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Implementation of nondestructive testing and mechanical performance approaches to assess low temperature fracture properties of asphalt binders

Salman Hakimzadeh [a], Behzad Behnia [b,*], William G. Buttlar [a], Henrique Reis [c]

[a] *Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 205 Mathews MC 250, Urbana, IL 61801, USA*
[b] *Department of Civil and Environmental Engineering, Western New England University, 1215 Wilbraham Road, Springfield, MA 01119, USA*
[c] *Department of Industrial and Enterprise Systems Engineering, University of Illinois at Urbana-Champaign, 104 S. Mathews Ave., Urbana, IL 61801, USA*

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Abstract

In the present work, three different asphalt binders were studied to assess their fracture behavior at low temperatures. Fracture properties of asphalt materials were obtained through conducting the compact tension [C(T)] and indirect tensile [ID(T)] strength tests. Mechanical fracture tests were followed by performing acoustic emissions test to determine the "embrittlement temperature" of binders which was used in evaluation of thermally induced microdamages in binders. Results showed that both nondestructive and mechanical testing approaches could successfully capture low-temperature cracking behavior of asphalt materials. It was also observed that using GTR as the binder modifier significantly improved thermal cracking resistance of PG64-22 binder. The overall trends of AE test results were consistent with those of mechanical tests.

Keywords: Thermal cracking; Indirect tensile strength test; Compact tension test; Nondestructive approach; Acoustic emission test; Embrittlement temperature

1. Introduction

Low temperature cracking, a.k.a thermal cracking, is one of the most dominant distresses in asphalt pavements in areas with cold climates. This type of cracking manifests itself with series of top–down evenly spaced cracks which are perpendicular to the flow of traffic as shown in Fig. 1. The mechanism of low-temperature cracking is related to the tensile stresses induced within the pavement layer due to significant drop in temperature. As a continuous layered system without any periodic joints, asphalt pavements when subjected to cold temperatures are restrained from contraction. As a result thermally induced tensile stresses will build up within the pavement and progressively increase as the surrounding temperature decreases. Eventually, when the induced tensile stresses exceed the tensile strength of the pavement material, thermal cracks initiate from the surface of the pavement and propagate downward leading to more types of distresses in the pavement system (especially after infiltration of water) resulting in further reduction of performance, service life, and structural integrity of the pavement structure.

A significant number of research studies have been conducted to tackle the thermal cracking problem in

* Corresponding author.
E-mail addresses: hakimza1@illinois.edu (S. Hakimzadeh), behzad.behnia@wne.edu (B. Behnia), buttlar@illinois.edu (W.G. Buttlar), h-reis@illinois.edu (H. Reis).
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Fig. 1. Typical thermal cracking in asphalt pavements.

pavements [1–11]. Based on recent studies, low-temperature fracture characteristics of asphalt binder is one of the most important factors controlling thermal cracking of asphalt pavements. Current specification utilizes the Bending Beam Rheometer (BBR) test along with the Direct Tension Test (DTT) to determine binder stiffness, the m-value, which reflects the ability of binder to relax the induced stresses, and the failure strain of asphalt materials at low-temperatures [12,13]. Although the parameters obtained from the Strategic Highway Research Program (SHRP) tests such as stiffness and failure strain are necessary to characterize the behavior of asphalt binders at low-temperatures, they alone are not adequate to evaluate the resistance of asphalt binders to premature cracking. Recent studies have shown that accurate evaluation of the low-temperature cracking performance of asphalt binders, especially polymer-modified asphalt materials still remains a challenge [14,15]. As a result, there is still a need for new binder testing methods to accurately capture low-temperature properties of asphalt binders.

In 1986, Little and Mahboub investigated the use of the J-integral method for fracture properties of plasticized sulfur binders and suggested that the J_{IC} value could be used for binder performance testing at low-temperatures [16]. In 1994, Lee et al. developed a three-point bending configuration test which was a more practical method for measuring fracture toughness and fracture energy of asphalt binders in the linear-elastic regime [17]. Ponniah et al. utilized three point notched bending beam test to determine fracture toughness and fracture energy of asphalt binders [18]. In 2001, using the notched BBR test, Anderson et al. showed that fracture toughness (K_{IC}) provides a more definitive ranking of resistance to thermal cracking as compared to Superpave criteria [19]. In 2004, Andriescu et al. used double-edge-notched tension specimen to determine the essential work and plastic work of asphalt binder fracture [20]. Hoare et al. used results obtained from the three-point notched bending beam test and showed that fracture toughness and fracture energy are sensitive to factors such as stiffness, binder's morphology, and polymer content [15]. In another investigation in 2006, Edwards et al. developed a new compact tension test for the grading of asphalt binders [21]. Behnia et al. developed an acoustic emission-based testing method to evaluate the behavior and embrittlement temperature of asphalt binder at low-temperatures [22]. In 2011, Rosales et al. proposed a new Single-Edge-notched beam test configuration to determine the stiffness and fracture energy of modified binders [23]. Recently, Roque et al. developed a new binder Direct Tension Test to determine fracture energy of asphalt binder at intermediate temperatures [24].

With recent advances in the field of fracture mechanics, development of valid fracture tests for asphalt binder seems to be an important step and a plausible endeavor in the evolution of asphalt binder selection to control thermal cracking. The present study focuses on characterization of low-temperature fracture properties of asphalt materials (i.e. fracture toughness, fracture energy, tensile strength, and embrittlement temperature) using both mechanical fracture performance tests, the indirect tensile (IDT) test and the compact tension (CT) test, as well as a nondestructive testing method, i.e. the acoustic emission-based test. Different types of asphalt binders (modified and unmodified) at different temperatures are evaluated and the results are presented and discussed.

2. Materials and methods

In the present work, three different asphalt binders including: PG64-22, PG64-22 plus 10% Ground Tire Rubber (GTR) by weight, and PG70-22 (Styrene–Butadiene–Styrene (SBS)-modified) were utilized. The objective was to evaluate the effect of GTR on PG64-22 asphalt binder and also comparing the GTR-modified PG64-22 asphalt binder against one grade higher asphalt binder, i.e. PG70-22. Two mechanical performance tests, i.e., the Indirect Tension test [ID(T)] and the compact tension test [C(T)], which are commonly used for testing asphalt mixtures, were implemented to assess low-temperature fracture performance of asphalt binders. In addition to conducting fracture tests, a nondestructive acoustic emission-based testing approach was performed to determine the embrittlement temperature of asphalt materials and to provide a better perspective of fracture behavior of asphalt binders in the micro-scale level.

2.1. Indirect tensile test [ID(T)]

The Superpave Indirect Tension test [ID(T)], developed under the Strategic Highway Research Program (SHRP), commonly used to determine the creep compliance and indirect tensile strength of asphalt mixtures, was utilized to measure the tensile strength of asphalt binders. The ID(T) strength test was performed in accordance with AASHTO TP9-96 [25], which involves application of compressive load through the diametrical axis of a cylindrical