Evaluation of Viscoelastic and Fracture Properties of Asphalt Mixtures with Long-Term Laboratory Conditioning

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Abstract

Aging affects the properties of asphalt mixtures in different ways; increase of stiffness, decrease of relaxation capability, and the increase of brittleness, resulting in changes in cracking behavior of asphalt mixtures. In this study, ten plant produced, lab compacted mixtures with various compositions (recycled materials, binder grades, binder source, and NMAS) are evaluated at different long term aging levels (24 hour at 135°C, 5 days at 95°C, and 12 days at 95°C aging on loose mix and 5 days at 85°C on compacted specimens). The asphalt mixture linear viscoelastic properties ($|E^*|$ and δ) and master curve shape parameters measured from complex modulus testing and fracture properties (measured from DCT and SCB fracture testing) are compared at different levels of aging. The results indicate that the mixture exposure time to aging is proportional to the dynamic modulus and phase angle changes. Generally, the fracture parameters of mixtures become worse when aging level changes from 5 to 12 days aging. In spite of the similar viscoelastic properties, the mixtures with 24 hour at 135°C and 12 days at 95°C aging do not show similar fracture parameters.

Keywords: Long term aging, Fracture, Viscoelastic Properties, DCT, SCB

Introduction

Cracking has always been a challenging issue for asphalt pavements that negatively impacts the ride quality and pavement service life. Typically, cracking susceptibility of asphalt mixtures change over the time as asphalt materials age. Asphalt materials undergo aging during production, construction, and over the service life of the pavement. The aging process is the change of binder chemistry due to two primary processes: volatilization and oxidation. Volatilization is the evaporation of lighter fractions (hydrocarbons) resulting in the increase of asphalt specific gravity. Volatilization occurs primarily during the production and construction stages where the binder temperature is very high (about 150° C). The volatilization rate increases dramatically with the increase of temperature [1].

Oxidation occurs due to the chemical reaction of asphalt hydrocarbons with oxygen that occur over its service life. The interaction of hydrocarbons with hydroatoms like oxygen causes an imbalance in electrochemical forces and the polarity increases in the binder molecules. More polarity results in stronger intermolecular forces, and accordingly, the elastic modulus and viscosity of the asphalt increase. It is well known that the ambient temperature has a significant effect on aging rate. Other environmental conditions (e.g. pressure and moisture), traffic loading and mix volumetrics also effect the aging process.

Aging causes physical property changes to asphalt mixtures by increasing stiffness and brittleness and decreasing relaxation capability. Consequently, the cracking resistance of aged mixtures is expected to be lower than that of unaged mixtures. Considering the importance of performance-based design methodologies, the evaluation of fatigue and thermal cracking properties of aged asphalt mixtures is desired during the mix design stage. To this aim, the aging of asphalt materials must be simulated in the laboratory. Limited laboratory conditioning methods directly applicable to the methods used in this study are presented here, but more comprehensive literature review is presented elsewhere [2].

1. The current standard to simulate short and long term aging of asphalt mixtures is AASHTO R30. In this standard practice, the loose mix asphalt is placed in a forced-draft oven for 4 hours at a temperature of 275°F (135°C) to simulate short term aging [3]. For long term aging, short term aged mixtures are compacted (following AASHTO T 312) into a specimen that is then conditioned in a forced-draft oven for 5 days at 85°C. Studies have shown that this laboratory aging method only simulates 5 to 10 years of field aging [4]. Only one conditioning time and temperature is considered for all locations and climate conditions [4].
2. The Asphalt Institute procedure proposed by Blankenship et al. recommends loose mix asphalt conditioning in an oven for 24 hours at 135°C, [5]. This level of conditioning is expected to simulate 7 to 10 years of aging in the field. Braham et al. suggested that this level of aging might be slightly conservative for fracture evaluation of asphalt mixtures [6].
3. The recent findings of the NCHRP 09-54 project on long-term aging of asphalt mixtures for performance evaluation suggests the aging of loose mix asphalt at 95°C for various times depending upon the climatic location of the pavement to be simulated [7]. These findings are based on temperature conditioning of asphalt for both compacted and loose mix with and without pressure. Volumetric, stiffness and fatigue properties of the mixtures were compared. Oven aging on loose mix asphalt was recommended because of the uniformity of aging gradient in the final test specimen. Various research indicates that a conditioning temperature above 100^{o}C impacts binder chemistry and differences in the

response of the mixtures to damage [8&9]. Yousefi Rad et al. recommended the conditioning temperature of 95°C as an optimal temperature for aging of loose mix asphalt [10]. The conditioning time should be adjusted based on climate and depth in the pavement; for example, their results show 8.2 days aging of loose mix at 95°C can match 17 years of aging for the top 6 mm of a pavement in Marathon County, WI in terms of binder rheology.

The objective of this study is to evaluate how the viscoelastic and fracture properties of asphalt mixtures change as a function of conditioning level.

Mixtures and Materials

This study includes testing on nine different recycled mixtures and one virgin mixture. Table 1 shows the mixtures evaluated and the combinations of aging levels and testing conducted for each mixture. Insufficient materials were available for a full factorial experiment. Letters in the cells indicate the testing conducted at each of the mixture-aging combinations: All tests, only Complex modulus tests, and No tests conducted. In the results and discussion section, 18.9% RAP, and 28.3% and 31.3% RAP mixtures are labelled as 20% RAP and 30% RAP for simplicity. The mixtures containing both RAP and RAS are labelled as RAP/RAS mixtures.

TABLE 1 Summary of Mixtures and Testing Conducted at Different Aging Levels

Binder PG Grade	NMAS (mm)	%Total Binder Replacement (% RAP/ % RAS)	LTOA			
			5 days 85°C Compacted	24 hr 135°C Loose	12 days 95°C Loose	5 days 95°C Loose
76-22	9.5	0	N	A	A	C
58-28	12.5	18.9 (18.9/0)	C	A	A	A
	12.5	18.5 (7.4/ 11.1)	N	A	A	A
	12.5	28.3 (28.3/ 0)	C	A	A	A
	19	20.4 (8.2/ 12.2)	N	A	A	A
52-34	12.5	18.9 (18.9/0)	C	A	A	A
	12.5	18.5 (7.4/ 11.1)	N	A	A	A
	12.5	28.3 (28.3/ 0)	C	A	A	A
	19	20.4 (8.2/ 12.2)	N	A	A	N
	19	31.3 (31.3/ 0)	N	A	A	N

A (Complex modulus, DCT, and SCB testing), C (only Complex modulus), N (No test)

Methodology

Aging

The asphalt materials (both loose mix and compacted specimens) were conditioned in ovens for long-term aging. The aging of compacted samples was performed following AASHTO R-30. Compacted specimens were cored and trimmed to final test specimen dimensions and wrapped in wire mesh with clamps to prevent any changes in the shape of the specimens during aging.

Three different conditioning protocols for loose mix asphalt were evaluated in this study:

- 24 hours at 135°C
- 12 days at 95°C

- 5 days at 95°C

The 24 hours at 135°C follows the Asphalt Institute procedure. The selection of two other aging levels is based on preliminary recommendations from the NCHRP 09-54 project [10]. Based on the mixtures used in this study, 12 days at 95°C is selected to match with 24 hours at 135°C, and 5 days at 95°C is considered as intermediate aging level evaluated to determine evolution of properties with aging duration.

The loose mix asphalt was spread in steel pans at an approximate depth of 1 inch. The materials were stirred every other day and the pans were rotated around the oven to obtain a consistent aging condition in all materials. The materials were reheated at 135°C for 2 hours before compaction to achieve final test specimens with air void contents of 6 ± 0.5%.

Testing Methods

The complex modulus testing was conducted following AASHTO T 342 using an asphalt mixture performance tester (AMPT). The raw data were analyzed using Abatech RHEA® software. Dynamic modulus and phase angle master curves were constructed based on the time-temperature superposition principle.

Two common testing methods to characterize the fracture behavior of asphalt materials in laboratory were used in this study: Disc Shaped Compact Tension (DCT) and Illinois Flexibility Index using Semi Circular Bending (SCB) testing. The asphalt mixture materials follow a quasi-brittle behavior under the fracture process. The typical load displacement curve obtained from both tests is shown in Figure 1.

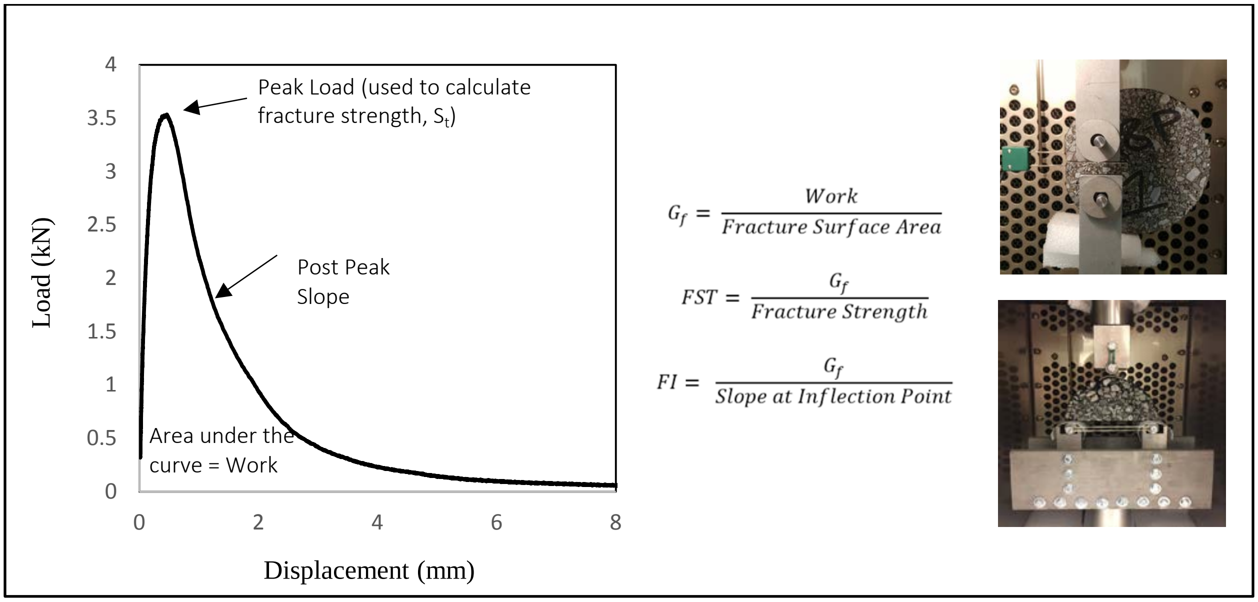


FIGURE 1 Typical Load-Displacement Curve of Fracture Tests

The DCT test (ASTM D 7313) was conducted to compare the thermal cracking behavior of the various mixtures and aging levels. The appropriate low temperature PG grade for the recycled mixtures was determined to be -28°C using LTPPBind software based on typical construction location for these mixtures. DCT testing was performed at -18°C (10°C warmer than low temperature PG grade requirement for the pavement location) for these mixtures and -12°C for the virgin mixture. This test was developed to measure the fracture energy of circular notched specimens under a tension load, which provides an oriented crack propagation along the notch. The fracture work is defined as the area under the load versus Crack Mouth Opening Displacement (CMOD) curve. Fracture energy is determined by normalizing the fracture work by specimen thickness and ligament length. The fracture energy is the amount of energy required to develop a unit surface fracture of the asphalt mixture. The fracture strain tolerance (FST), a new parameter suggested by Zhu et al. (2017), is calculated by normalizing the fracture energy of mixture with the fracture strength (G_f/S_f), [11].

The SCB fracture test (AASHTO TP 124) is performed at an intermediate temperature (25ºC) and evaluates the resistance of asphalt mixtures to fatigue cracking. The load is applied to a notched semi-circular specimen at a displacement rate of 50 mm/min. The crack propagates along the notch in the middle of the specimen. 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 equations 1 & 2.

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

(1)

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

(2)

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.

Results and Discussion

Linear Viscoelastic Parameters

Example results of dynamic modulus and phase angle master curves for different aging levels are presented as the average of three replicates for one mixture (PG 52-34, 12.5 mm, 28.3% RAP) in Figure 2. The overall trend is similar for all mixtures evaluated in this study: as the asphalt materials age the stiffness (|E*|) increases while the relaxation capability of mixtures, as represented by phase angle (δ), decreases. Statistical testing (t-test) was conducted for dynamic modulus and phase angle results at each temperature and frequency combination using the measured data obtained from 3 replicates of each mixture. With a confidence level of 95%, there is a significant difference between |E*| and δ of STOA mixtures with all levels of long term aging. Statistical significance testing also indicate neither dynamic modulus nor phase angle show a statistical difference between 24 hour and 12 days aged mixtures. Also, two shorter levels of aging (5 days on loose mix and 5 days on compacted samples) are not statistically different. It should be mentioned that this comparison was conducted for only four available mixtures. Comparing 12 days and 5 days aging levels, there is a significant difference for all mixtures, except the two 19 mm, PG 52-34 mixtures.

One interesting observation is that the peak phase angle value moves down and left (lower frequencies) as materials age, so that for the two high levels of aging (24 hour and 12 days) the peak phase angle was not measured within the standard testing temperatures (4.4, 21.1, and 37.8°C) and frequencies (25, 10, 5, 1, 0.5, and 0.1 Hz). To capture the peak point for these two levels of aging, the complex modulus testing also included 0.01 Hz at 37.8°C test in addition to standard frequencies and temperatures.

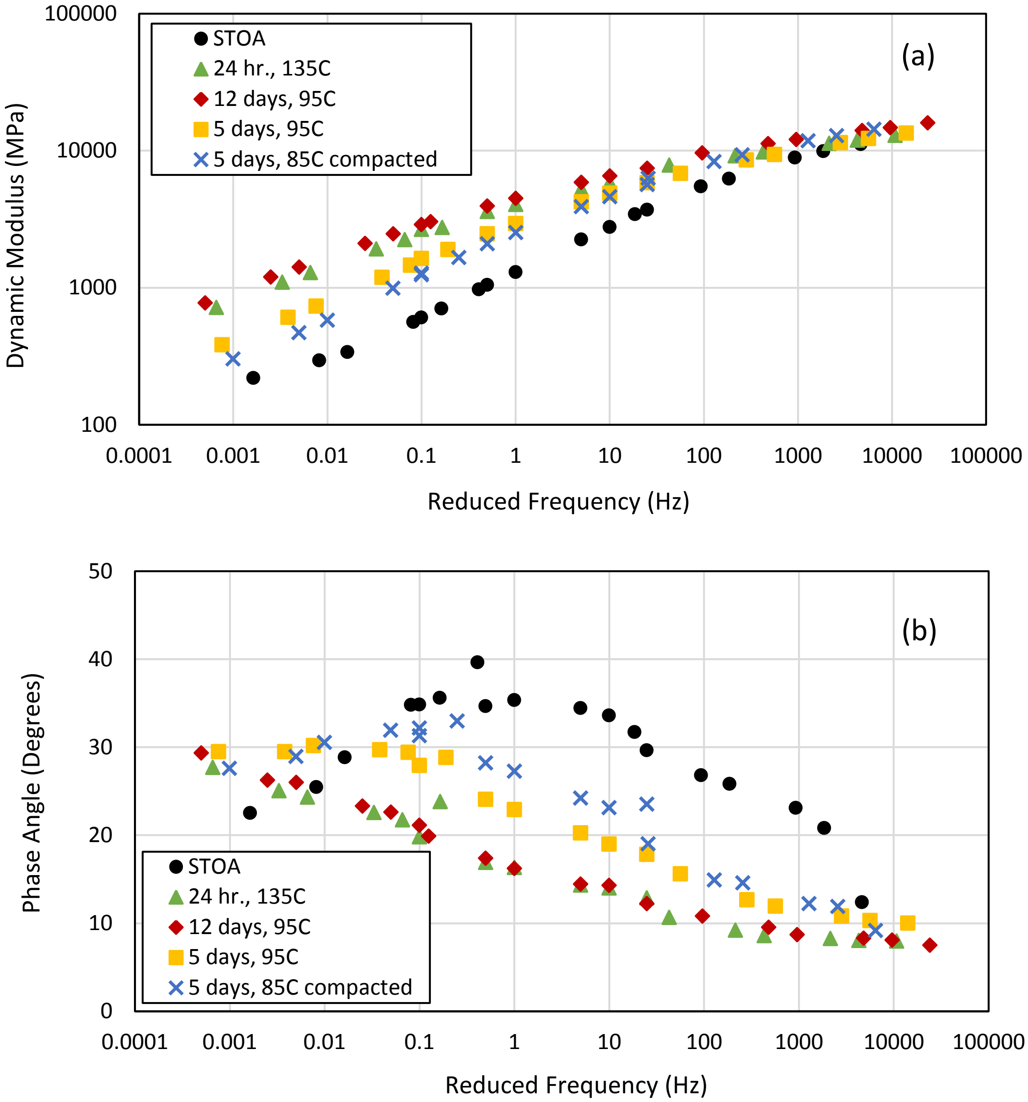
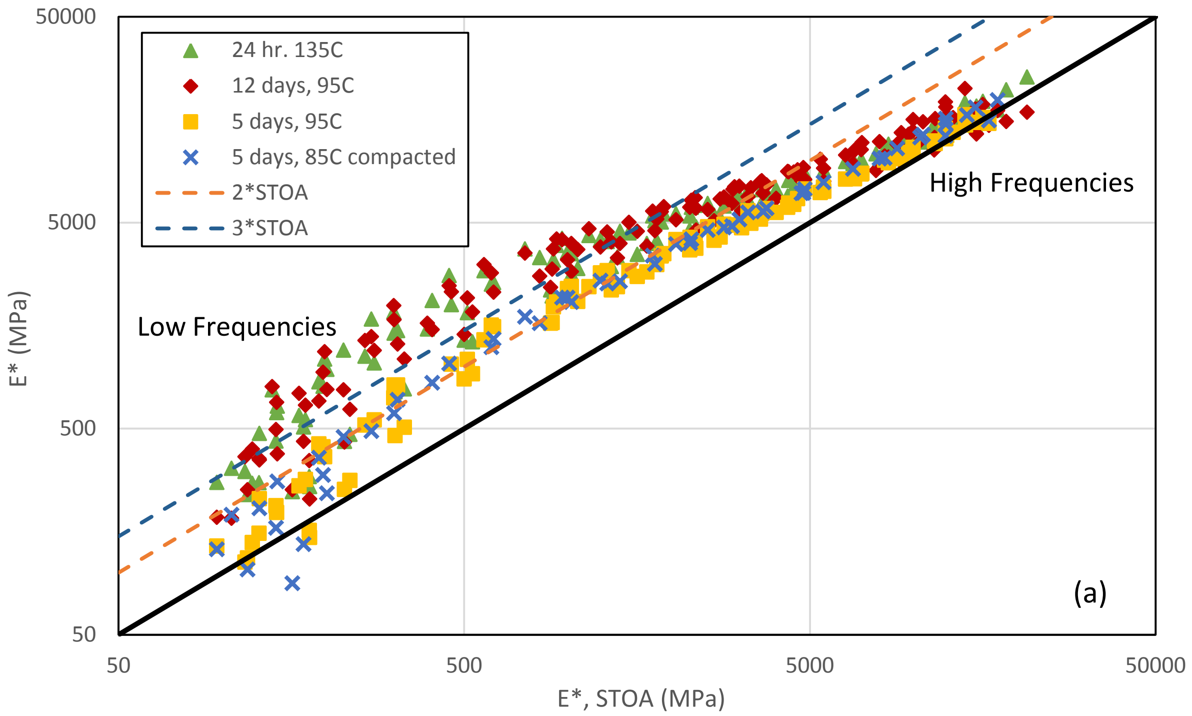


FIGURE 2 Example (a) Dynamic Modulus and (b) Phase Angle Master Curves for Sample Mixture (PG 52-34, 12.5 mm, 28.3% RAP) at Different Aging Levels (Reference Temperature 21.1°C)

Figure 3 compares the average dynamic modulus and average phase angle master curves (in the frequency range of 10^{-5} to 10^{5} Hz) at different long term aging levels versus short term aging values for all of the mixtures evaluated in this study. As expected, all LTOA mixtures have higher dynamic modulus than STOA mixtures. This shows the clear difference between the two intermediate aging levels and the two longer term aging levels, and the similarities of the two long term aging levels at the intermediate frequencies. At the very low and high frequencies, the |E*| of aged mixtures becomes closer to the line of equality, while the difference is greater at intermediate frequencies. Lines representing double and triple the $|E^*|_{(STOA)}$ values are drawn in Figure 4a for added perspective. At frequencies higher than 10 Hz, the dynamic modulus of long term aged mixtures are less than twice the $|E^*|_{(STOA)}$, while at frequencies around 0.01 Hz, the dynamic modulus of long term aged mixtures increase to as high as six times the dynamic modulus of short term aged condition. The reason is that the response of asphalt mixtures at very high frequencies is dominated by elastic behavior which appears to have not been as impacted by long term aging.

The phase angle values of all LTOA mixtures are lower than those of STOA mixture at low and intermediate temperature, which is expected as the relaxation capabilities of mixtures reduce with long-term aging. As shown in Figure 2b, a horizontal shift is observed in phase angle master curves as the aging level increases. At the lower frequencies, the phase angle of STOA mixtures begins to decrease after the inflection point, while the phase angle values of LTOA mixtures are still increasing. At the frequencies lower than the intersection point of STOA and LTOA master curves, the phase angle of STOA mixtures are lower than those of LTOA mixtures (as shown in Figure 3b). As the aging level increases, two curves intersect at a lower frequency. Although it changes from one mixture to another, the longer aged mixtures intersect with STOA mixtures master curves between 0.001 to 0.01 Hz. The intersection of intermediate aged and short term aged mixtures is between 0.01 to 0.1 Hz. At the frequencies lower than these values, the phase angle of LTOA mixtures are higher than phase angle of STOA mixtures.



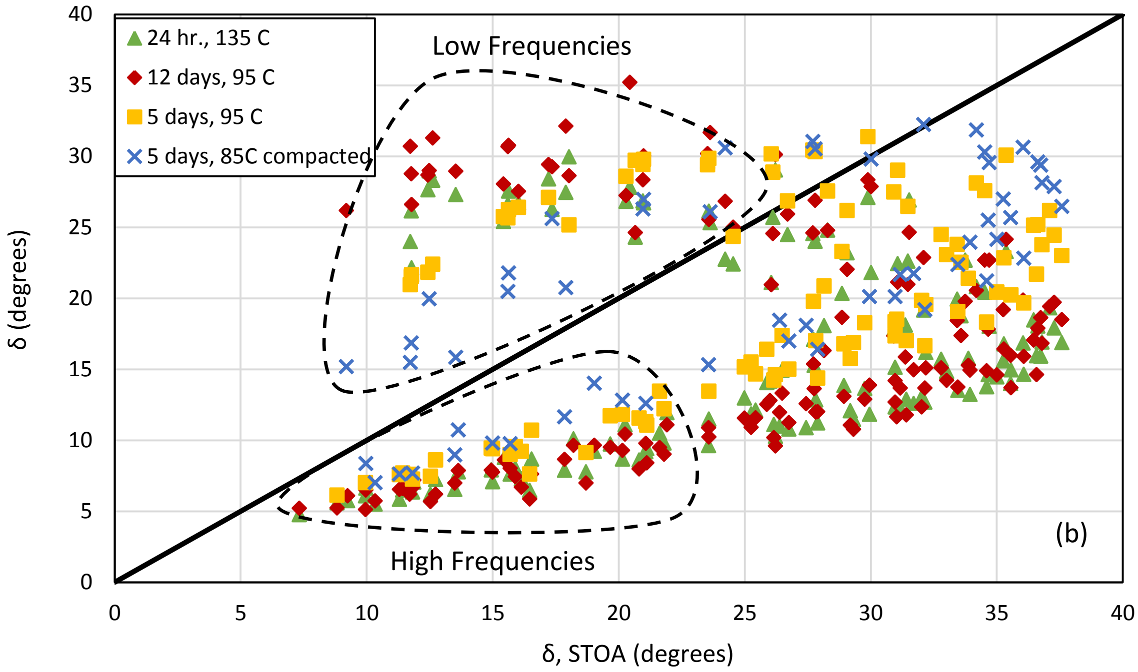


FIGURE 3 LVE Properties a) Dynamic Modulus, b) Phase Angle of LTOA Mixtures versus STOA Mixtures for Different Mixtures

To capture the combination of stiffness and relaxation capability of mixtures in a single plot, Black space diagrams are shown in Figure 4. The figure shows how Black space curves move with additional amount of aging. The inflection point moves to the bottom left side as more aging occurs. The observations in Black space diagram can be used to estimate thermal cracking susceptibility of asphalt mixtures. Generally, a mixture with higher stiffness at a constant phase angle is expected to incur greater thermal stress values. If the relaxation capability (phase angle) of this mixture is lower, the mixture relieves the thermal stress at a lower rate, resulting in higher thermal cracking potential. In Figure 4, higher phase angle for STOA with decreasing phase angle values are seen for STOA condition as compared to long term aged condition at constant value of stiffness (|E*|). This indicates that even for same level of thermal stress, relaxation capabilities of asphalt mixtures would diminish with increasing aging levels. Thus, aged mixtures would be more prone to cracking at a lower cooling rate than short term aged mixtures.

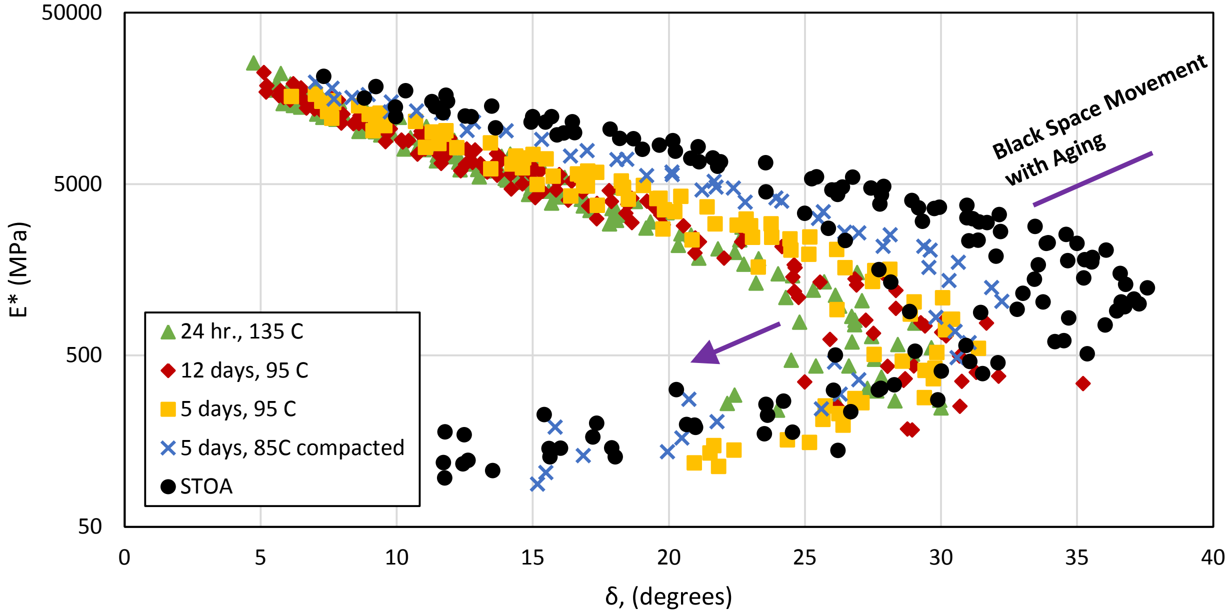


FIGURE 4 Black Space Diagrams of Different Aging Levels

Generally, a standard or generalized sigmoidal model is used to fit the dynamic modulus master curve. In this study, the standard sigmoidal model (Equation 3) is employed:

$$\log|E^*| = \delta + \frac{\alpha}{1+e^{\beta+\gamma\log(\omega)}} \qquad (3)$$

where $|E^*|$ is dynamic modulus, ω is frequency, and δ, α, β, and γ are the fit coefficients that describe the shape of dynamic modulus master curve. As the asphalt materials age, the shape of master curve changes, resulting in a variation in fit coefficients. Accordingly, these coefficients can be the indicators of aging level. The α and δ parameters are related to the equilibrium modulus (lower asymptote) and glassy modulus (upper asymptote) of master curve, respectively. The γ value controls the width of relaxation spectra, and the frequency of the inflection point can be calculated from $10^{-\beta/\gamma}$. As the asphalt material ages, the $|E^*|$ master curve tends to flatten and the inflection point is shifts to lower frequencies [12].

The inflection point parameter ($-\beta/\gamma$) versus relaxation spectra width parameter (γ) plot for mixtures (Figure 5a) is similar in concept to a crossover frequency versus rheological index (R value) plot for binders. The $-\beta/\gamma$ parameter decreases and γ increases, moving points further towards the lower right as more aging occurs. The dashed lines connecting the points at different aging levels are drawn for three mixtures to show the trend from STOA to higher levels of aging. The parameter $-\beta/\gamma$ for all the short term aged mixtures (except virgin mix) is about zero. This parameter for 5 days compacted and 5 days loose aged mixtures varies between -1.1 to -1.5, and -2 to -2.9, respectively, while the variation of $-\beta/\gamma$ for two more severely aged mixtures (24 hour and 12 days) is greater. There is a gap between $-\beta/\gamma$ values of 24 hour aged mixtures which splits the mixtures into two groups. All the PG 52-34, 24 hour aged mixtures have higher $-\beta/\gamma$ than PG 58-28 mixtures, indicating less impact from aging on the viscoelastic properties for these mixtures. As a hypothesis, the severe conditioning of 135°C in a short duration (24 hours) might have different effects on mixtures with different binder grades than 12 days aging at the lower temperature. It should be noted that the results of binder testing on extracted and recovered binders from short term aged mixtures showed elevated zinc levels in two 19 mm mixtures with PG 52-34 binder, indicating that re-refined engine oil bottoms (REOB) may have been used in the production of the virgin binder. One of the concerns about using REOB in asphalt mixtures is that it might increase the aging of binder [13].

A Lorentzian equation (Equation 4) has been shown to accurately model the phase angle master curve [14] and is used in this study.

$$\delta = \frac{a.b^2}{[(\log(\omega) - c)^2 + b^2]} \tag{4}$$

where δ is phase angle (degree), ω is frequency (Hz), and a, b, and c are the fit coefficients as follows: "a" shows the peak value, "b" controls the width of transition, and "c" is related to the horizontal position of the peak point. As the testing results show (Figure 2b), the phase angle master curves shift vertically and horizontally with different aging conditions. Therefore, the variation of vertical position of peak (a) and the parameter related to horizontal position of peak (c) were selected for aging evaluation and are designated as "vertical peak" and "horizontal peak", respectively. Figure 5b shows how both vertical and horizontal peak values decrease with increased aging level, moving the points towards the bottom left of the plot. The plot can be an indicator of the relaxation capability of asphalt mixtures. The mixtures with higher horizontal and vertical peak values are expected to have higher relaxation capability and better fatigue and fracture behavior. Similar to what was observed with the dynamic modulus coefficients, for 24 hour aging, PG 52-34 mixtures (except PG 52-34, 12.5 mm, RAP/RAS) are separate from PG 58-28 mixtures with a higher horizontal peak value, shown with two circles in Figure 5a. The mixtures containing REOB (two PG 52-34, 19 mm mixtures) show lower vertical peak (a) values in all levels of aging. However, the decrease of horizontal peak (c) for these mixtures was less than the other mixtures.

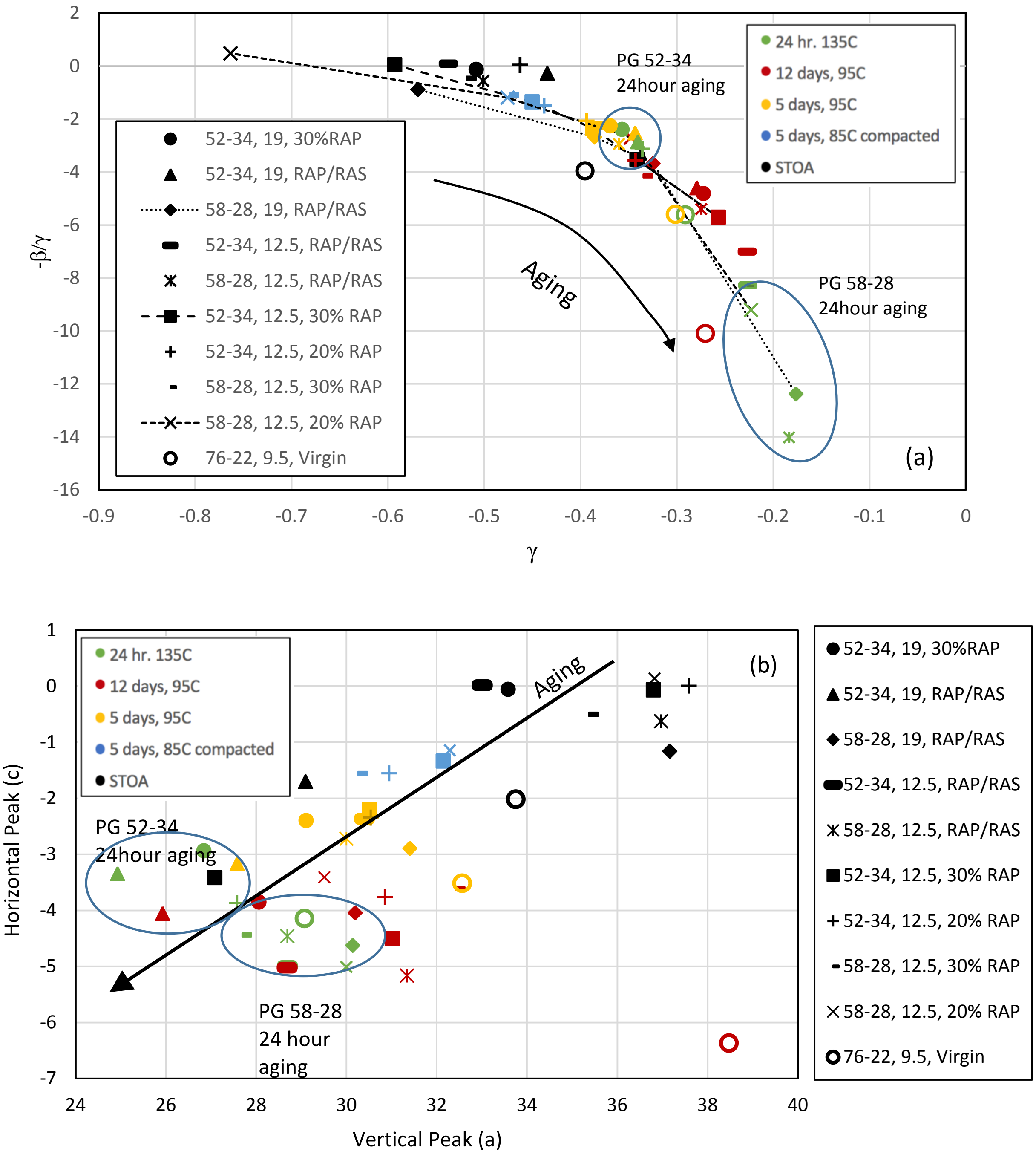


FIGURE 5 Shape Parameters: a) Variation of Dynamic Modulus Master Curve parameter b) Variation of Phase Angle Master Curve Parameters with Aging

Mensching et al. [12] developed a parameter to evaluate the cracking performance of asphalt mixture in the format of the binder Glover-Rowe parameter ($\frac{|E^*|\cos\delta^2}{\sin\delta}$). In this study, the parameter is calculated at the temperature-frequency combination of 15°C-0.005 rad/s to be consistent with the binder Glover-Rowe parameter. The ratio of mixture G-R parameter in LTOA condition to the STOA condition is presented in Figure 6. As expected, the mixture G-R parameter increases as the level of aging changes from short term to intermediate and then to high aging levels, indicating higher susceptibility to cracking. There is a substantial increase in mixture G-R ratio when aging level increases from 5 days to 12 days at the same temperature. The intermediate aging levels increase the mixture G-R parameter from 1 to 3 times, but this ratio is from 3 to more than 7 for two high aging levels. This ratio is smaller for 19 mm, PG 52-34 mixtures (mixtures with REOB) and agrees with the variation of horizontal peak in Figure 6b.

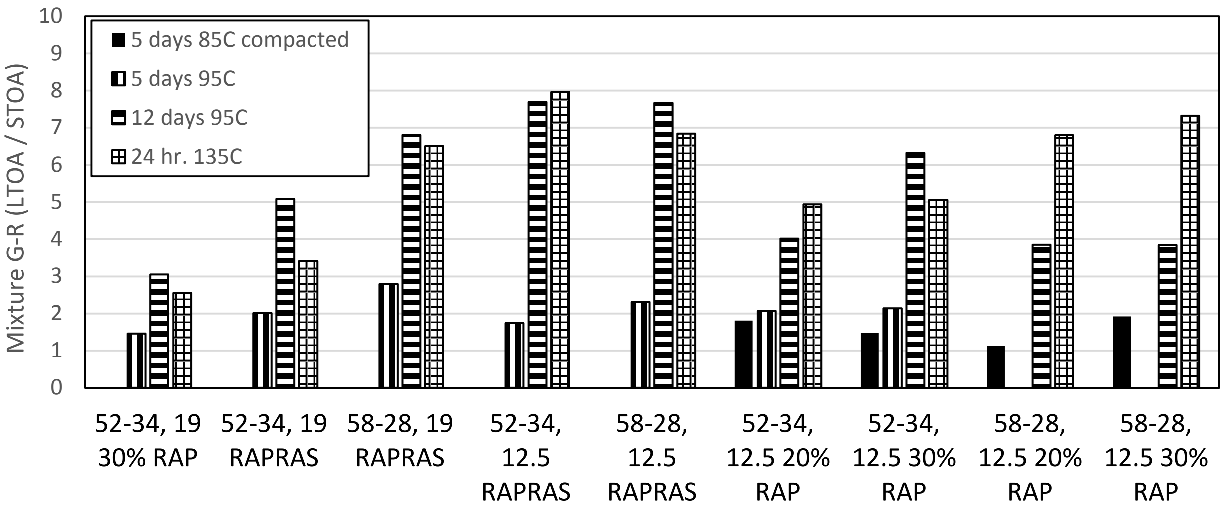


FIGURE 6 Ratio of Mixture G-R_{LTOA} / Mixture G-R_{STOA} (15°C and 0.005 rad/sec)

Fracture Parameters

The results of DCT and SCB fracture testing is presented and discussed in this section. Figure 7 shows the average fracture energy and fracture strain tolerance for the various mixtures at different aging levels. The error bars show the standard deviation of three replicates tested for each mixture. A threshold value of 400 J/m^2 for fracture energy of DCT has been proposed by previous researchers [15,16] for short-term aged mixtures and is shown for visual comparison. Most of the high aged mixtures have the fracture energies less than this limit. There is not a significant difference between the fracture parameters of intermediate and high aging levels for two PG 52-34, 19 mm mixtures (with REOB). This agrees with the mixture G-R and phase angle shape parameters, indicating that the LVE and fracture properties of these mixtures do not increase much with aging. The trend of fracture strain tolerance (FST) is similar to fracture energy for these mixtures. For all the 12.5 mm only RAP mixtures, the trend is that both G_f and FST decrease when aging level changes from 5 days to 12 days, and 24 hour, while for the RAP/RAS mixtures, 24 hour mixtures show better fracture parameters than 12 days aged mixtures. The 24 hour aging level seems to be less detrimental to fracture energy than 12 days aging for all RAP/RAS mixtures. A potential reason for this behavior of RAP/RAS mixtures might be the greater amount of already aged and oxidized asphalt binder present in these mixtures, which is not as prone to a more severe aging temperature as other mixtures. There is a significant difference between the fracture properties of 5 days and 24 hour aging for PG 52-34, 12.5mm mixtures, while fracture energy and FST of 5 days aged, PG 58-28, 12.5mm, RAP/RAS mixtures are very close to those of high aged mixtures.

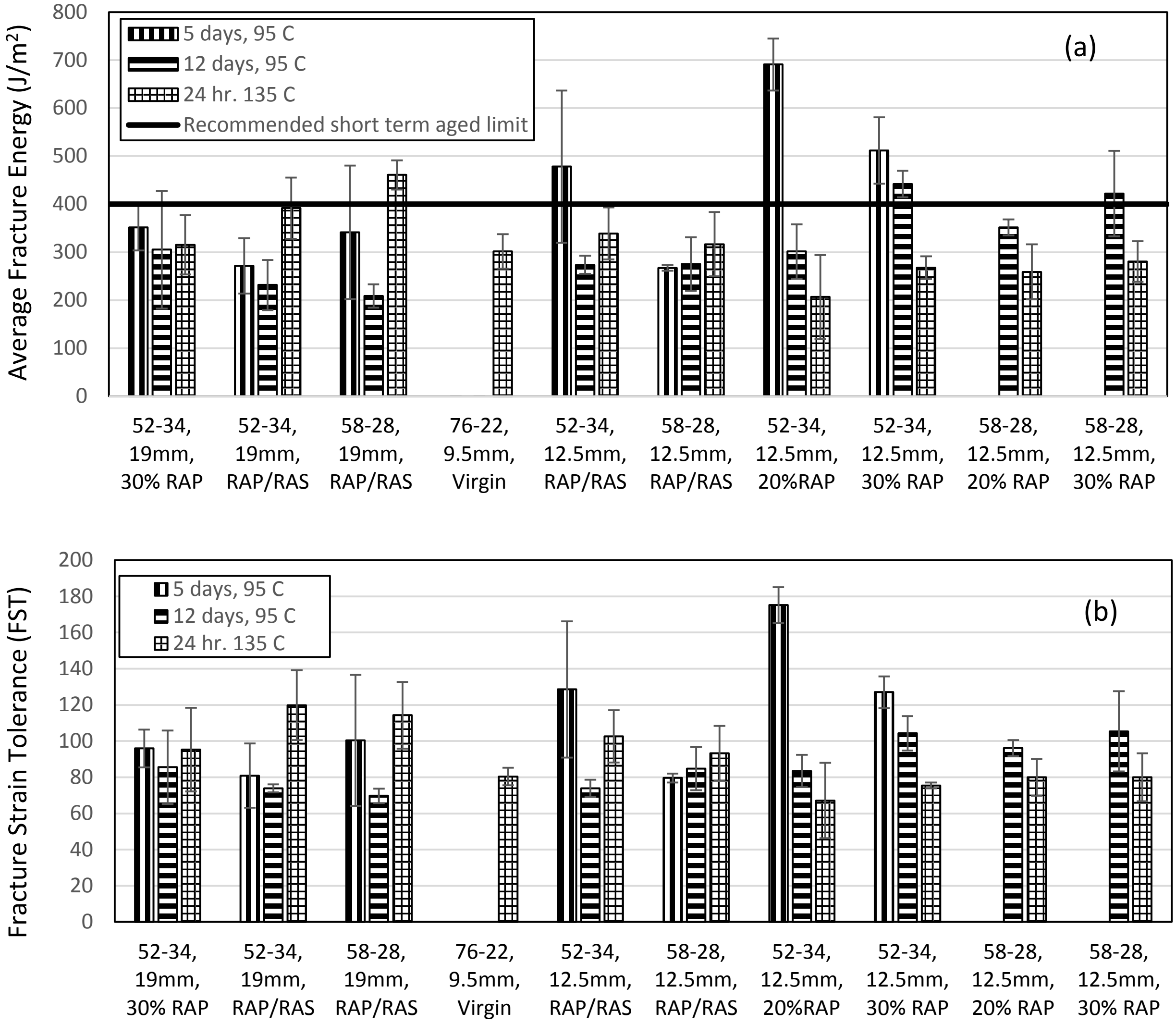


FIGURE 7 (a) Fracture Energy and (b) Fracture Strain Tolerance Values (DCT Testing)

Figure 8 shows the flexibility index (FI) parameter which is the average of 3 to 4 replicates for each mixture, with the standard deviation error bars. The FI values of 5 days aged mixtures are higher than 24 hour and 12 days aged values for all mixtures, with higher differences observed for RAP/RAS mixtures. The flexibility index of PG 52-34 mixtures is generally higher than the similar PG 58-28 mixtures, especially for 5 days aging level. The fracture properties obtained from SCB testing do not show a similar trend with the results of DCT testing. It is not surprising since the loading mode and testing temperature are different in these two fracture tests. Results shown here agree with recent work by Haslett et al. [17] that showed that a single 25°C test temperature for SCB testing may not as clearly distinguish between mixtures with different low temperature binder grades.

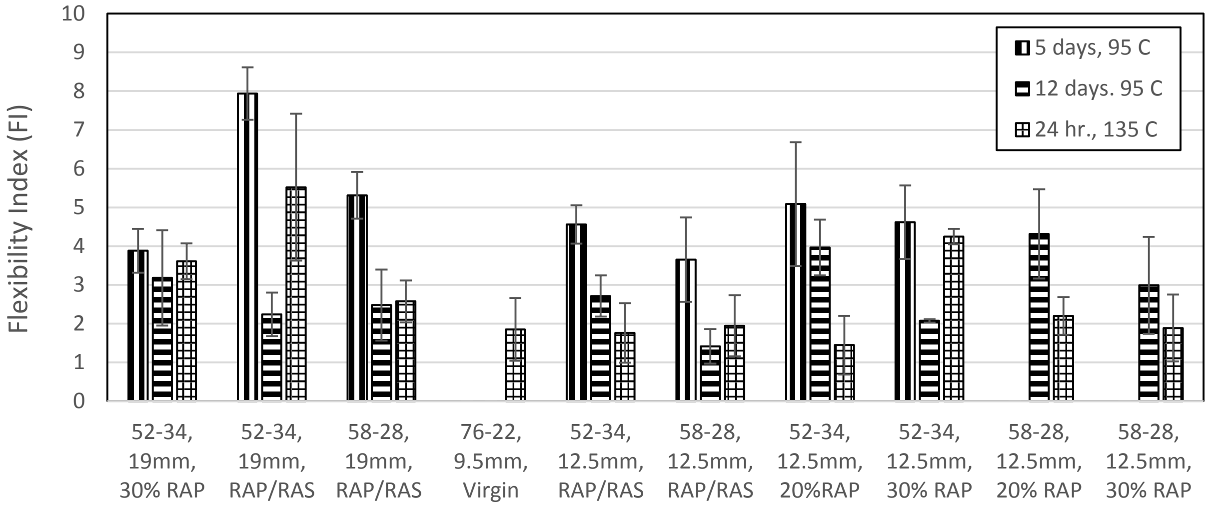


FIGURE 8 Average Flexibility Index Values (SCB Testing)

SUMMARY AND CONCLUSION

The main objective of this research was to investigate how mixtures properties change with different long term aging levels (5 days at 95°C, 12 days at 95°C, and 24 hour at 135°C) on loose mix and 5 days at 85°C on compacted samples. This study includes nine recycled mixtures and one virgin mixture evaluated by complex modulus, DCT, and SCB fracture testing. The following conclusions can be drawn from the results of the testing and analysis:

- All levels of long term aging have made a significant difference on linear viscoelastic properties ($|E^*|$ and δ) as compared with the properties measure at the STOA level. There was a similar trend in the variation of dynamic modulus and phase angle at different aging levels for the various mixtures. Based on the Black space diagram, the combination of higher dynamic modulus (at constant phase angle) and lower phase angle (at constant dynamic modulus) can be translated to higher thermal stress and higher relaxation capability, respectively.
- For the mixtures available in this study, 24 hour aged mixtures show very similar dynamic modulus and phase angle values with 12 days aged mixtures. Although 24 hour and 12 days aging create the similar effects on LVE properties, the fracture properties of asphalt mixtures obtained from SCB and DCT testing are different for these two aging levels.
- The shape parameters from dynamic modulus and phase angle master curves can indicate the relative aging levels and cracking behavior in mixtures. The evolution of characteristic shape parameters can be utilized in the future to develop aging models.
- Generally, the fracture properties of asphalt mixtures (fracture energy, flexibility index, and fracture strain tolerance) decrease as the aging level changes from 5 days to higher levels of aging, but there is not an evident trend between the fracture properties of 24 hour and 12 days. For the RAP/RAS mixtures, the 24 hour aged mixtures show better fracture properties than 12 days aged mixtures, while there is an inverse trend for most of the RAP only mixtures.

Future Work

Additional mixture testing (i.e. uniaxial fatigue testing) and analysis are underway to compare the fatigue properties of long term aged and short term aged mixtures. Most of the mixtures were placed in the field during the 2013 construction season and are being monitored. The cracking performance of field aged asphalt mixtures will be evaluated by laboratory testing on field core samples. Also, additional mixtures from different areas and with a wider range of binder grades and recycled materials are being evaluated.

Further analysis is planned to investigate the correlation between the viscoelastic characteristics, damage coefficients, and different cracking mechanisms including fatigue and reflective cracking and their relationship with field performance. Work is being conducted on the development of an aging prediction model for LVE and fracture properties of asphalt mixtures and comparison with other existing models such as global aging model (Mirza and Witczak, 1995) that is used in Pavement ME.

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