Effect of Temperature on Flexibility Index Results

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In the quest to assess the effect of temperature, two AC mixes were tested in this study: SMA 4.75 and FG 9.5; SMA is stone mastic asphalt, and FG is fine graded. The fracture properties of the new AC mixes were determined using the SCB test at the following temperatures: -12, 0, and 10 °C. For the two lower temperatures (-12 and 0 °C), a CMOD controlled test was performed. While for the 10°C temperature, the SCB test was performed with an LLD. The reason behind this selection is that at low temperatures, an LLD-controlled test cannot capture the post-peak slope due to the brittle behavior of AC (specimen snaps). The post-peak slope is required for the computation of the Flexibility Index [1].

Materials

The gradations of both AC mixes were designed using the Bailey method and have the following mix design characteristics: Mix 1 – SMA 4.75: SMA with NMAS of 4.75 mm. This mix is composed of a gap-graded aggregate structure with high asphalt content and high mineral filler content. Using a gap-graded structure for the crushed aggregates allows a strong interlock bonding between aggregates, leading to a tough, durable, and deformation-resistant AC mix (less rutting). The aggregates used are primarily composed of quartzite blended with a mix of dolomite and natural sand. The binder used is polymer modified with PG 70-22. Moreover, cellulous fibers were added to the mix to increase film thickness around the aggregates and control the drain down of the asphalt binder.

Mix 2 – FG 9.5: FG with an NMAS of 9.5 mm. For this mix, locally available dolomite and natural sand were mixed with a polymer-modified binder with PG 70-22.

The characteristics of these AC mixes are summarized in Table 1.

Table 1 Mixes Characteristics

HMA Mix	Gradation type	NMAS (mm)	Binder Grade	AC (%)	VMA (%)	VFA (%)
4.75 SMA	SMA	4.75	PG 70-22	7.3	18.5	78.4
9.5 FG	Fine graded	9.5	PG 70-22	5.8	15.2	73.7

Effect of Temperature on Load-Displacement Curve Patterns

The temperature at which the SCB test is performed has a direct impact on the pattern of the load-displacement curve. As shown in Figure 1, the increase in temperature leads to a significant change in the load-displacement curve pattern: an increase in fracture energy, a reduction in peak load and a smoothening of the post-peak slope. The explanation of this phenomenon lays in the viscoelastic theory. The behavior of asphalt binder is directly linked to its temperature. When temperature increases, the asphalt binder becomes softer, leading to a reduction in brittleness of the AC mix. On the other hand, when temperature decreases, the asphalt binder becomes stiffer causing the AC mix to become more brittle.

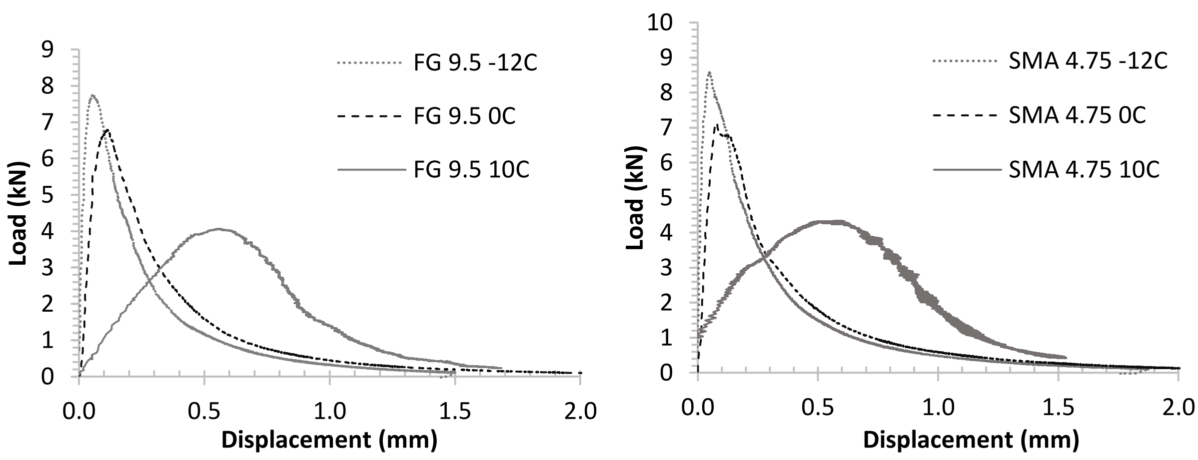
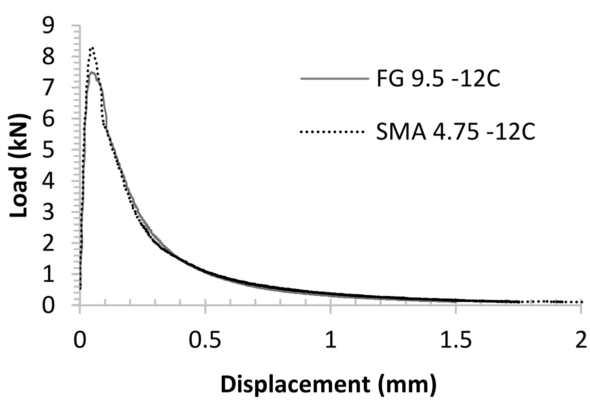


Figure 1 Load-displacement curves for mixes FG 9.5 and SMA 4.75 at -12, 0 and 10°C.

Effect of Temperature on Performance Discrimination

The difference in aggregate type and gradation, NMAS, asphalt content, and the presence of additives are expected to influence the performance of the two AC mixes. Figure 2 shows that the SCB test conducted at a temperature of -12°C is not able to discriminate among the tested AC mixes. The load-displacement curves of SMA 4.75 and FG 9.5 are almost overlapping. Both have the same displacement range, close peak loads, and same post-peak slopes. When the temperature is increased to 10°C, the ability of the test to differentiate between AC mixes increases. At a higher temperature, the load-displacement patterns are more distinct among AC mixes. Fracture energy, secant modulus, displacement range, peak load, and post-peak slope are all affected by the change in temperature, which has also been reported in previous research studies [2, 3].



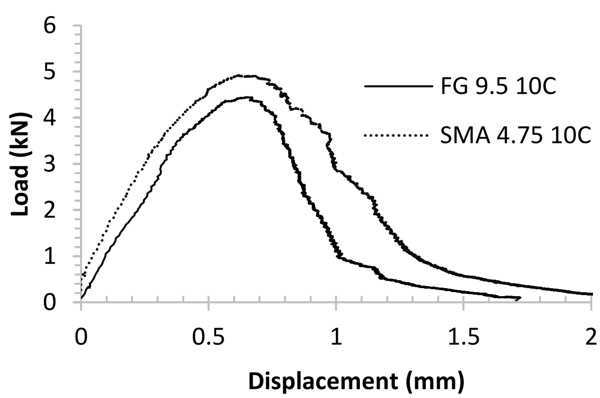


Figure 2 SCB load-displacement curve for mixes FG 9.5 and SMA 4.75: (Left) Load-CMOD curves at -12°C, (Right) Load-LLD curves at 10°C.

Field Performance of SMA 4.75 and FG 9.5 mixes

A field study was performed to better understand the performance of SMA 4.75 and FG 9.5 under more realistic field conditions (load and environment). Two sections with leveling binder (19 mm) and AC wearing surface (31.5 mm) were constructed in Barrington, Illinois. The wearing surfaces were SMA 4.75 and FG 9.5, respectively. The sections were monitored over the course of two years to assess the short and long-term performance of the AC mixes of interest. Field measurements showed that the SMA 4.75 and FG 9.5 perform differently under actual environmental conditions and traffic loading. The rutting and cracking performance of the two mixes were clearly distinguishable. While the SMA mixture displayed higher durability, fracture resistance, and friction, the FG 9.5 mixes had a better rutting performance. More information regarding the findings of this study can be found elsewhere [4]. The outcome of this research corroborates the laboratory testing results by showing that low-temperature SCB does not accurately predict the cracking behavior of AC mixes in the field.

Effect of Temperature on Fracture Energy

As a general trend, it was noticed that the fracture energy increases with increasing temperature (Figure 3). Moreover, the difference in fracture energy between SMA 4.75 and FG 9.5 becomes more extensive as the temperature is raised. The numbers presented in Figure 8 were computed using the average of at least three replicates of SCB test specimens. The amplification in fracture energy difference allows better cracking susceptibility discrimination. At 10°C, the fracture energy range is 402 J/m^2 which is 4.5 times higher than the same range observed under the SCB test at a low temperature (-12°C). Note that the rate of change in fracture energy with temperature is AC mixture-dependent.

It is evident, so far, that both tests may not discriminate between AC mixes at low temperatures, and it is cumbersome to use CMOD extensometer during testing. Given that many of the load-displacement curve characteristics are manifested as testing temperature increased, and DCT testing at in-service temperature is difficult, a new test was developed making use of the aforementioned, Illinois Flexibility Index Test (I-FIT) [1,5-11].

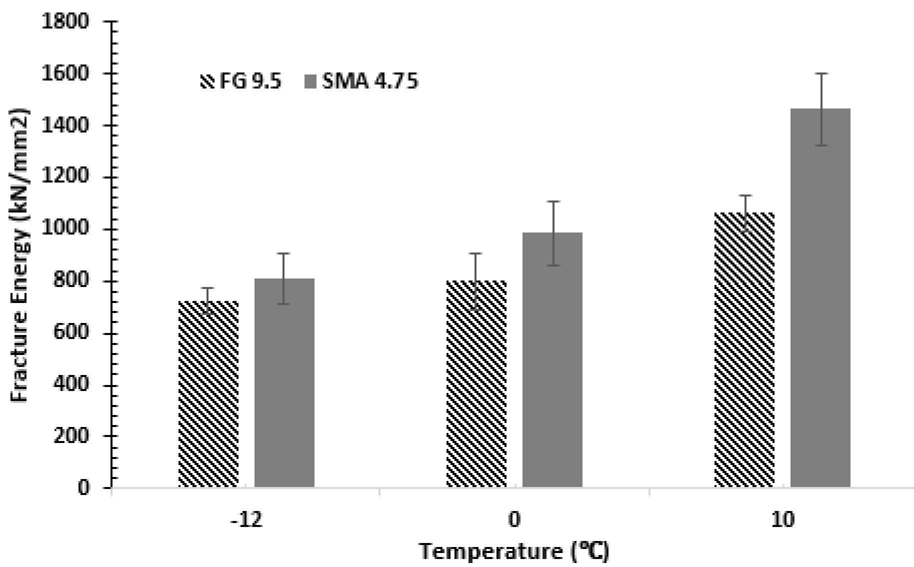


Figure 3 Fracture energy at -12, 0, 10°C for mixes FG 9.5 and SMA 4.75.

Flexibility Index (FI) Results

Fracture energy of a material mainly depends on its load-displacement curve pattern. The maximum load peak (strength) and displacement range (ductility) dictate the fracture energy value of an AC mixture. Hence, this combination may mask the difference between AC mixes since different peak load and displacement range combinations can in some cases provide the same value of fracture energy. To avoid misleading results, flexibility index (FI) was developed by incorporating the fracture energy and a post-peak slope parameter at the inflection point. The FI at in-service temperatures proved its ability to capture the differences in materials and volumetric among AC mixtures better than the single value fracture energy. Figure 4 shows that at -12 and 0°C temperatures, the FI is not able to discriminate between the AC mixes. At a low temperature, the two AC mixes are brittle, which result in relatively similar load peaks and steep slopes. As the temperature increases, the difference in FI becomes more amplified leading to an easier identification of the cracking potential of various mixes. Hence, the I-FIT is performed at 25°C.

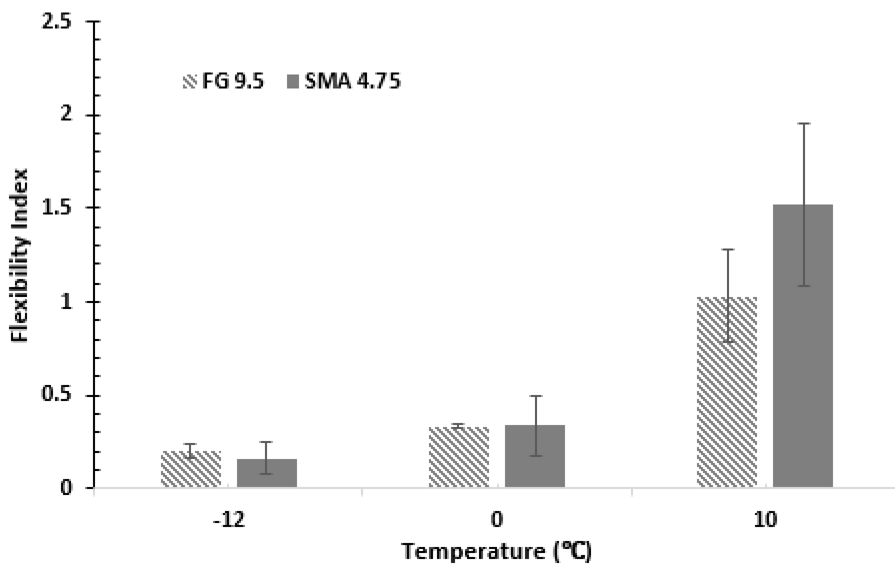


Figure 4 Flexibility index of FG 9.5 and SMA 4.75 at -12, 0, 10°C.

The fracture characteristics of AC mixes are loading rate-dependent, time-dependent, and temperature-dependent. This dependency is primarily due to the viscoelastic, viscoplastic, and viscodamage behavior of AC under applied loading. To appropriately identify the cracking potential of an AC mixture using laboratory testing, both temperature and displacement rate should be carefully selected. This study showed the importance of using relatively higher temperatures when testing SCB specimens but did not consider the effect displacement rate on fracture characterization. This finding is in agreement with the testing condition of the Illinois Flexibility Index Test (I-FIT), developed at the Illinois Center for Transportation (ICT), which consists of a notched semicircular AC specimen tested at room temperature (25°C) and a displacement rate of

50 mm/min [1,5-11]. The primary outcome of this test is the flexibility index (FI), which indicated the cracking susceptibility of AC mixtures. The advantages of testing at 25°C include practicality and lower cost due to the non-necessity of an environmental chamber. Moreover, the displacement rate used provides good repeatability, the ability to differentiate between AC mixes, and it is readily available in testing frames.

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