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Characterization of embrittlement temperature of asphalt materials through implementation of acoustic emission technique

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HIGHLIGHTS

- AE test appear to be a reliable low temperature performance test for asphalt.
- AE results correlated well with thermal cracking performance of MnROAD sections.
- AE embrittlement temperature procedure has lower CoV% than BBR and DTT tests.

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ABSTRACT

The present study focuses on the application of an acoustic emission (AE) based laboratory test to evaluate low-temperature cracking performance of several types of asphalt materials in the context of a recently completed national pooled fund study on low-temperature cracking (LTC). Comparisons are made between AE test results and the critical cracking temperature of asphalt binders determined from Bending Beam Rheometer (BBR) test and Direct Tension Test (DTT), which are in turn compared to field observed thermal cracking in the corresponding test sections. Based upon our findings, recommendations are made as to the potential use of the AE-based technique in asphalt binder specification.

1. Introduction

Cracks in asphalt pavements are expensive and difficult to properly treat. In cold climates, thermal cracking is a prevalent cause of asphalt pavement premature deterioration. This type of distress can be developed early in pavement life, thereby contributing to loss of pavement serviceability long before the design life has been reached. Fig. 1 shows a typical thermal cracking pattern occurring in asphalt pavements. Detrimental effects of low-temperature cracking have motivated a number of studies in an effort to experimentally design and control asphalt properties related to the low-temperature performance of asphalt pavements.

For a given pavement, the cracking temperature of its asphalt binder can be used as a useful indicator of the low-temperature cracking behavior of the pavement [1]. As a result, considerable interest exists for rapid, accurate, and practical testing methods capable of predicting the cracking temperature of asphalt binders. The acoustic emission based testing method described in this paper addresses the current shortage of rapid, accurate and practical testing procedures for asphalt binders and mixtures.

Acoustic emission is a term used to describe the spontaneous release of localized strain energy in the form of transient mechanical elastic waves within a stressed material. Emitted AE waves from micro-damage sites travel within the material and are detected by sensitive surface-mounted piezoelectric acoustic emission (AE) sensors. Fig. 2 schematically illustrates crack nucleation and propagation and corresponding AE wave transmission and detection for material under stress [2].

The present study describes implementation of the AE-based approach to determine the embrittlement temperature of different types of asphalt binders. The source of these emissions is thermally induced cracking occurring in thin films of asphalt binder samples bonded to a granite substrate and cooled down to low temperatures. Different thermal contraction between the asphalt binder

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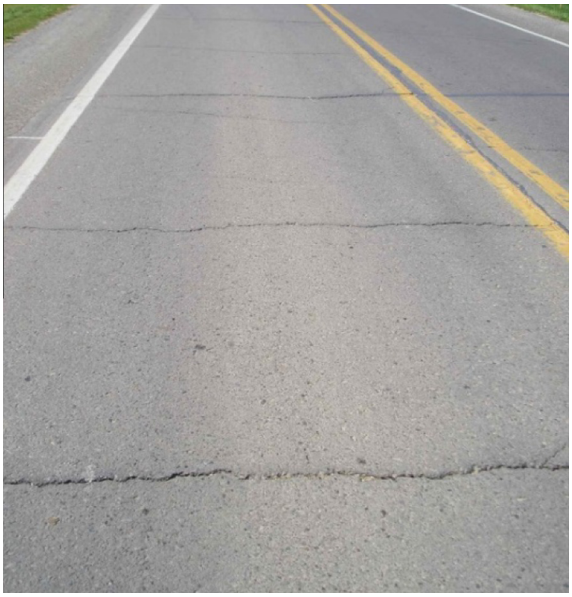

Fig. 1. Thermal cracking in asphalt pavement.

sample and granite slab causes progressively higher thermal tensile stresses within the binder sample resulting in thermal crack formation. Transient elastic energy in the form of elastic mechanical waves is released upon formation of these thermal cracks in the binder sample. It was observed that the majority of acoustic emission activity starts at a certain temperature which is termed the "embrittlement temperature" of the material [1,3].

The asphalt binder samples used in this study were derived from a national pooled fund study [4,5] on low temperature cracking (LTC). The pooled fund LTC study involved the investigation of twelve existing pavement sections, some from the sponsor state, Minnesota, along with sections from other participating states. Materials from five of the Minnesota pavement sections were available for investigation in this study. In addition to the AE-based test, standard Superpave binder tests namely, the Bending Beam Rheometer (BBR) test and Direct Tension Test (DTT) results from the LTC project were utilized to determine the critical low-temperature cracking of asphalt binders.

Comparisons are made between embrittlement temperature of asphalt binders tested using the AE approach and the critical low-temperature cracking results obtained from BBR and DTT testing. Finally, comparisons are also made between the field observed cracking performance of the test sections and traditionally utilized asphalt binder tests such as the BBR and DTT and the AE testing procedure described in this paper [6,7].

3. Experimental procedure

In this paper, five test sections from the Minnesota Department of Transportation's cold weather Road Research Facility (MnROAD) were studied, including test cells 03, 19, 33, 34, and 35, as depicted in Fig. 3.

The AE-based embrittlement temperature test was carried out on asphalt binders extracted from these five asphalt mixtures. The binder samples for testing were obtained through a chemical extraction and recovery procedure of the aforementioned mixtures in accordance with the AASHTO T319-03 specification for "Quantitative Extraction and Recovery of Asphalt Binder from Asphalt Mixtures." This method involves the use of an extraction vessel for asphalt extraction and a Rotovap unit for the binder recovery. During each run of extraction and recovery about 1000 g of asphalt mixture sample was used. To minimize aging during centrifuge processing, the asphalt–solvent mixture was blanketed with nitrogen in the centrifuge bottles. The N-propyl bromide (nPB)-based solvent, which is an environmentally friendly material, was utilized for binder extraction. The binder extraction and recovery equipment used is shown in Fig. 4.

The thin, rectangular asphalt binder samples used in the AE test were molded to be identical to standard BBR samples: 6.25 mm wide by 125 mm long by 6 mm thick. This geometry was selected for the convenience of using existing molds, and because it was found to have sufficient dimensions to produce several thermal cracks during cooling per specimen. To create realistic interface conditions and thermal coefficient mismatch, a 10 mm thick granite slab with dimensions of 50 mm $\times$ 150 mm was used as substrate. Asphalt binder was heated to 135 °C then poured into molds placed on the preheated granite slab. In each of the binder samples tested, very good bonding between asphalt binder and granite substrate was observed [1,3].

An energy-efficient and quiet portable freezer, Shuttle ULT-25, was used as the cooling system for AE testing. Using free-piston Stirling engine technology, ULT-25 works very quietly without generating any detectable AE noises. It employs the Stirling cycle in which helium is cyclically expanded and compressed.

Prepared samples were placed inside the cooling chamber (Fig. 5), and temperature was recorded using a K-type thermocouple, which was placed adjacent to asphalt sample at the interface with the granite substrate. During the course of the AE activity monitoring test, thermally-induced cracks in the asphalt specimens were induced by exposing the restrained asphalt specimen to temperatures starting at 0 °C and decreasing to −50 °C. The wideband AE sensors (Digital Wave, Model B1025) with a nominal frequency range of 50 kHz to 1.5 MHz were utilized to monitor and record the acoustic emission activity of the samples during the tests. Vacuum grease was used to couple the AE sensors to the granite substrate. The signals from AE sensors were pre-amplified by 20 dB using broad-band pre-amplifiers. To reduce extraneous acoustic noise, the signals for all the AE events were then further amplified by 21 dB (for a total of 41 dB) and filtered using a 20 kHz high-pass double-pole filter using a Fracture Wave Detector (FWD) signal conditioning unit.

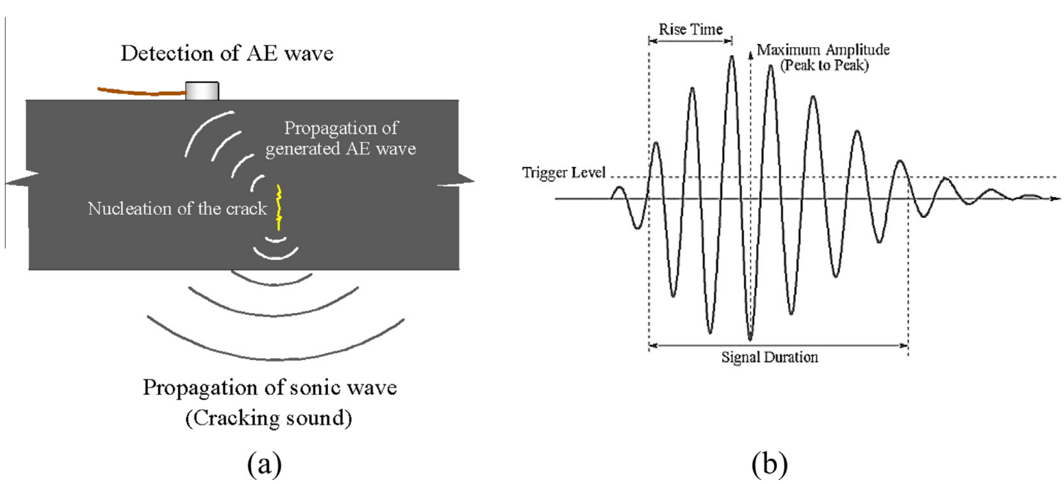

Fig. 2. (a) Nucleation, propagation and detection of AE waves (b) typical acoustic emission signal.