a balance of both good rut and crack resistance properties, to perform well in the field [3–5]. Over the past decade, HMA's designed in Texas have been modified to minimize the deformation of roads and moisture susceptibility of new mixtures using the Hamburg rutting test. This test applies vertical deformation to a specimen simulating constant traffic loading. Less attention has been paid to the cracking resistance of the new HMA surfaces. Stiffer binders and good stone-to-stone contact may improve rut resistance but it may also reduce the mix flexibility and cracking resistance [3].

The pavement industry is moving towards physics-based computational models as opposed to data-founded models for life prediction. Experimental fracture mechanics has become the de facto choice of many scientists and researchers in this area to obtain physical measures of fracture resistance. Much effort has been directed towards the development of testing and analysis methods to study the cracking mechanisms of asphalt pavement [4–9]. To date, several performance tests have been proposed to determine the cracking resistance of HMAs such as the flexural fatigue, dissipated creep strain energy, indirect tension, Texas overlay, single-edge notch bend, disk-shaped compact tension (DCT), and semi-circular bend (SCB) tests [10]. So far, the definitive or best fracture test method to determine the cracking resistance of asphaltic materials has yet to be determined.

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Nomenclature

HMA	hot mix asphalt
DCT	disk-shaped compact tension
SCB	semi-circular bending
LEFM	linear elastic fracture mechanics
EPFM	elastic-plastic fracture mechanics
COV	coefficient of variation
SP-D	dense grade superpave
3D-DIC	three-dimensional digital image correlation
G_f	fracture energy
K_{IC}	fracture toughness
J_c	critical strain energy release rate
AV%	air void percentage
a	notch depth
P_{max}	peak load
W_f	work of fracture
A_{lig}	ligament area
$Y_{I(0.8)}$	dimensionless geometric factor
U	strain energy to failure
ε_{yy}	strain in the vertical direction
ε_{xx}	strain in the horizontal direction

Hot mix asphalts exhibit a viscoelastic plastic response, where cracks tend to grow through the asphalt binder and along the asphalt-aggregate interfaces. This tortuous cracking process creates a large plastic zone that exceeds the small-scale plasticity limitation of the linear elastic fracture mechanics (LEFM) approach. The fracture toughness K_{IC} has continued to be used to analyze the fracture resistance of HMAs despite the deficits of LEFM [11–15]. The LEFM approach is assumed reasonable if the test temperature is 10 °C below the performance grade lower limit of the asphalt binder and the modulus changes less than 5% for the duration of the test. These conditions are rarely met. In practice HMAs are subjected to a wider temperature range. As an alternative, elastic-plastic fracture mechanics (EPFM) has been introduced to measure the fracture resistance of HMAs. In EPFM, fracture resistance is measured using the energy of fracture (i.e. the energy required to open a crack).

The EPFM-based DCT and SCB tests have been identified as two of the most popular approaches to fracture resistance measurement of HMAs [16]. The prevalence of SCB testing stems from its simplicity, repeatability, and consistency [9]. Recent studies by the Louisiana Transportation Research Center have shown that the SCB test is promising in evaluating the cracking resistance of HMAs [7]. They concluded that specimens with a pre-fabricated notch are more suitable at measuring the cracking properties of asphalt mixtures. The SCB test exhibits certain advantages as a cracking resistance predictor:

(a) different notch depths, notch orientations, and specimen positioning can be introduced; hence, mixed-mode fracture properties can be evaluated directly;
(b) the test setup and procedure are fairly simple and rapid;
(c) the SCB specimens can be prepared directly from cylindrical samples obtained from standard cores prepared in a super pave gyratory compactor or can be taken from field cores; and
(d) multiple specimens can be obtained from one field core, reducing the error caused by the heterogeneity among cores [17].

The main disadvantages of the SCB test is that it is susceptible to operator error where a small misalignment of the specimen will lead to mixed-mode fracture and fracture resistance measurements can exhibit low repeatability. The DCT test exhibits certain advantages as a cracking resistance predictor:

(a) according to the National Cooperative Highway Research Program, the DCT test often produces the lowest coefficient of variation (COV) of all HMA fracture tests with a COV in the 10–15% range [18];
(b) the DCT test provides a larger fracture area which is important because it reduces the impact that a single large aggregate or zone of weakness might have on the overall fracture resistance of the HMA [19];