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Development of a Single-Edge Notched Beam Test for Asphalt Concrete Mixtures

ABSTRACT: This paper describes the development of a fracture test for determining the fracture energy of asphalt concrete. The test will be used in combination with numerical analysis and field studies to obtain a better understanding of the mechanisms of reflective cracking in asphalt concrete overlays. A review of the literature revealed that a single-edge notched beam (SE(B)) test specimen was the most promising fracture test for the objectives of the reflective cracking study. Existing servohydraulic testing equipment was modified to perform the SE(B) test along with new loading fixtures, sensors, data collection, and analysis procedures. Preliminary tests were conducted to develop test procedures, to obtain a better understanding of crack-front characteristics, to investigate test repeatability, to examine variations of fracture energy with temperature, and to investigate mixed-mode fracture. The results from the tests follow expected trends and test variability appears to be within a range typical for asphalt concrete fracture testing.

KEYWORDS: asphalt concrete, fracture, single-edge notched beam, mixed-mode fracture, cohesive zone model

Introduction

A typical rehabilitation of a deteriorated pavement is the overlayment of the existing pavement with a layer of asphalt concrete. A major cause of premature failure of the new asphalt concrete layer is reflection cracking, or the propagation of existing cracks in the old pavement through the new asphalt concrete layer [1]. The present project takes an integrated approach to the reflective cracking problem by combining numerical analysis with laboratory experiments and full-scale field studies. The integrated approach requires compatibility between the laboratory experiments and the numerical analysis procedures. Currently, a cohesive zone fracture model appears to be the most promising model [2–7], and the selected fracture test should provide fracture properties that are repeatable and accurate to allow for predictive capabilities of the numerical analysis.

Although there are many standardized fracture tests [8,9], they were developed for metallic materials that are essentially homogenous at the engineering scale and the applicability of these tests to asphalt concrete may be questionable. Also, research of asphalt concrete fracture using fundamental fracture mechanics is in its infancy and satisfactory laboratory tests and analyses have yet to be developed. Therefore, consideration is given to identify fracture tests that have the flexibility to investigate several key points:

- Specimen size effects.
- Loading rate and temperature effects.
- Capability to handle mixed-mode fracture.

A final consideration was given to the ease of adapting standard test equipment and to readily produced test specimens. An excellent introduction into fracture mechanics principles can be found in the textbook by Anderson [10].

Objectives

The primary objectives of this paper are as follows:

- To describe the selection and development of a fracture test for determining fracture properties of asphalt concrete.
- To provide a detailed description of testing and analysis techniques developed in the study.
- To show preliminary test results investigating test control method, crack front development, test repeatability, test temperature, and mixed-mode fracture of asphalt concrete.

Selection of Fracture Test for Asphalt Concrete

The integrated approach to understanding the key mechanisms of the reflective cracking problem requires that the fracture test and numerical analysis technique employed be compatible with each other. The fracture test should provide the required inputs for the selected fracture model, while the selected fracture model should describe the fracture behavior of the material. A cohesive zone model (CZM) [2–7] was selected to describe the fracture behavior of asphalt concrete. Initially, cohesive crack models were developed to describe ductile materials, but were adapted by Hillerborg [11] to describe the softening behavior of Portland cement concrete. The CZM currently used for this study is the potential-based approach, described by Xu and Needleman [12], which was recently implemented as a user-subroutine in the general-purpose finite-element software ABAQUS™ [2]. The potential-based CZM has the

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capability to describe the softening response ahead of the crack tip due to aggregate bridging and interlocking, ductility of the asphalt binder, and the interactions between the asphalt binder and aggregates. The CZM requires three material properties to fully describe the cracking process: critical stress (tensile strength), critical crack opening, and fracture energy. Only two of these three properties are independent and the third can be calculated analytically [10]. The crack tip opening is a difficult parameter to measure experimentally; therefore, emphasis was placed on obtaining the tensile strength and fracture energy. The tensile strength of asphalt concrete can be estimated using the Superpave indirect tensile strength test (IDT) described in AASHTO Standard Test Method for Determining the Creep Compliance and Strength of Hot Mix Asphalt (HMA) Using the Indirect Tensile Test Device (TP9-96) [13]. The fracture energy can be defined as the amount of external energy required to create a unit surface area of crack [14]. Other types of CZM are currently being investigated.

Several tests have been proposed to determine fracture properties of asphalt concrete with the main purpose of these tests being focused on estimating the fatigue life of asphalt concrete pavements [15–19]. Some of these tests make use of standard fracture specimens and some are unique to the particular fracture model of interest. Three test configurations were selected as potentially satisfying the following criteria:

- Pure mode I loading.
- Test simplicity (specimen fabrication, test fixtures, etc.).
- Ease of obtaining field specimens.
- Amenable stress states (simple stress fields, minimal end effects).

The advantages and disadvantages of each test configuration are shown in Table 1.

After reviewing the proposed test configurations, the single-edge notched beam (SE(B)) fracture test was determined to be a promising test to provide the relevant material inputs for the CZM [2,3]. A main factor in selecting the SE(B) test was that the size of the beam could be readily adjusted to ensure that the ligament was large enough to encompass the fracture process zone. Although the size of the fracture process zone in asphalt concrete has not been thoroughly investigated, it is hypothesized that it should depend on several testing variables and material characteristics for a given test configuration, including temperature, loading rate, maximum aggregate size, void level, binder content, and binder ductility. However, two initial approaches were taken to estimate the fracture process zone size. A typical assumption for asphalt concrete requires the minimum specimen dimension to be at least three to four times larger than the maximum aggregate size to ensure that the experimental results are statistically valid [20]. This assumption, along with the knowledge that the majority of asphalt concrete mixtures use a maximum aggregate size of 19 mm or less, leads to the minimum ligament length of 76 mm. Another approach for determining the fracture process zone size is to use a modification of Irwin's estimation [14]. After reviewing this approach, it was concluded that Irwin's estimation does not apply to the quasi-brittle materials of interest in the present research. For materials such as asphalt concrete, the fracture process zone contains microcracks and slippage, while Irwin's estimation is based on material yielding ahead of the crack tip. For example, fracture process zones that have been calculated for Portland cement concrete using Irwin's estimation can range from 0.3 m to 2 m [14], which is unrealistic. Such observations are in agreement with those of Ruiz et al. [21], who investigated fracture of Portland cement concrete using CZMs. Further investigation of the fracture process zone size for asphalt concrete is needed for a better understanding of the effects of cracked specimen size.

Another important factor in the selection of the SE(B) test is the ability to induce mixed-mode fracture. As other researchers have shown [22,23], the SE(B) specimen configuration can be readily modified to test materials in mixed-mode (mode I and mode II) by simply offsetting the mechanical notch from the centerline of the beam. Mixed-mode fracture is important for asphalt concrete pavement analysis since the critical loading most often involves a combination of thermal loading (tension) and wheel loading (bending tension and shear). Thus, the mixed-mode testing capability is desirable for pavement studies and will be explored in future research.

The SE(B) test configuration has been used for testing asphalt concrete fracture properties and the following is a brief summary of that work. A representative review of the specimen sizes and other test specifics is shown in Table 2. In reviewing these studies, it is clear that different test procedures, data analysis techniques, and beam dimensions have been used based upon the selected crack model for each research study.

Several researchers [17,18] used the SE(B) test to determine the stress intensity factor, K_I, and then applied Paris's Law [29] to

TABLE 1—*Advantages and disadvantages of selected fracture specimen configurations.*

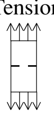
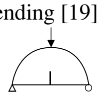
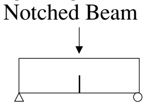
Test Configuration	Advantages	Disadvantages
Direct Tension [15] 	Simple stress state Pure mode I loading	Possibility of load eccentricity due to end fixtures Difficult to obtain field specimens Closed-loop CMOD control is difficult
Semi-Circular Bending [19] 	Easily obtained field specimens Simple three-point bending load	Complex stress state (arch effect arrests long cracks) Specimen size
Single-edge Notched Beam 	Pure mode I loading Simple loading configuration Flexibility to investigate other areas (mix-mode, specimen size effect, etc.)	Difficult to obtain field specimens

TABLE 2—*Summary of SE(B) specimen sizes from the literature.*

Source	Beam Size (mm)	Test Temperature (°C)	Test Control
Majidzadeh et al. [17]	25 × 25 × 305 50 × 75 × 356	−5, 5, 25	Load-Line Displacement Load
Ramsamooj [18]	75 × 100 × 406	23.9	Load
Mobasher et al. [24]	89 × 89 × 406	−1, −7	Crack Mouth Opening
Kim and El Hussein [25]	70 × 50 × 300	−5, −10, −15, −20, −25, −30	Load-Line Displacement
Bhurke et al. [26]	50.8 × 50.8 × 203.2	−10	Load-Line Displacement
Hossain et al. [27]	75 × 100 × 400	5, 25	Load-Line Displacement
Marasteanu et al. [28]	75 × 95 × 356	−18, −34	Crack Mouth Opening

estimate the crack growth rate of the mixture. The crack length was determined through the compliance approach as described by Majidzadeh et al. [17]. The compliance approach uses several loading-unloading cycles to determine the initial compliance and the compliance of the beam as the crack develops and grows. From the compliance approach, the crack length can be estimated at discrete points where the unloading occurs. The procedure then typically involves the application of Paris's Law to estimate the number of repetitions (cycles) to failure.

Other approaches have been used to analyze the SE(B) fracture test results. One such approach is the two-parameter model [30], which involves using the compliance approach described above and determining the critical crack tip opening displacement and the fracture toughness of the material. This method was developed for Portland cement concrete, but can be applied to asphalt concrete because both materials exhibit softening behavior after peak load. Along with the two-parameter method, Mobasher et al. [24] used the R-curve method to determine the stress intensity in front of a propagating crack. Bhurke et al. [26] used the J-contour integral to compare the fracture resistance of various asphalt concrete mixtures.

Once again, no standard test method or analysis has been developed for obtaining fracture properties of asphalt concrete. Therefore, an integrated approach was taken in obtaining relevant fracture properties using experimental results and numerical analysis. The numerical analysis approach has been described elsewhere [2,3], and the focus of this paper consists of describing the approach taken in obtaining relevant fracture properties from experimental data. Therefore, the remainder of the paper describes the test development and preliminary test results investigating repeatability, temperature, and mixed-mode fracture.

Test Development

After determining that the SE(B) test configuration is the most promising fracture test to satisfy the required criteria, the next step was to develop the testing equipment and analysis procedures to acquire the desired fracture properties, which build upon our previous experience with such tests [31]. The following sections describe the development of the specimen preparation, loading fixtures, test procedures, and analysis.

Specimen Preparation

The initial beam dimensions were selected based on the capability of the beam compactor that was used to compact the asphalt concrete mixtures. The maximum compacted beam size is 375 mm long by 127 mm wide by 75 mm tall. To reduce any end effects (density variations, aggregate segregation, etc.), the compacted beams were cut using a water-cooled masonry saw to the final dimensions of 375 mm long by 100 mm tall by 75 mm wide (Fig. 1). A mechanical notch was then fabricated with a depth of 19 mm, producing a notch to depth (a/W) ratio of 0.19. For standardized fracture tests [8,9], the required a/W ratio is between 0.45 and 0.55. However, using deep-notched specimens with asphalt concrete may produce undesirable test results, such as large statistical variation and crack initiation under self-weight.

The option of cutting the mechanical notch into the beam instead of using a metal insert in the mold was selected because the insert could affect the mixture compaction (align aggregates, segregate the mixture, etc.) at the notch tip region. The disadvantage of cutting the mechanical notch is that the resulting notch tip is blunt as compared to the sharper notch obtained with a metal insert. To reduce the effects of the blunt notch tip, a two-step procedure was utilized to create an apparently sharper notch. The assumption was made that if the leading edge of the notch was narrow as compared to the majority of aggregates, then the stress intensity created would be suitably representative of a sharp crack. First, a water-cooled masonry saw, with a 5 mm wide blade, was used to cut the notch to 50 % of the target depth. Then, to produce a notch with a width of 1 mm, a handsaw with a metal cutting blade was used to finish the notch (see Fig. 1). It should be acknowledged that an alternative approach would be to apply a small cyclic load to the beam to create a fatigue crack. Further investigations will be performed to quantify differences in fracture properties between specimens produced with a blunt notch and a fatigue crack.

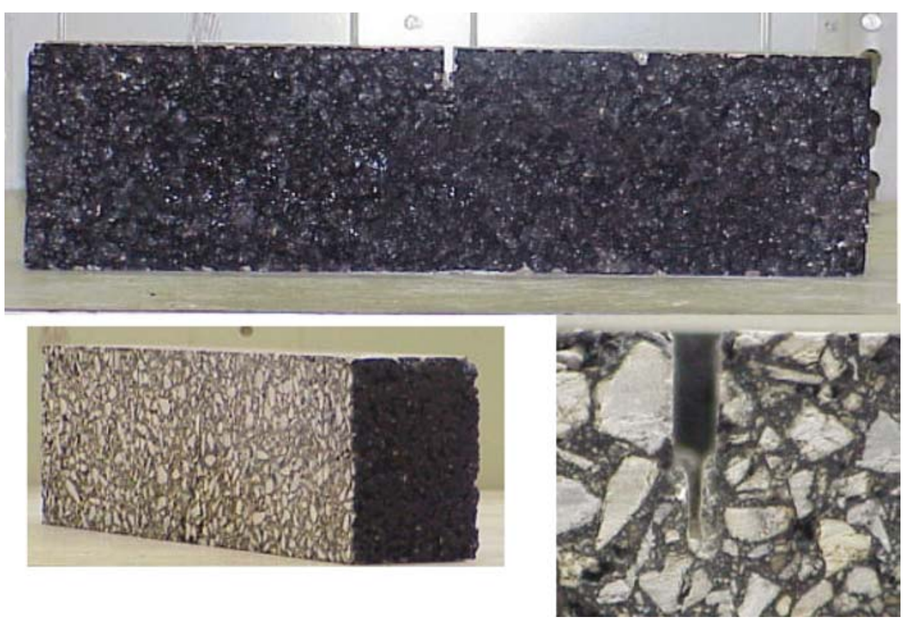


FIG. 1—*Final SE(B) specimen with mechanical notch.*

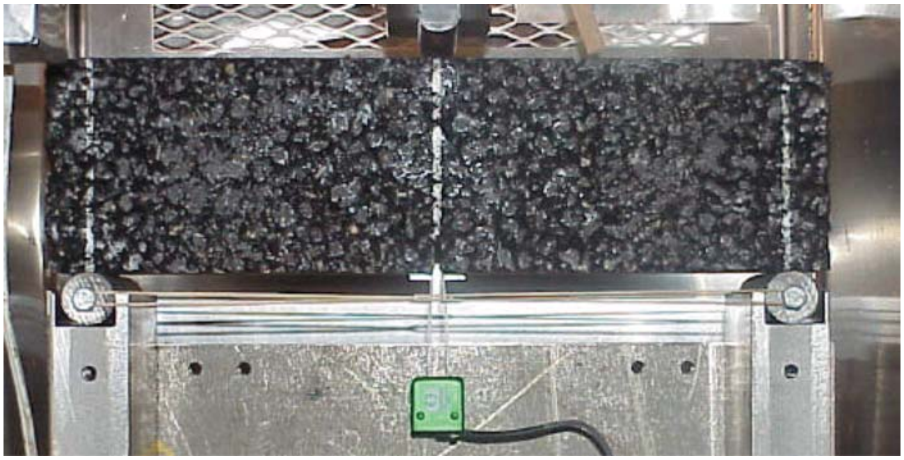


FIG. 2—*SE(B) test fixture and clip gage.*

Loading Fixtures

The SE(B) specimen is loaded under a simply supported, three-point bending configuration. Although the E 399 Standard Test Method [8] is not directly applicable to asphalt concrete, the specifications for the loading fixture dimensions were used as a reference. The fixture has a span length of 330 mm with a width of 100 mm. The rollers are 25.4 mm in diameter and are free to rotate and translate outward during testing to reduce friction. The rollers are held at the initial span length at the beginning of the test by soft springs. The center loading point has a radius of 12.7 mm and can swivel in the transverse direction to promote more uniform loading conditions across the width. For load application, an Instron 8500, 100 kN load frame was used with a custom LabVIEW™ data acquisition program to collect the applied load, load-line displacement, crack mouth opening displacement (CMOD), and crack detection gages. The load was monitored using a 10 kN load cell with the load-line displacement being measured by the LVDT at the load frame actuator. An Epsilon Model 351-0020-250-ST Clip-on Gage (Fig. 2) with a range of 6.35 mm was used for measuring CMOD. The CMOD gage was attached to the beam using gage points that were glued to the edge of the notch. The test was conducted in a refrigerated environmental chamber capable of maintaining air temperature within ±0.2°C during the test.

Test Procedures

The procedure for asphalt concrete SE(B) testing developed in this study is based upon the information derived from a literature review and from preliminary laboratory results. The time to peak load is used to determine the loading rate. The desired time to peak was 5 s, a typical rate for strength tests on asphalt concrete. Initially, the beam loading was performed with a constant load-line displacement, but the post-peak fracture was unstable (snap-back) for the lower test temperatures (Fig. 3). The control of the test was then changed to a constant CMOD response to produce a stable post-peak crack. From preliminary tests, a CMOD rate of 0.7 mm/min satisfactorily fulfilled the criteria and was used for all subsequent tests.

The tests were performed at low temperatures (0, −10, and −20°C) for two main reasons: to induce brittle behavior and reduce viscoelastic effects. At low temperatures, the asphalt mixtures can behave in a brittle fashion and the control of the post-peak behavior can be more difficult when rapid crack growth occurs. Thus,

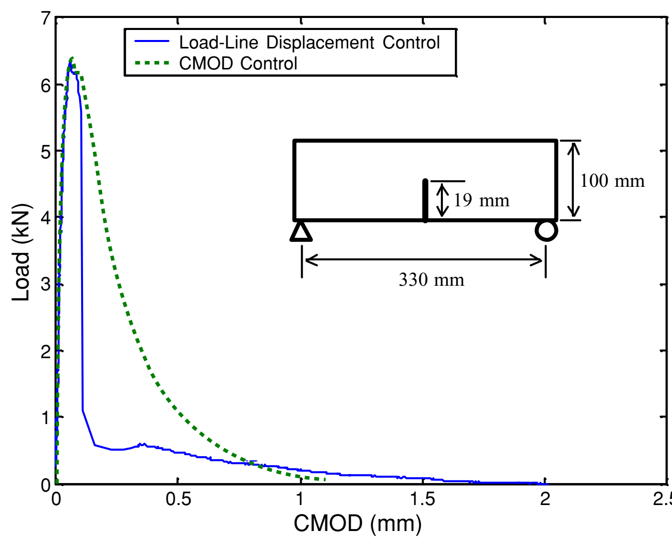


FIG. 3—*Difference between load-line displacement and CMOD control methods (tests conducted at −10°C).*

if the test controls can be developed to perform adequately under this condition, then the test would be expected to perform properly at higher temperatures. Furthermore, at lower test temperatures, the viscoelastic effects of the asphalt concrete should be less pronounced, thereby reducing the complexity of the problem for initial calibration procedures. Beams were placed in the cooling chamber for 3 h before the beginning of the test to ensure that the temperature was uniform throughout the beam. Once the temperature was stabilized, a small preload (∼0.2 kN) was applied to the specimen before the beginning of the test to ensure that the beam was firmly seated on the loading fixture. The test was then performed using CMOD control until the load was reduced to below 0.1 kN or until the beam was completely broken.

Analysis of Test Results

The main objective of fracture testing in this study was to determine the fracture energy of asphalt concrete mixtures and to obtain load-versus-CMOD data (required for CZM calibration). Several proposed techniques were found in the literature for determining the fracture energy, but for this analysis, the fracture energy was computed as the area under the load-CMOD curve normalized by the initial ligament length and beam width. The self-weight of the beam was neglected at these temperatures after it was verified that the self-weight of the beams produced negligible change in CMOD. However, the self-weight could have an influence on the test results at higher temperatures. In order to reduce the effects of self-weight, the beam could be inverted so that the notch is located at the top of the beam and the center loading point is at the bottom [30]. In the computation of fracture energy, unavoidable electronic noise in the sensors creates unreliable estimates of area under the load-CMOD curve. To circumvent this problem, the CMOD data were smoothed using linear regression through the CMOD-time curve. The use of linear regression is valid since the test is in fact controlled at a constant CMOD rate.

Test Results

The purpose for methodically developing the SE(B) test for asphalt concrete mixtures is to ensure that the test produces repeatable property inputs and calibration of the cohesive zone fracture model. For preliminary testing, three asphalt concrete mixtures were used to represent a cross-section of typical mixtures. Figure 4 shows an example of each mixture, each consisting of a different nominal maximum aggregate size (NMAS) and asphalt binder.

Following the test procedures described above, several beams were tested to investigate crack development in asphalt concrete. The first step was to use single wire crack detection gages glued to the surface of the specimen. Two sets of crack detection gages were placed on either side of the specimen, one set at the tip of the mechanical notch and the other set at the midpoint between the notch tip and the top surface of the beam (see Fig. 5 for reference). The macrocrack initiated from the mechanical notch slightly after peak load and propagated in a vertical path from the notch tip. From Fig. 5, the crack front does not appear to be uniform through the thickness of the beam since the crack detection gages are not breaking at the same time. This observation also can be verified in conjunction with Fig. 6. When the crack reaches the midpoint of the ligament, the load reduces to approximately 15 % of the peak load.

For each mixture and temperature, three beams were tested to evaluate the repeatability of the SE(B) test procedure developed in this study. Figure 7 shows the load-CMOD curves for three replicates of the 19 mm NMAS mixture at –10°C. The three replicates exhibited similar intitial compliance, peak loads, and softening curves. The results are typical of the other mixtures and temperatures used in this study. For each mixture and temperature, the average of three replicates was obtained (Fig. 8) along with the maximum and minimum fracture energy values, plotted as the error bars in Fig. 8 to illustrate the range of fracture energy values obtained. The overall repeatability of the testing appears to be satisfactory, with the largest deviation from the average being 25 % (9.5 mm NMAS 0°C). The increase in the variabiltiy of the fracture energy as the temperature increases can be attributed to a more tortuous crack path. As the temperature increases, the difference in the strength between the asphalt binder and the aggregates increases, resulting in the crack travelling around the aggregates. Therefore, the aggregate structure could influence the fracture characteristics of asphalt concrete.

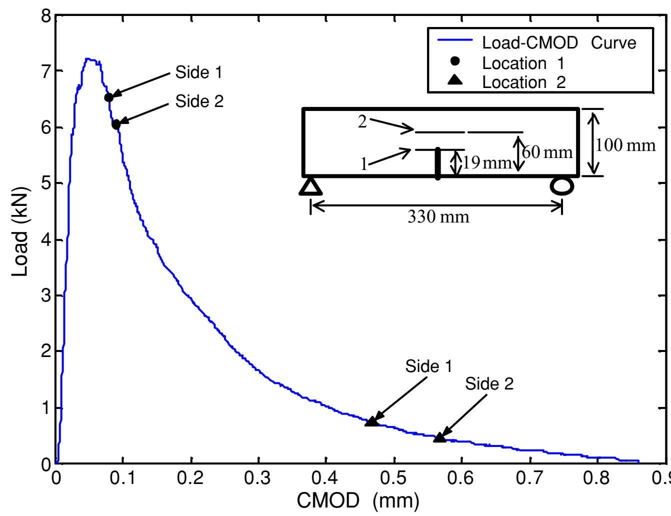
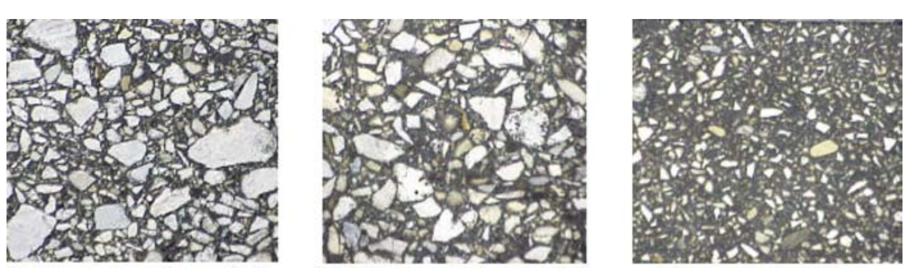


FIG. 5—*Load versus CMOD with crack detection gages.*

The effect of temperature on the fracture properties of asphalt concrete was examined at three temperatures: –20, –10, and 0°C. Figure 9 shows the load-CMOD curves for the 19 mm NMAS mixture at these three temperatures. The initial compliance and peak loads for these temperatures were very similar (Fig. 9). However, the temperature, as expected, affected the brittleness of the mixtures, as shown in the softening curves. The fracture energy also decreases as the temperature decreases for all of the mixtures, also denoting that the brittleness of the material is increasing. Figure 8 shows that the effect of temperature is the same for all of the mixtures tested; however, the 4.75 mm NMAS mixture produces the highest fracture energy at all temperatures, while the 19 mm NMAS mixture produces the lowest fracture energy at all temperatures. The reason behind the differences in the fracture energy between the mixtures is thought to be twofold. First, the NMAS affects the fracture energy by creating larger discontinuities (weak points) in the mixture as larger aggregates are used. Secondly, the type of asphalt binder can also affect the fracture energy by having different properties (adhesion, ductility, etc.). The 4.75 mm NMAS mixture utilizes a polymer-modified binder, which is significantly



(a) 19 mm NMAS and PG64-22 Asphalt Binder (b) 9.5 mm NMAS and PG58-22 Asphalt Binder (c) 4.75 mm NMAS and Polymer-Modified Binder

FIG. 4—*Asphalt concrete mixtures with nominal maximum aggregate size (NMAS) and asphalt binder type.*

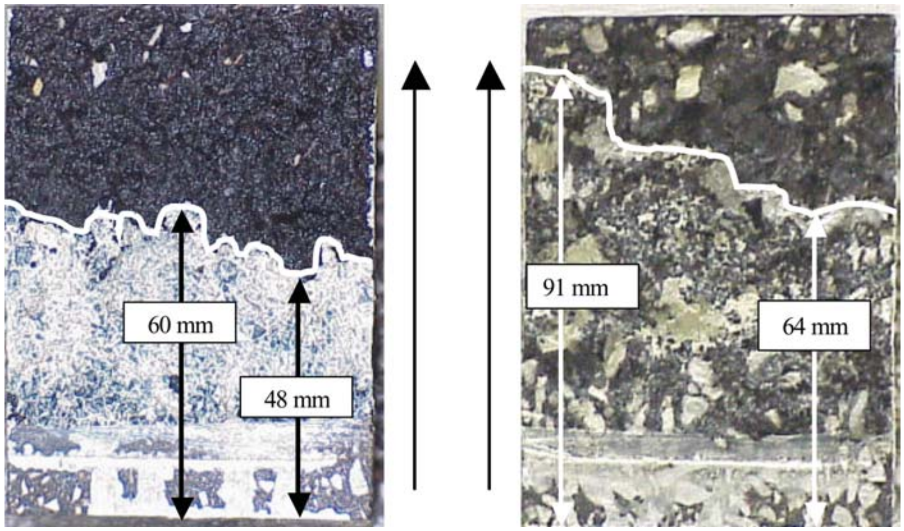


FIG. 6—*Crack-front profile using dye penetration for 4.75 mm NMAS (left) and 9.5 mm (right) mixtures.*

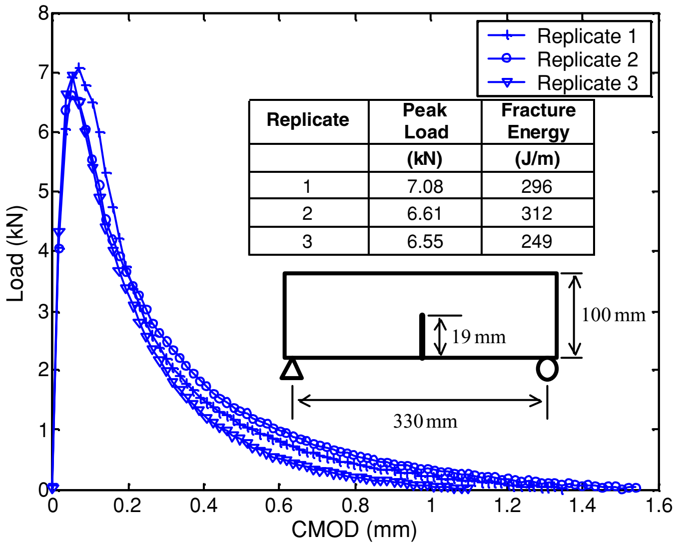


FIG. 7—*Load-CMOD curves for three replicates of the 19 mm NMAS mixture at −10°C.*

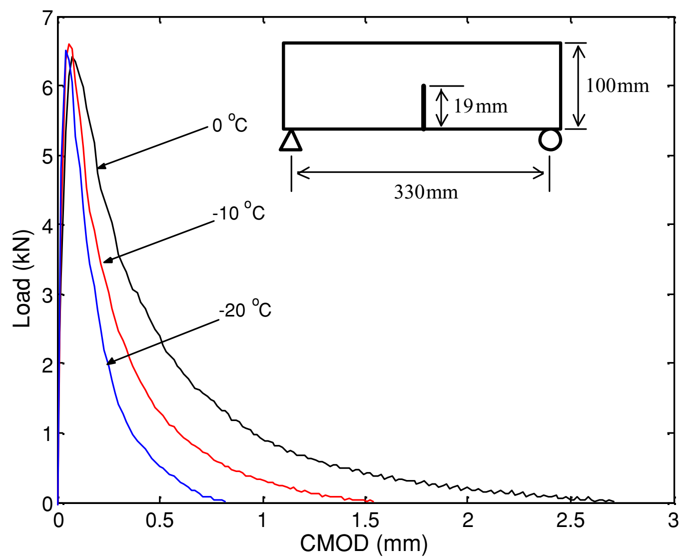


FIG. 9—*Load-CMOD curves for the 19 mm NMAS mixture at three temperatures: −20, −10, and 0°C.*

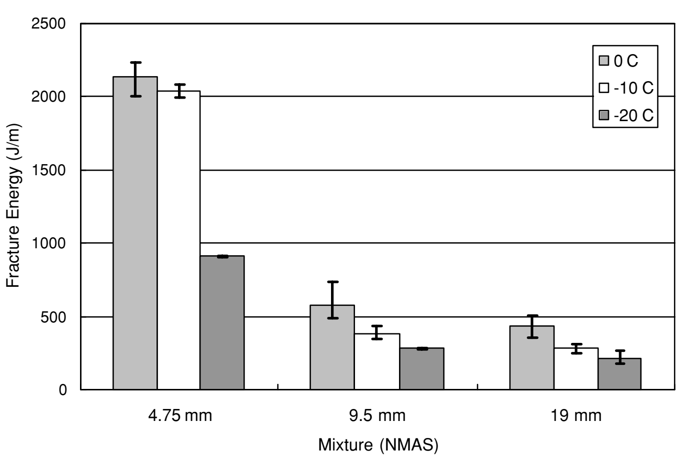


FIG. 8—*Average fracture energy for each mixture and temperature with minimum and maximum deviation from the average.*

more ductile than the more conventional binders used in the other mixtures. The increase of the fracture energy of the 4.75 mm NMAS mixture over the other mixtures could be attributed to both the NMAS and the polymer-modified binder. More testing will be performed in the future to further investigate the effects of aggregate gradation and asphalt binder on the fracture energy of the mixture.

Mixed-Mode Fracture

A major advantage of using a notched beam as a fracture specimen is that the beam can be modified to test for mixed-mode fracture properties [21–23]. As mentioned before, asphalt concrete pavements are loaded in both tension and shear, and thus understanding the mixed-mode fracture properties of asphalt concrete is important. For a preliminary test, one specimen (4.75 mm NMAS mixture at 0°C) was machined with a notch offset by 65 mm from the centerline with all other dimensions the same as the mode I specimens ($S = 330$ mm, $B = 75$ mm, $W = 100$ mm, $a = 19$ mm).

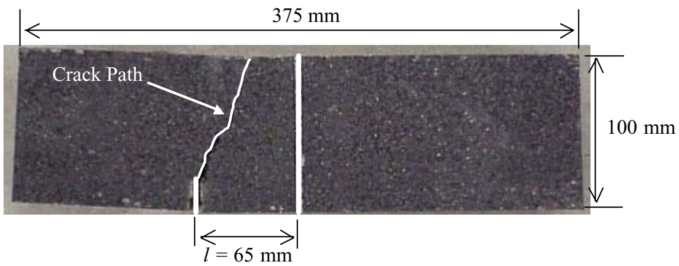


FIG. 10—*Mixed-mode fracture test using the offset notch method (a/W = 0.19).*

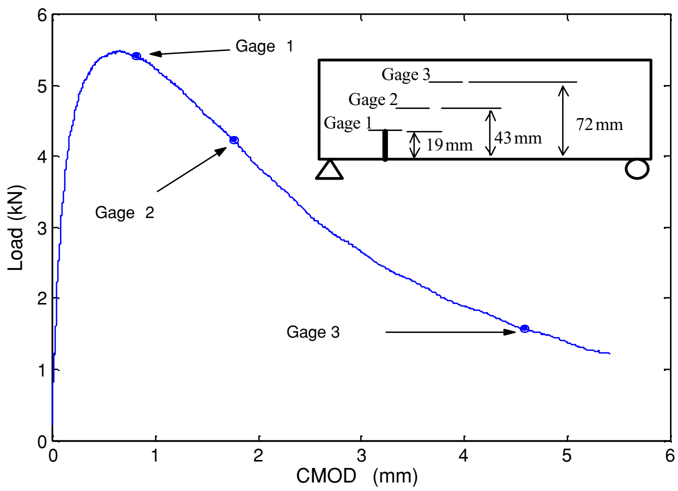


FIG. 11—*Load-CMOD for mixed-mode fracture test with crack detection gages at 19, 43, and 72 mm from the bottom of the beam.*

The feedback response for servohydraulic control for the mixed-mode fracture test was changed to load-line displacement for two reasons. First, the clip gage would not measure the crack mouth opening displacement (pure tensile opening), but would measure the crack mouth displacement (combination of tensile opening and shear sliding). Secondly, if the notch is placed far enough from the centerline, the crack initiation would not occur at the notch tip [32]. Thus, controlling the test through crack mouth displacement would be impractical.

Once the test was completed, the crack path was recorded (Fig. 10). One method for calibrating the CZM is to compare the crack path and the crack initiation angle. For this specimen, the crack initiated at the notch tip at an angle of 26.5°. As we offset the crack (as given by the offset length, l, in Fig. 10), the crack angle increases until a critical offset length is reached. At the critical configuration, the crack will not propagate from the offset notch tip, but it will nucleate and initiate at the center region of the specimen. This important investigation is under consideration by the authors [31] and is a subject for future studies. The specimen was instrumented with crack detection gages at the notch tip (19 mm), 43 mm, and 72 mm from the bottom of the beam. According to this simplified test procedure, the crack initiated slightly after peak load (Fig. 11) and reached the 43 mm gage at approximately 75 % of peak load and the 72 mm gage at approximately 25 % of the peak load.

Discussion and Outcome

A major distress mode for asphalt concrete overlays is reflection cracking, or the propagation of an existing crack through the new overlay. Research is ongoing into the fundamental mechanics underlying the initiation and propagation of cracks in asphalt concrete. The approach that is being taken is an integrated approach using numerical analysis, laboratory experiments, and field studies. One of the first tasks was to select and develop a suitable fracture test to provide fracture properties of asphalt concrete. The SE(B) fracture test was selected as the most promising test after a literature review of the different tests and procedures used for asphalt concrete mixtures. A preliminary testing program was developed to study the applicability of the SE(B) for asphalt concrete. Included in this program were the following:

- The development of testing and analysis techniques for the asphalt concrete.
- Tests to examine the effects of control mode (load line versus CMOD control).
- Tests to examine the crack front profile/propagation and test repeatability.
- Influence of test temperature on asphalt concrete fracture properties.

Based upon the results of this investigation, the following observations can be drawn:

- The crack front profile and crack path is influenced by aggregates in the mixture.
- The repeatability of the prototype SE(B) test developed in this study appears to be well within the expected test variability associated with asphalt concrete fracture testing.
- The SE(B) test appears to provide very reasonable estimates of fracture energy at low temperatures (0, –10, and –20°C). As expected, the fracture energy was found to increase with increasing temperature as the mixture becomes more ductile.

The SE(B) test was found to produce satisfactory results in the preliminary investigation described herein. Therefore, the testing program will be expanded to consider the influence of aggregate size and asphalt binder type, fracture characteristics at higher temperatures, process zone size, effects of rate and specimen size, and mixed-mode fracture.

Summary and Concluding Remarks

This work presents a reliable SE(B) fracture test that provides an estimate of the fracture energy for asphalt concrete. An integrated approach is currently underway using numerical analysis, laboratory experiments, and field studies to provide an understanding of asphalt concrete fracture. The integrated approach requires that the fracture model, the cohesive zone model, and the selected fracture test be compatible and complementary. A single-edge notched beam was selected as a fracture test to provide the fracture energy based upon the ability to adjust the beam dimensions to ensure that edge effects would be minimized and that the fracture process zone could be fully encompassed in the initial ligament. The initial work required the adaptation of an existing servohydraulic system, fabrication of new loading fixtures, and new instrumentation and analysis procedures. With satisfactory preliminary work completed, a testing program was developed to investigate the test repeatability, to examine the influence of temperature on fracture energy and crack front characteristics, and also to investigate mixed-mode fracture. Based upon the results from the testing program, the fracture energy obtained from the SE(B) test follows expected trends and variability of the test results are within a range typical for asphalt concrete fracture testing. The testing protocols are well established for mode I fracture testing.

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