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Developing a Model for the Effect of Temperature and Thickness of Asphalt Mixture on Fracture Toughness under Pure Mode I

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1. Introduction

A large amount of money is spent every year on designing and constructing of asphalt pavements due to the increase in the number of vehicles and, consequently, a higher demand for constructions of new roads. In addition, overtime, different factors such as severe climates and traffics make cracks on the road surface that also require spending money on roads maintenance.

Fracture mechanics, as a powerful tool, has been successfully used to study crack initiation and propagation in all types of materials. This approach has been applied to explore the mechanism of fracture in asphalt mixtures as early as in 1960s and has become increasingly popular in the research community after 1990s.

Low temperature cracking is one of the major distress modes of asphalt concrete in cold regions. Further propagation of such cracks may occur because of tensile thermal stresses induced by temperature fluctuation which can result in pure mode I fracture mechanism in the asphalt pavement. Therefore, including low temperature performance in the design procedure of asphalt mixture in seasonal frozen areas is of high priority.

This study aimed at evaluating asphalt mixtures resistance under mode I cracking at low temperatures by considering fracture toughness (K_{IC}) as a fundamental parameter for estimating the load bearing capacity of cracked pavements against crack propagation.

2. Fracture Test

Fracture test in this study was performed using Semi-Circular Bend (SCB) specimens to evaluate the fracture toughness of asphalt mixture. To this end, the asphalt mixtures were manufactured with AC 60/70 bitumen. SCB specimens with effective crack in approximately 23 mm depth have been prepared in three thicknesses (35, 50, and 65 mm). The specimens were tested under mode I using GALDABINI (QUASAR 600) testing machine. A constant displacement rate of 5 mm/min is applied during the mechanical test. The test was carried out at three subzero temperatures (-5 °C, -15 °C, and -25 °C). The data was collected by calculating the fracture toughness values using critical fracture loads. Figure 1 shows the location of samples on the supports and the distances relative to cracks.

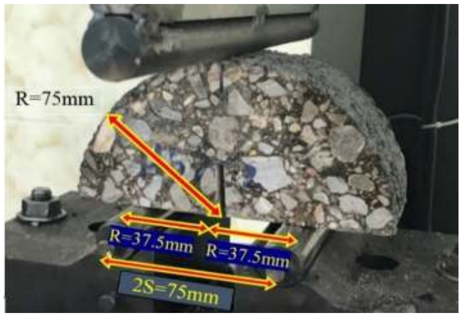

Figure 1. Loading configuration of asphalt SCB specimens in test

3. Calculation of Fracture Toughness ($\mathrm{K_{IC}}$)

The values of mode I fracture toughness (K_{IC}) was determined for each cracked specimens from the Eq. (1).

$$\mathrm{K_{IC}} = \frac{\mathrm{P_f}}{2\mathrm{Rt}}\sqrt{\pi \mathrm{a}}\,\mathrm{Y_I}\left(\frac{\mathrm{a}}{\mathrm{R}},\frac{\mathrm{S}}{\mathrm{R}}\right) \tag{1}$$

where $\mathrm{P_f}$ (N) is the critical load to failure which consist the obtained values of the test, R=75 (mm) is the specimens radius, t (mm) is the specimen thickness which includes three quantities (35, 50, and 65), a (m) is the initial crack length of specimens that includes a quantity between 22 and 23 which is considered 22.5 mm in average, S=37.5 (mm) is the loading span, and $\mathrm{Y_I}$ is the geometry factor of the SCB specimens under pure mode I which is considered 2.60 for two ratios according to Figure 2: (i) the crack length to radius ratio ($\frac{a}{R} = \frac{22.5}{75} = 0.3$), and (ii) the loading span to radius ratio ($\frac{S}{R} = \frac{37.5}{75} = 0.5$).

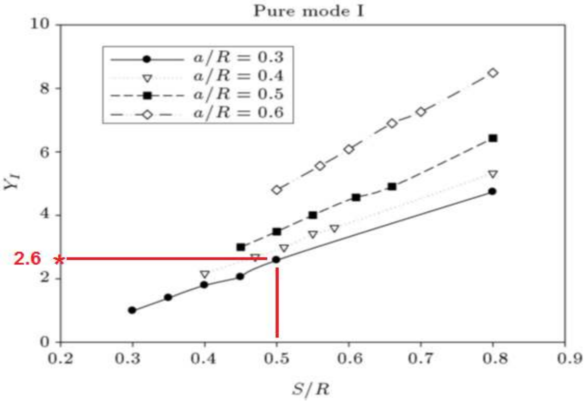

Figure 2. Variations of pure mode I geometry factor ($\mathrm{Y_I}$) on the SCB specimens with a/R and S/R

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4. Results of Calculated Fracture Toughness

The values of fracture toughness (K_{IC}) are presented in Figure 3 for three thicknesses (35, 50, and 60 mm) of asphalt specimens at three different temperatures (-5, -15, and -25 °C). Figure 3 shows that the fracture toughness increases by the increase of specimens thickness at different test temperatures. In general, the increase of specimens thickness from 35 mm to 65 mm increases the fracture toughness by approximately 29% at two test temperatures (-5 °C and -15 °C) and increases approximately 24% at -15 °C. Moreover, Figure 4 shows that decreasing test temperature of each specimens thickness causes increases the fracture toughness. In general, it can be observed that fracture toughness increases about 25% by the decrease in test temperature from -5 °C to -25 °C in each thickness of specimens.

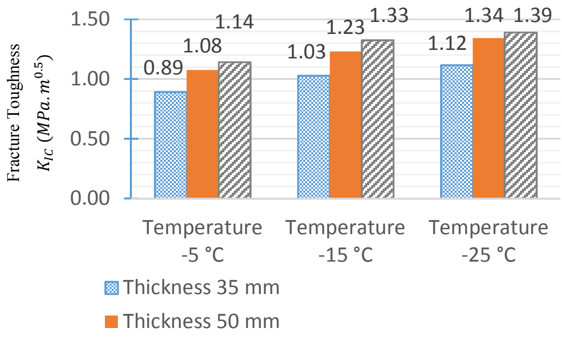

Figure 3. The effect of specimen thickness on K_{IC} at three test temperatures

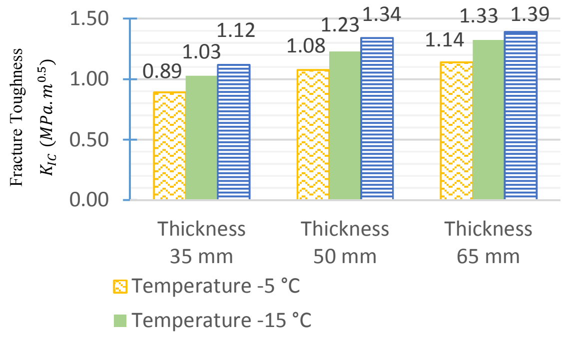

Figure 4. The effect of temperature on K_{IC} in different thickness

5. Developing a Model for Estimation of Asphalt Fracture Toughness Based on Two Parameters of Temperature and Thickness

In this study, fracture test on 45 samples of asphalt mixture was used to estimate the fracture toughness values, test temperatures, and specimens thickness as dependent, independent, and independent variables respectively in MATLAB statistical software. To this end, nine values of the fracture toughness have been calculated in software by the average of 5 values for tested samples in three thicknesses under three test temperatures. Finally, a model was presented according on Eq. (2) with evaluation on several polynomial functions from "Curve Fitting Tool" on MATLAB software. Moreover, the response surface has been shown in Figure 5 to provide a better comprehension of K_{IC} values which were obtained from the following model interacted by two parameters of test temperature and specimens thickness.

$$K_{IC} = -0.1977 + 0.03824\,x - 0.02167\,y - 0.0002963\,x^2 - 0.000033\,x\,y - 0.0003667\,y^2 \tag{2}$$

where K_{IC} $(MPa.m^{0.5})$ is the fracture toughness value, x (mm) is the sample thickness, and y (°C) is the test temperatures.

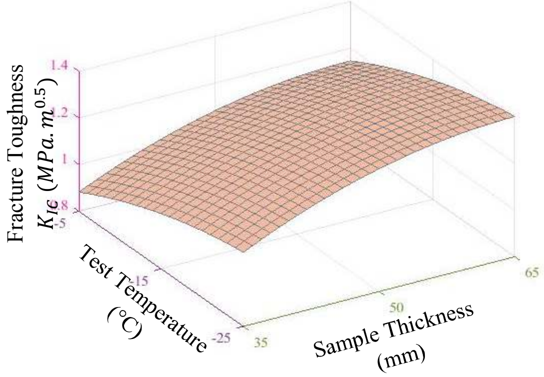

Figure 5. K_{IC} Surface response according to two parameters of temperature and thickness

6. Conclusion

In this study, the effect of two parameters of temperature and specimens thickness on the fracture load, fracture energy and fracture toughness of asphalt mixture was evaluated under mode I loading. The most important results from performed tests are summarized in the following:

- The increase in specimens thickness and the decrease in temperature tend to increase the fracture energy and fracture load. The results show that thickness parameter has more significant effect on the increasing behavior compared to the temperature.
- In general, K_{IC} has been increased about 25% by the increase on specimen thickness at different temperatures and also by the decrease at temperature in different thicknesses.
- The minimum and maximum of K_{IC} have been seen at -5 °C in 35 mm and -25 °C in 65 mm, respectively.
- The K_{IC} obtained from our tests are between 0.89 $MPa.m^{0.5}$ and 1.39 $Pa.m^{0.5}$. Considering values obtained by similar studies, our values are in an acceptable range.
- The results shows that the presented model can provide a good estimate for the values of fracture toughness of prepared asphalt mixtures considering the ranges of temperature and thickness studies in this study.