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Development of an index to evaluate the cracking potential of asphalt mixtures using the semi-circular bending test

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HIGHLIGHTS

- A review of the Illinois Flexibility Index Test (I-FIT) is presented.
- An alternative cracking parameter called Cracking Resistance Index (CRI) is developed.
- CRI is less variable and easier to calculate as compared to the Flexibility Index (FI) parameter.
- CRI shows greater distinction between different asphalt mixtures with different properties.
- CRI is sensitive to binder PG, recycled materials content, and the presence of recycling agents.

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ABSTRACT

This study introduced a cracking parameter, called the Cracking Resistance Index (CRI), derived from the load-displacement response obtained during a semi-circular bending test, and compared it to the recently developed Flexibility Index (FI). Laboratory test results indicated that both FI and CRI are sensitive to binder Performance Grade, recycled materials content, and recycling agent dosage. The results indicated the dependency of the two indices on specimen thickness and air voids content. A reasonable correlation between FI and CRI was verified. As compared to the FI, the proposed CRI provided better distinction between different asphalt mixtures, less variability, and easier calculation.

1. Introduction

Cracking in asphalt pavements occurs in response to several factors including poor mix design, repetitive traffic loading, moisture damage, and aging of the asphalt binder in the mixture. Cracking is further exacerbated with the growing use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS), both manufactured waste asphalt shingles (MWAS) and tear-off asphalt shingles (TOAS), due to the presence of very stiff or heavily aged asphalt binders in these recycled materials. As a result, mixtures with high recycled materials content are stiffer, more brittle, and more prone to fatigue, thermal (low-temperature), reflection, block, and top-down cracking during the service life of the pavement [1–4].

A number of laboratory tests have been developed in previous research efforts and are currently used by State Departments of Transportation (DOTs) and other highway agencies to evaluate the cracking resistance of asphalt mixtures. These tests include the indirect tensile (IDT) test (AASHTO T 322), disk-shaped compact tension (DCT) test (ASTM D7313), low-temperature semi-circular bending (SCB) test (AASHTO TP 105), bending beam fatigue test (AASHTO T 321), the simplified viscoelastic continuum damage (S-VECD) test (AASHTO TP 107), and Texas overlay (OT) test (Tex-248-F). When highway agencies implement a specific cracking test for routine use, a number of aspects are considered, includ-

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ing sensitivity to mix design variables, test simplicity, test variability, availability of standard test methods, and correlation of the test result to field performance [5,6]. Among these factors, special emphasis should be given to the sensitivity of the test to mix design variables because asphalt mixtures with different components and proportions, such as binder Performance Grade (PG), binder content, RAP and/or RAS content, warm mix asphalt (WMA) technologies, and recycling agents (RA), are likely to influence the cracking resistance of the mixture.

Among the previously mentioned cracking tests, the SCB mode of loading has gained popularity among highway agencies due to its sensitivity to mix design variables, ease of sample preparation and quick testing time, availability and low cost of test equipment, ability to test field cores with limited thickness, and good correlation to field cracking performance [5–10]. SCB testing for asphalt mixtures was originally developed to characterize low-temperature performance of asphalt mixtures (AASHTO TP 105). Recent studies by Zofka and Braham (2009) [11] showed that Low-Temperature SCB can be used for qualitative cracking performance predictions at low temperatures, where the fracture energy from the SCB test showed good correlation with the field data of ten asphalt pavement sections in Minnesota and Illinois.

Recently, researchers at the Illinois Center for Transportation (ICT) developed and verified the Illinois Flexibility Index Test (I-FIT) to assess the intermediate temperature cracking resistance of asphalt mixtures [9]. An AASHTO provisional standard (AASHTO TP 124) "Determining the Fracture Potential of Asphalt Mixtures Using Semicircular Bend (SCB) Geometry at Intermediate Temperature" has been introduced for the I-FIT. Specimens 150 mm in diameter and 50 mm thick are cut in half to create a semicircular test specimen 75 mm in diameter and 50 mm thick, and a notch is introduced along the axis of symmetry 15 mm deep and 1.5 mm wide. The test procedure relies on a simple three-point bending mechanism where a monotonic loading is applied by the actuator at a constant load-line displacement (LLD) rate of 50 mm/min in the direction of the load application. Load, load-line displacements are recorded, and the load-displacement curve is plotted. The test is performed at 25 °C. The Flexibility Index (FI), the primary output parameter from the I-FIT, is defined as the total fracture energy divided by the slope of the post-peak load-displacement curve at the inflection point, as expressed in Eqs. (1) and (2). High FI values are desired for asphalt mixtures to provide good cracking resistance [9].

$$G_f = W_f/A = \int (P)du/A \tag{1}$$

$$FI = G_f/|m| \times 0.01 \tag{2}$$

where G_f is the total fracture energy (J/m^2); W_f is the work of fracture (J); P is the load (kN); u is the load-line displacement LLD (mm); A is the ligament area (mm) (equals the ligament length × the thickness of the specimen); FI is the Flexibility Index; and m is the slope at the inflection point of the post-peak load versus displacement curve.

A number of studies have reported that the FI parameter is sensitive to asphalt binder PG and the inclusion of RAP and/or RAS. Other studies observed that FI values of field cores correlate well with field cracking performance of different asphalt mixtures with different characteristics (different properties or components) [6,9]. However, the FI has been reported to be unable to identify changes in asphalt binder content [6], and unable to characterize brittle mixtures where the asphalt mixture samples fractured at the peak load, and thus, no post-peak displacement data is available to calculate the m and FI.

There is no data available regarding the sensitivity of the SCB test to inclusion of RA or long-term aging of asphalt mixtures. In addition, the effect of air voids (AV) content on the FI has not been evaluated, although density (i.e., AV content) is a significant factor in mixture cracking performance and durability [12]. Finally, an alternative method to analyze I-FIT results to rank brittle asphalt mixtures, including field cores, based on cracking resistance is needed.

2. Objectives and scope of work

The objectives of this study were to: (1) develop an alternative SCB cracking parameter with the potential to differentiate and rank asphalt mixtures with different components and properties, including brittle mixtures and (2) evaluate the sensitivity of the FI and the alternative SCB cracking parameter to various factors, including mix design variables, specimen thickness, AV content, and laboratory aging condition.

3. Background and methodology

Fracture energy is one of the main output parameters in SCB testing (i.e. G_f); it is defined as the work required to initiate and propagate the crack in the specimen until fracture (the load magnitude reaches 0.1 kN or below), and is represented by the area under the load versus displacement curve [13]. In developing the I-FIT, Al-Qadi et al. (2015) [9] pointed out that G_f is a function of both the strength (defined by the peak load) and ductility (defined by the maximum displacement at the end of the test) of the material; higher peak loads and displacements correspond to higher G_f values. However, fracture energy is not sufficient as a single parameter to distinguish between different asphalt mixtures, due to the inability of fracture energy to distinguish between mixtures with high peak load and steep post-peak slope (brittle mixture) and mixtures with low peak load and shallow post-peak slope (more flexible mixture) [14], as illustrated in Fig. 1 for example.

During the SCB test, the crack initiates at the tip of the notch when the peak load is reached. Afterward, the load decreases and the displacement increases as the crack propagates through the specimen, until fracture occurs. Based on fracture mechanics, the rate of crack propagation is dependent upon the brittleness of the material. For brittle mixtures (such as mixtures with RAP and/or RAS) with high stiffness and poor relaxation properties, little post-peak displacement is expected due to fast crack propagation. Conversely, for flexible mixtures, large post-peak displacement is expected due to slow crack propagation. Based on the post-peak load-displacement curve, the inflection point is where the curvature changes from negative to positive and it is determined by setting the second derivative of the post-peak equation (post-peak load-displacement curve) to equal zero, and the

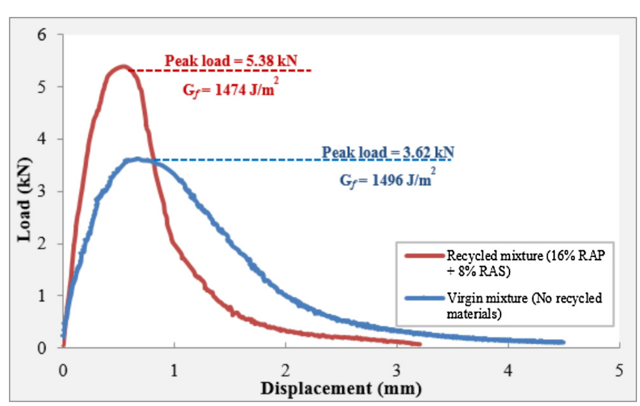

Fig. 1. Load-displacement curve of two distinct asphalt mixtures.