Impact of Aging on Cracking Behavior of Asphalt Mixtures

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ABSTRACT

Cracking is one of the main distress types in asphalt pavements. A lower stiffness and higher relaxation capability are generally favorable for better resistance of asphalt materials against cracking. Aging causes changes that impact asphalt mixtures properties. Different laboratory conditioning protocols are employed in this research to simulate a range of aging levels in the field. The objective of this study is to evaluate how the viscoelastic, fatigue, and fracture properties of mixtures change as a function of conditioning level. Six plant produced, lab compacted mixtures are evaluated at different aging levels (24 hr. at 135°C, 5 days at 95°C, and 12 days at 95°C). The mixtures use either a PG 58-28 or PG 52-34 virgin binder and contain recycled materials (20% & 30% RAP or RAP/RAS). Comparison between mixtures is conducted by constructing dynamic modulus master curves and Black space diagrams. SVECD fatigue and SCB fracture testing are used to evaluate the fatigue and fracture behavior. The results show the 24 hr. at 135°C and 12 days at 95°C conditioning protocols induce statistically similar changes in linear viscoelastic properties but significantly different cracking performance indices. This indicates that various aging protocols differentially impact the rheological and fracture properties of mixtures.

Keywords: STOA, LTOA, Fatigue Cracking, Thermal Cracking, SVECD, SCB

1. INTRODUCTION

Cracking is a critical distress in asphalt pavements that can result in poor riding quality and shorter pavement service life. There are various factors that affect the cracking potential of asphalt mixtures. Asphalt mixtures undergo aging during production and also over the pavement service life. Aging is an important factor that can change the cracking susceptibility of asphalt materials by increasing the stiffness and decreasing the relaxation capability and ductility. Consequently, the cracking potential of aged mixtures is expected to be higher than that of unaged mixtures. The cracking assessment of asphalt mixtures in short term aged condition in laboratory is a routine practice, however the question remains regarding prediction of the performance of aged asphalt pavements in the field. The accelerated oven aging method helps to simulate the aging in laboratory and evaluate the properties of aged asphalt mixtures.

The main objective of this study is to evaluate how the cracking properties of mixtures evolve with aging. AASHTO R30 is the current standard practice for aging of hot mix asphalt mixtures in the laboratory to simulate both short and long term aging conditions. To simulate short term aging, the pans of loose mix asphalt are placed in a forced-draft oven for 4 hr ± 5 min at a temperature of 275 ± 5° F (135 ± 3° C). STOA material is compacted and then conditioned in a forced-draft oven for 5 days (120 ± 0.5 hr) at 85 ± 3°C to simulate long term aging. It is well accepted that the AASHTO R30 procedure is not sufficient to reflect the mechanical performance of long term aged mixtures in the field [1]. Another issue related to the aging of compacted samples is the aging gradient within specimens in both radial and vertical directions. The aging gradient may result in the increase of variability with changes in shape and size of compacted samples and air void content [1, 2]. This can be minimized by the loose mix aging method.

Several researchers have recommended the long term oven aging of loose mix [3, 4]. The procedure used by the Asphalt Institute recommends loose mix asphalt conditioning for 24 hr at 135°C. This level of conditioning is expected to simulate 7 to 10 years of aging in the field [5]. The recent findings of the NCHRP 09-54 project on long term aging of asphalt mixtures suggests 95°C as an optimal temperature for aging loose mix [1, 6]. The aging time varies with the geographical location of the pavement and should be adjusted based on climate conditions and pavement depth. The Asphalt Institute procedure (24 hr at 135°C on loose mix) and NCHRP recommended 95°C for 5 and 12 days are used in this study. The 12 days at 95°C corresponds to preliminary recommendations of NCHRP 09-54 study for the pavement locations used in this work.

2. MATERIALS AND TESTING

This study includes laboratory testing on six plant mixed, lab compacted recycled mixtures. All mixtures were produced in a drum plant in 2013 and placed in the field as pavement surface layer along NH state route 12 near Westmoreland, NH. The loose mixtures were kept in sealed buckets in the laboratory for fabricating the lab compacted samples. The performance of asphalt mixtures were compared in short term and long term aging conditions. The short term aged specimens were fabricated and tested in 2014, while the conditioning and testing on long term aged specimens were conducted in 2016. Table 1 shows the mixture information and aging combinations evaluated in this study.

TABLE 1 Mixture Types and Aging Levels

Binder PG Grade	NMSA (mm)	%Recycled Binder Replacement (% RAP/ % RAS)	STOA	LTOA		
				5 days, 95°C	12days, 95°C	24hr, 135°C
58-28	12.5	18.9 (18.9/0)	Complex Modulus and Fatigue results only. (No SCB testing)	N/A	✓	✓
		18.5 (7.4/ 11.1)		✓	✓	✓
		28.3 (28.3/ 0)		N/A	✓	✓
52-34	12.5	18.9 (18.9/0)		✓	✓	✓
		18.5 (7.4/ 11.1)		✓	✓	✓
		28.3 (28.3/ 0)		✓	✓	✓

To compare the linear viscoelastic properties of asphalt mixtures at different aging levels, the complex modulus testing was conducted following AASHTO T 342, using an asphalt mixture performance tester (AMPT) machine. The stiffness and relaxation capability of mixtures at different aging levels are compared using the mastercurves obtained from Abatech RHEA® software.

Fatigue cracking behavior of asphalt mixtures is characterized using uniaxial direct tension testing and based on Simplified Viscoelastic Continuum Damage (SVECD) approach, following AASHTO TP 107. The testing temperature for this test is recommended to be 3 degrees colder than the average of virgin binder PG high and low temperatures, but higher testing temperatures were used in this study for the long term aged mixtures. Damage analysis is performed and damage characteristic curves (DCC) are obtained using the models available within Alpha-F software. One of the energy based fatigue failure criteria developed by North Carolina State University is G^R. This parameter is defined as the rate of change of the averaged released pseudo strain energy (per cycle) throughout the entire history of the test, and calculated from Eq. (1).

$$G^R = \frac{\int_0^{N_f} W_C^R}{N_f^2} \tag{1}$$

Where W^R_C is total released pseudo strain energy, and N_f is the number of cycles before failure [7].

To evaluate the fracture characteristics of asphalt mixtures, Semi Circular Bending (SCB) testing was used. The SCB fracture test (AASHTO TP 124) is performed at an intermediate temperature (25°C) and evaluates the resistance of asphalt mixtures to fatigue cracking. The measured data are analyzed using the IFIT software developed by Illinois Center of Transportation (ICT), to calculate the fracture energy and flexibility index (FI) parameters defined by Eqs (2, 3).

$$G_f = \frac{W_f}{t \times a} \tag{2}$$

$$FI = \frac{G_f}{m_{Inflection\ Point}} \tag{3}$$

where W_f is fracture work, t is the thickness of specimen, and a is ligament length. $m_{Inflection\ Point}$ is the slope of the post-peak softening curve at an inflection point near the middle of the post-peak region [8, 9].

3. RESULTS AND DISCUSSION

Examples of dynamic modulus and phase angle master curves for different aging levels are presented in Figure 1; each series represents the average of three replicates for one study mixture (PG 52-34, 12.5 mm, 28.3% RAP). The overall trend is similar for the all mixtures evaluated in this study. The dynamic modulus of asphalt material increases as the aging level increases. The two higher levels of aging (24 hr. at 135°C and 12 days at 95°C) show statistically similar dynamic modulus and phase angle values.

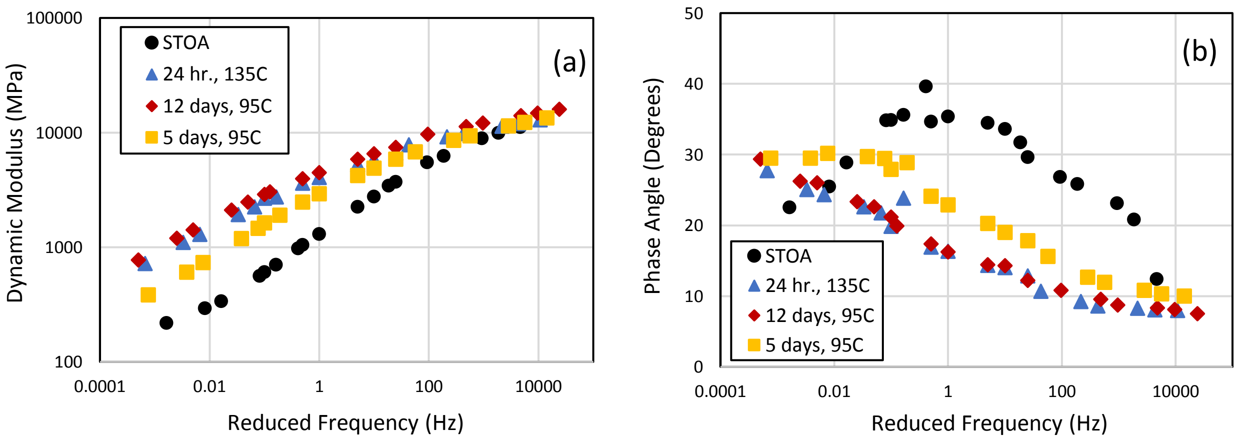

FIGURE 1 Example (a) Dynamic Modulus and (b) Phase Angle Master Curves at 21.1°C

Generally, a lower phase angle value is observed for two high aging levels (24 hr., 135°C and 12 days, 95°C), followed by 5 days at 95°C, and short term aged mixtures. The peak phase angle decreases and occurs at a lower frequency as materials age. Based on the complex modulus testing results, the aged materials show higher stiffness (dynamic modulus) and lower relaxation capability (phase angle), which, in combination, can result in higher cracking susceptibility.

Figure 2 shows the ratio of complex modulus for 12 days aged mixtures to complex modulus of short term aged mixtures for different frequencies. The 18.9% RAP, 28.3% RAP, and 18.5% RAP/RAS mixtures are labelled as 20% RAP and 30% RAP, and 20% RAP/RAS respectively. The |E*| ratio varies approximately from 1 to 6, with the lower ratio at very high and very low frequencies, and the highest ratio around 0.01 Hz. Generally, the softer binder (PG 52-34) shows a larger increase in modulus with aging than the PG 52-28 binder. The stiffness of RAP/RAS mixtures increases more than the stiffness of RAP only mixtures. One explanation for this could be that less blending occurs with the RAS materials and therefore the difference is due to the aging of the virgin binder. The impact of RAP level shows different trends with the two virgin binders, which may be confounded by differences in air void levels in the STOA test specimens. Similar trends were observed for the complex modulus ratios with 5 days and 24 hr aging levels.

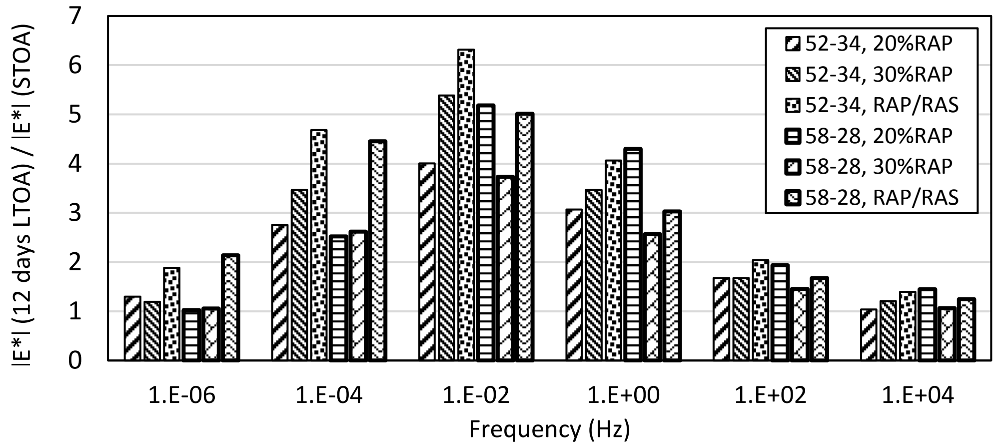

FIGURE 2 The Ratio of |E*| (12 days LTOA) to |E*| (STOA)

The flexibility index (FI) parameter, which is the average of 3 to 4 replicates for each mixture, is shown in Figure 3. The error bars show one standard deviation interval. The FI values of 5 days aged mixtures are higher than 24 hr and 12 days aged FI values for all mixtures. 12 days aging makes a significant difference in FI values as compared with 5 days aged mixtures, except for the PG 52-34, 20% RAP mixture. The FI for most of the 12 days aged mixtures are higher than that of 24 hr aged mixtures, but PG 52-34, 30% RAP, 24 hr. aged mixture shows a much higher FI value than 12 days aged one. Although, the linear viscoelastic characteristics of 12 days and 24 hr aged mixtures are similar, the fracture properties (FI index) of these mixtures do not follow a consistent trend.

The flexibility index of 5 days aged mixtures does not seem to be sensitive to the recycled materials content, while there is a statistically significant decrease in the FI parameter of 12 aged mixtures with 30% RAP over 20% RAP. No specific trend is observed between PG 58-28 and PG 52-34 mixtures.

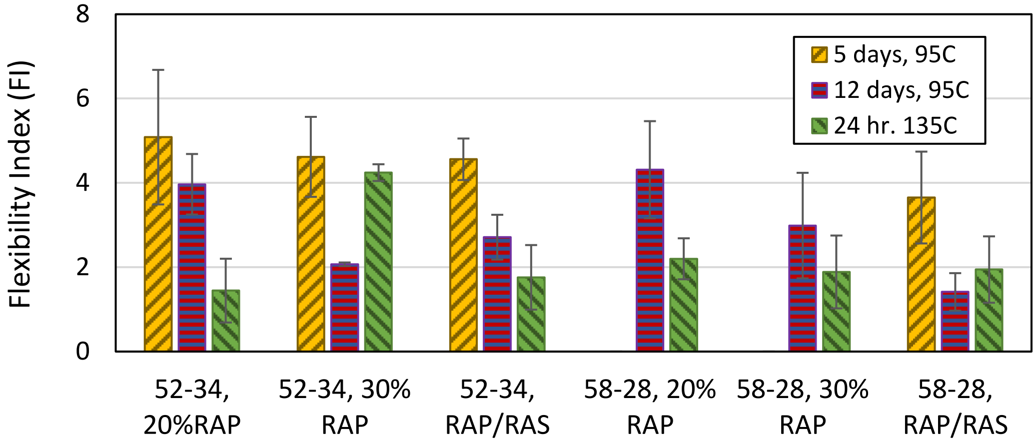

FIGURE 3 Average Flexibility Index Values (SCB Testing)

Figure 4 shows the damage characteristic curves (DCC) and fatigue failure criterion (G^R) diagrams for 20% RAP and 20%RAP/RAS mixtures. Gnerally, the DCC curves are the average of at least three replicates and show how the material integrity changes as damage is growing in the specimen during the test. The effect of aging on the fatigue characteristics of mixtures with PG 58-28 binder seems to be higher than that of PG 52-34 mixtures. The DCC curves of all the mixtures with PG 58-28 binder that are subjected to 24 hr., 135ºC aging level dropped significantly. Another observation is that in most cases, the last point of DCC curves indicating pseudo stiffness in failure (C_F) increases with higher percentages of RAP or level of aging.

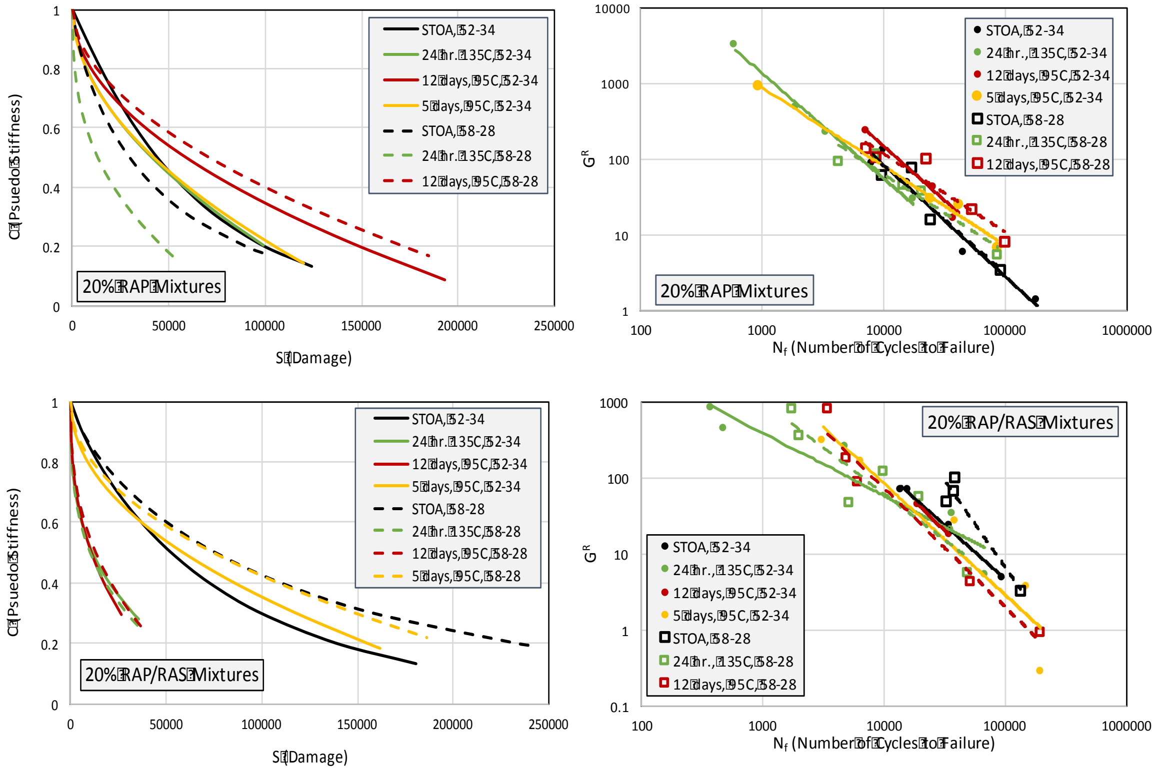

FIGURE 4 Damage Characteristic Curves and Fatigue Failure Critrion

For RAP/RAS mixtures, the integrity of 5 days aged materials is very similar to short term aged mixtures, while at the higher levels of aging (24 hr at 135ºC and 12 days at 95ºC) the psuedo stiffness (C) value decreases significantly. It indicates that the RAP/RAS mixtures are probably more prone to fatigue cracking at higher levels of aging as compared with RAP only mixtures.

Generally, the higher G^R values at the same number of cycles (N_f) indicate better fatigue behavior. The fatigue failure criterion does not seem to be very sensitive to aging for these mixtures, since the G^R-N_f diagrams of different aging levels are very close and the distribution of points is scattered. Comparison of fatigue and fracture (SCB) results shows they do not follow a consistent trend, which is in agreement with the results of another study [10].

4. SUMMARY AND CONCLUSION

The major objective of the study was to investigate the effect of aging on the cracking behaviour of asphalt mixtures. This study includes six surface course mixtures with different binder grades and recycled materials content, evaluated by complex modulus, SCB fracture, and SVECD fatigue cracking testing. The following conclusions can be drawn from the results of the testing and analysis:

- As asphalt materials age, the linear viscoelastic characteristics change with the increase of stiffness and decreases of relaxation capability.
- The stiffness of RAP/RAS mixtures increase more than that of 30% and 20% RAP mixtures, respectively, especially in low frequencies. This difference varies from minimum values in very high and very low frequencies to maximum values around 0.01 Hz at a reference temperature of 21.1ºC.
- The fracture properties of asphalt mixtures become worse as aging level increases from 5 days, 95ºC to 12 days, 95ºC, but there is not a consistent trend between the Flexibility Index of 12 days 95ºC and 24 hr 135ºC. The variation of flexibility index by type and amount of recycled materials is greater for higher aging levels (12 days, 95ºC and 24 hr 135ºC) than 5 days aging.
- High levels of aging (24 hr at 135ºC and 12 days at 95ºC) contribute to a significant reduction in psuedo stiffness of RAP/RAS mixtures, indicating the higher rate of damage growth that can result in more craking potential.
- The linear viscoelastic properties of mixtures with 24 hr at 135ºC and 12 days at 95ºC aging are very similar, but the fracture and fatigue characteristics of these mixtures are different, indicating the LVE parameters are not sufficient to predict the cracking behavior of asphalt mixtures over the service lives of pavement.

Future work and analysis is planned to investigate the correlation between the viscoelastic properties, fracture, and fatigue cracking characteristics of aged asphalt mixtures and their relationship with the cracking performance of field cored samples and field performance over time. Also, additional mixtures are being included in this study to obtain a wider range of information about the effect of aging on mixture properties and develop a database for future rsearch.

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