Construction and Building Materials 126 (2016) 682–690

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Investigating the effects of aging and loading rate on low-temperature cracking resistance of core-based asphalt samples using semi-circular bending test

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HIGHLIGHTS

- Low-temperature cracking resistance of core-based asphalt samples was examined using SCB test.
- The effect of asphalt aging on its cracking resistance was evaluated.
- The effect of loading rate on fracture parameters of SCB samples was examined.
- Fracture parameters including stress intensity factor, fracture energy and critical energy release rate were obtained.
- By increasing samples' service life, asphalt cracking resistance was decreased.

ARTICLE INFO

Article history:
Received 6 December 2015
Received in revised form 15 September 2016
Accepted 17 September 2016

Keywords:
Aging
Core-based asphalt samples
Fracture energy
Fracture toughness
J-integral
Low temperature cracking
Semi-circular bending test
Stress intensity factor

ABSTRACT

In this study, the asphalt concrete (AC) cracking resistance was examined at -15 °C, under mode I loading using semi-circular bending test (SCB). The SCB samples were prepared through pavement coring under the same conditions (i.e. mix design, passing traffic volume and weather) with varying years of service life. First, the effect of asphalt aging on its cracking resistance was evaluated using field-aged AC cores. Second, the effect of loading rate on fracture parameters of SCB samples was examined using two different rates. Evaluating the load-displacement curves obtained from test results showed that the asphalt mixtures behaved as a linear elastic material at low temperature. Also, an increase in the pavement's life led to a significant decrease in failure deformation, fracture energy and critical energy release rate of the samples. Moreover, by increasing loading rate, the samples' peak load increased; however, fracture energy and failure deformation decreased.

1. Introduction

Low-temperature cracking is one of the most common distresses in hot mix asphalt (HMA) pavements. A decrease in temperature results in the contraction of the asphalt concrete layer. Moreover, the friction between asphalt and its sub-layer prevents the asphalt layer movement. This causes tensile stresses in the asphalt layer. With further decrease in temperature, values of these stresses increase. When the stress values reach the asphalt tensile strength, cracking initiates at the bottom of asphalt layer. Continuous weather cycles and the repetition of the traffic loading cause the growth and propagation of crack over the pavement surface. Water infiltration through cracks increases failure and reduces pavement's load-bearing capacity. Lack of timely repair and maintenance of damaged pavement requires spending high costs to repair and reconstruct the pavement. AC is a composite material composed of several components which are binder, aggregate, filler and air voids. Thus, AC's behavior depends on the properties of these components. Bitumen is a petroleum hydrocarbon which is composed of three main components: 1) Asphaltenes that are solid part of bitumen and they are sustainability factor of bitumen; 2) Resins that cause adhesion of bitumen; 3) Aromatics that are thermal sensitivity factor in binder. Due to the exposure of the binder to oxygen, oxidative aging happens gradually. During this

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http://dx.doi.org/10.1016/j.conbuildmat.2016.09.054

process and due to the reduction of volatile substances, binder experiences aging. This causes reduction of adhesion and ductility of binder and affects asphalt mixture performance. Binder, as the main adhesive material for asphalt mixture becomes brittle at low temperatures and causes asphalt mixture brittleness at this temperature. As a result, the likelihood of cracking in asphalt pavements is increased.

For determining fracture toughness of asphalt mixtures, finding a straightforward and appropriate laboratory test with acceptable, reasonable and repeatable results is difficult. In recent years, researchers have used various laboratory tests for evaluating the fracture toughness of asphalt mixtures. Each of these methods has encountered with some limitations and problems. Among these methods, Single-Edge Notched Beam (SENB) under three and four-point bending [1–3], Disc-Shaped Compact Tension (DCT) test [4–6], Indirect Tensile Test (IDT) [7–8], Brazilian Tensile Test [9], Semi-Circular Bending Test (SCB) [10–27] and Fenix test [28] can be mentioned. The SCB test has been more fortunate than other methods due to ease of sample preparation both in laboratory and through the field coring, ease of cutting crack on the flat side of samples, ease of conducting test and the availability of required facilities and equipment.

The SCB test was first presented in 1984 by Chang and Kuruppu [10] to determine the fracture toughness of rock. Before that, the use of proposed specimen in standard ASTM E399-81 [29] for determining the fracture toughness of materials such as stone, concrete, ceramic was difficult and expensive. On the other hand, the weakness of these materials in tension requires an appropriate laboratory test for determination of fracture toughness so that applying compressive loading causes the tensile fracture in the samples. Therefore, they suggested using pre-notched semi-circular samples under three-point bend loading to determine the fracture toughness of rock. Then, Lim et al. [11] determined the stress intensity factor for a wide range of crack length to radius ratio (a/R), as well as the span to radius ratio (s/R) offered by Change [10]. Van De Ven and Smit [7] studied the use of SCB test instead of IDT test. Comparing the results obtained from asphalt tensile strength under SCB test and IDT test represented a logical connection between the results of these two tests. Huang et al. [8] compared the tensile strength obtained from IDT and SCB test. The IDT is widely applied as a standard test to determine the tensile strength of asphalt samples. Despite its broad usage and many advantages, the permanent deformation on the asphalt specimen under loading strips of test device is undesirable and in some cases its results are not appropriate to evaluate the cracking potential in the asphalt mixtures. The SCB test can significantly decrease the loading strip-induced permanent deformation and thus can be taken into account as a better option for determining asphalt tensile strength rather than the IDT test. Their research showed that the results of SCB and IDT tests were comparable and convertible to each other. Arabani and Ferdowsi [12] examined the use of SCB test. They found the tensile strength obtained from the SCB test was comparable and convertible to the results of the IDT test. Zhong et al. [13] investigated thirteen different asphalt mixtures composed of four different binder types with four different compaction levels at 25 °C to determine the asphalt fracture toughness. Then, they obtained the critical value of J-integral for samples based on an elasto-plastic fracture mechanic concept. Their research results showed the sensitivity of the J-integral values to the binder type and nominal maximum aggregate size (NMAS). In a laboratory study, Lancaster and Khalid [14] investigated the effect of loading rate on the fracture parameters of unmodified and modified asphalt mixtures with different percentages of SBS using SCB test. According to their research results, by increasing the loading rate, the critical value of stress intensity factor and also the critical value of J-integral in polymer modified specimens increased. Biligiri et al. [15] evaluated the crack growth of laboratory SCB specimens in the first part of their work. For this purpose, they applied two types of asphalt with the same aggregate and different binder contents for the sample preparation. In the second part, they evaluated the fracture toughness of field-cored samples. Their research results showed that asphalt mixture with higher binder content had lower fracture toughness.

An overview of the works done in the past show a comprehensive study on the determination of fracture toughness of core-based asphalt samples with varying years of service life has not been conducted yet. Accordingly, this research can be divided into two main sections. In the first section, to evaluate the effect of aging on asphalt cracking resistance, the asphalt samples with same conditions (in terms of mix design, passing traffic volume and weather) by considering varying years of service life (i.e. fresh, two and six year-old samples) were prepared through field coring of asphalt constructed in Shahrood-Miandasht road, Iran. In this section, all samples with a constant rate of 5 mm/min and at −15 °C temperature were SCB tested and their fracture parameters were determined. In the second section, to evaluate the effect of loading rate on cracking resistance at −15 °C, asphalt samples with service life of 2 years were subjected to loading with two different rates (5 and 50 mm/min).

2. Materials and methods

2.1. Material specifications

Mix design and material properties listed in this section was on the basis of mix design presented for asphalt mixtures in its construction year. All the results were based on the conducted tests in soil mechanic laboratory. AC composed of aggregates, binder, filler and an air void content. Each of these components has an impact on the properties and performance of asphalt. Thus, it is necessary to determine the properties of asphalt mixture.

Aggregates gradation is one of the most important factors that affects the strength and load-bearing capacity of pavement. Appropriate grading of AC is selected based on different factors including: type of pavement, type and location of the target layer in the pavement structure, asphalt layer thickness and NMAS. Table 1 shows the aggregates gradation of asphalt used in this study. Table 2 displays the physical properties of aggregates.

Table 1
HMA aggregate gradation.

Sieve size (mm)	Requirements (%)		Passing percentage
	Min.	Max.	
25	100	100	100
19	90	100	95
9.50	56	80	64
4.75	35	68	51
2.36	23	49	34
0.30	5	19	9
0.075	2	8	4

Table 2
Physical properties of aggregates.

Test	Standard test method	Test results
Specific gravity (Coarse aggregate)	AASHTO T 85-13	2.76
Apparent Specific gravity (Coarse aggregate)	AASHTO T 85-13	2.84
Specific gravity (Fine aggregate)	AASHTO T 84-13	2.74
Apparent specific gravity (Fine aggregate)	AASHTO T 84-13	2.86
Specific gravity (Passing #200)	AASHTO T 100-06	2.79
Absorption (Coarse aggregate) %	AASHTO T 85-13	1.10
Absorption (Fine aggregate) %	AASHTO T 84-13	1.50