SCB Samples Fracture Resistance Evalutaion of Hot Mix Asphalt vs Warm Mix Asphalt by ITS, Fatigue tests

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Abstract- Pavement cracking is a major pavement distress and its rehabilitation cost is astronomical. Low temperature cracking and bending cracking due to cold climate and traffic loading are two major pavement distresses in asphalt concrete pavements. In this paper, the fracture resistance of cracked asphalt concretes made from two different types of asphalt mixtures i.e. hot mix asphalt (HMA) and warm mix asphalt (WMA) modified by Rheofalt are compared. Beam fatigue testing was performed using beam specimens at 25 °C based on AASHTO T321 standard. Fatigue life for both mixtures were calculated using four-point beam fatigue test results.

Three-point bending tests were performed using semi circular bend (SCB) specimens at –10 °C and the critical mode I stress intensity factor KI was then calculated using the peak load obtained from the load–displacement curve. The indirect tensile strength (ITS) tests were also applied to asphalt mixtures and it was found that WMA has greater strength compared with HMA. It is observed that Rheofalt warm mix asphalt additives have a significant effect on indirect tensile strength, fatigue behavior and stress intensity factor of mixtures. The SCB samples were prepared from gyratory compactor cylinders. Crack within the sample was generated utilizing a water-cooled sawing machine with a thin blade. The results showed that the critical stress intensity factor of HMA is higher than that of WMA. Therefore, asphalt mixture type has an important role in fracture behavior of asphalts concretes.

Keywords--- Hot Mix Asphalt, Warm Mix Asphalt, Low Temperature, Semi-Circular Bend (SCB), Stress Intensity Factor.

I. Introduction

ASPHALT concrete (AC) cracking in the cold climate regions is considered as one of the major modes of deterioration in asphalt pavements, which occur in flexible pavement systems. AC cracking can be caused due to repeated traffic loads (fatigue cracking), by rapid fluctuations in pavement temperature (thermal cracking), or by a combination of these effects [1].

Asphalt mixtures are particulate composite materials containing aggregates, asphalt binder and air voids. Asphalt mixtures vary significantly as a result of using different binder-aggregate combinations and binder modification techniques. Warm Mix Asphalt (WMA) is a group of technologies that allow a reduction in the temperatures at which asphalt mixes are produced and placed on the road.

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These technologies tend to reduce the viscosity of the asphalt and provide for the complete coating of aggregates at lower temperatures. WMA is produced at temperatures 20 to 55 °C (35 to 100 °F) lower than typical hot-mix asphalt (HMA) by adding some additives called wax. In this research, WMA mixtures were made by adding Rheofalt wax to the asphalt. Benefits of WMA technologies include reduced fuel usage and emissions in support of sustainable development, improved field compaction, which can facilitate longer haul distances and cool weather pavement, and better working conditions. Increased awareness of the warm asphalt technology in the asphalt industry makes the investigation of its material properties necessary [2, 3].

Bending due to passing tire loads, cold temperature in winter and hardening of the asphalt with aging may cause severe tensile stresses in the surface asphalt layer of the pavement. When such stresses surpass the strength of the material, transverse cracks can be generated. Transverse cracks allow moisture infiltration and it causes further distresses in pavement layers [4,5]. So good fracture properties are an essential requirement in asphalt pavements for which the predominant failure mode is cracking due to high thermal stresses and bending that develop at low temperatures.

Warm Mix Asphalt (WMA) is the generic term for a variety of technologies that allow producers of Hot Mix Asphalt (HMA) pavement material to lower temperatures at which the material is mixed and placed on the road. Reductions of 10 to 40 degrees centigrade have been documented. Such drastic reductions have the obvious benefits of cutting fuel consumption and decreasing the production of greenhouse gases. With increasing awareness of the warm asphalt technology in the asphalt industry, several properties of warm asphalt should be investigated. While several studies have been conducted on the performance of WMAs, some of its characteristics have not been studied in detail [6].

This paper presents the effects of mixture type (HMA and WMA) on fracture mechanic characteristics of WMA and HMA. Fracture tests were carried out on semi-circular bend (SCB) specimens. Cylindrical samples were prepared by gyratory compactor machine, and then were cut in several stages to prepare SCB samples. The crack was created within the specimens using a water cooled cutting machine with a very thin blade. All tests were carried out at the temperature of -10°C, and the mode I critical stress intensity factor was then calculated using the peak load measured from the tests. Furthermore, the results of beam fatigue tests conducted on different asphalt mixtures were evaluated to justify fracture mechanic behavior of mixtures.

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II. Asphalt Mixtures And SCB Specimen Preparation

Aggregate gradation of the asphalt mixtures (HMA and WMA) used in this study was selected as Table 1 which was within the range of the recommendations by Iran Highway Asphalt Paving Code. The binder content of all mixtures (calculated according to the standard method) was the same. The binder PG 64-22 was utilized for preparation of both HMA and WMA mixtures. Cylindrical samples (130-mm in height, 150-mm in diameter) were prepared using superpave gyratory compactor (SGC) machine. These samples were sliced into three disks with 32-mm in thickness by means of a water-cooled masonry sawing machine. They were then halved to obtain six semi-circular bend specimens. These cutting processes have been schematically shown in Fig.1. At the next stage, an artificial crack (20-mm in length) was generated in the middle of the specimen utilizing a water-cooled cutting machine with a very thin blade. Fig. 2 shows typical of the generated crack within the SCB specimen.

Fig. 1 SCB Specimen preparation processes and a typical generated crack within the SCB

TABLE I
HMA AGGREGATE GRADATION

Sieve size(mm)	Requirements Min	Requirements Max	Percent passing
19	100	100	100
12.5	90	100	95
9	67	87	77
4.75	44	74	59
2.36	28	58	43
1.18	20	46	33
0.5	13	34	23
0.3	5	21	13
0.15	4	16	9.5
0.075	2	10	8.4

III. Test Procedure And Stress Intensity Factor

After preparation of the cracked SCB specimens from warm mix and hot mix asphalts, they were first kept in the temperature chamber for 4 hours at -10°C; afterwards, to simulate mode I loading, cracked SCB samples were compressively and symmetrically loaded by means of a universal machine with three-point bending fixture. Fig. 2 shows the test configuration, and Fig.3 shows fracture test set-up. The displacement rate of the upper fixture was set to a constant value of 3 mm/min and the load-displacement curve was recorded. Typical curves for two different mixtures have been presented in Fig.4.

The stress intensity factor KI was chosen as a fundamental parameter for characterizing fracture behavior of cracked SCB samples at low temperature. For SCB geometry, KI is written as:

$$K_I = Y_I \frac{P_{cr}}{2Rt}\sqrt{\pi a} \tag{1}$$

Where YI is the geometry factor. Using the J-integral technique in ABAQUS code, YI was obtained for the tested SCB specimen as 3.734. Pcr is the peak load at the load-load line displacement curve which is obtained from the test results. R, t, and a are the radius, thickness and crack length, respectively.

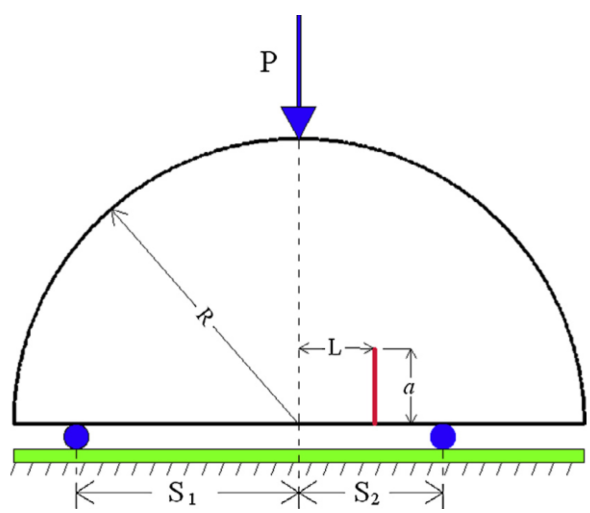

Fig. 2 Configuration of the SCB specimen test

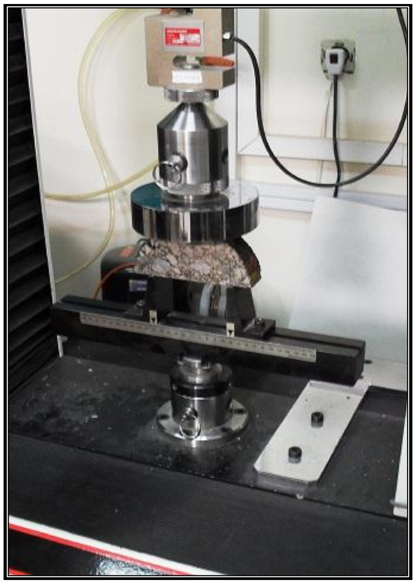

Fig. 3 Fracture test set up

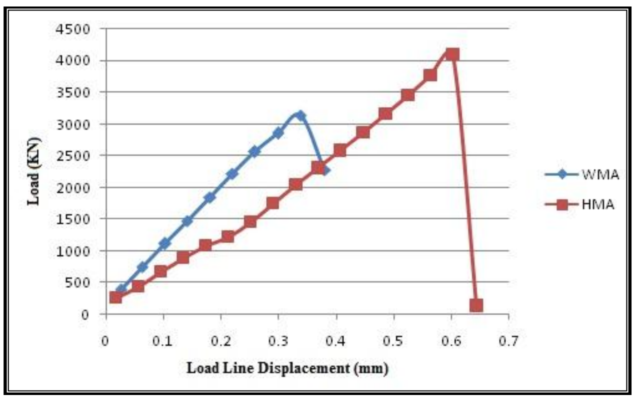

Fig. 4 Load versus load line displacement curves

IV. Results And Discution

A series of experiments were performed to characterize the critical stress intensity factors of mixtures prepared from two different kinds of asphalts with asphalt PG 64-22. Peak load measured from SCB tests along with its average value are shown in Table 2. For the comparison sake, the fracture loads obtained for the two kinds of mixtures (HMA and WMA) and calculated as an average value for three specimens from each mixture is displayed in Table 2. This Table and Figure 4 indicate that the required load for commencing crack extension in HMA mixtures is greater than that for WMA mixtures.

The critical stress intensity factor was calculated by replacing fracture load, presented in Table 2, into Eq.1. The results, critical stress intensity factor and its average value, for the both mixtures have also been presented in Table 2. It is clear that fracture toughness (KIc) for the HMA mixture is higher than WMA mixtures modified by Rheofalt. This phenomenon is associated to the fact that the WMA mixture in the cold temperature present a better elastic behavior than HMA mixture and thus is more brittle. This behavior can be justified from beam fatigue test results that can be seen in Fig.7. Due to more brittle property of warm mix asphalt in room temperature, the fatigue life for WMA mixture was lower than the HMA. Consequently, the results of Indirect Tensile Strength are shown in Table.3.

Table II
Test results for mixtures prepared from different technologies

Mixture type	*Replicate No.*	*Fcr (KN)*	$F_{cr}^{av}(KN)$	$K_{If}(MPa\sqrt{m})$	$K_{If}^{av}(MPa\sqrt{m})$
HMA	1	4.11	4.1	0.8	0.8
	2	4.09		0.8	
	3	4.1		0.8	
WMA	1	2.7	2.7	0.53	0.53
	2	2.81		0.55	
	3	2.63		0.51	

Fig. 6 shows a typical SCB sample after the fracture test. It is seen that the crack extends along the existing pre-crack line toward upper loading point.

Fig. 5 ITS test set up

Fig. 6 Crack propagation path on the SCB tests

Table III
Indirect Tensile Strength Test results for HMA and WMA mixtures

Mixture type	Replicate No.	ITS (KN)
HMA	1	8.17
	2	8.03
	3	7.92
WMA	1	11.1
	2	11.23
	3	11.17

According to Beam fatigue test result shown in table 4, Hot mix asphalt has greater fatigue life comparing with WMA mixtures. It can be due to the harder and more brittle structure of WMA containing Rheofalt additive.

Fig. 7 Beam fatigue test set up

TABLE IV
FATIGUE TEST RESULTS

Mixture type	Replicate No.	Beam Fatigue
HMA	1	62377
	2	60714
	3	60922
WMA	1	48631
	2	47925
	3	48233

V. CONCLUSIONS

In this study, a number of experiments were conducted on asphalt mixture samples under pure mode I loading, ITS test and beam fatigue test. The critical stress intensity factors for HMA and WMA mixtures were calculated from the fracture loads. It was observed that the critical stress intensity factor of HMA mixtures was higher than that of WMA mixtures. The ITS value for WMA mixtures was higher than HMA mixes on the other hand, the results of Fatigue test showed that WMA behavior is more weaker than HMA mixtures. Since cracking in asphalt mixture is inevitable and there has been no way so far to completely prevent this type of pavement deterioration, employing HMA mixtures in very cold climate can be a possible way to retard crack propagation.

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