Laboratory investigation of asphalt mixture aging

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ABSTRACT

The rheological properties of asphalt binders change with time. Asphalt mixtures get stiffer and more prone to fatigue cracking with aging. This study is a part of a comprehensive study undertaken to develop improved protocol for asphalt mixture conditioning in the laboratory to simulate asphalt mixture aging due to the climate conditions in the State of Qatar. In this study, asphalt mixtures were prepared by mixing Gabbro base aggregate with Pen 60-70 binder. Initially, mixtures were conditioned at short-term aging temperature of 135°C for different time periods (2, 4 and 6 hrs). Long-term aging was completed after compaction of test specimens to the desired air void level of 7 ± 0.5% by using Superpave gyratory compactor. Three different long-term aging temperatures (i.e., 75, 85 and 95°C) and four different aging levels (0, 2, 6, and 10 days) were evaluated in this study. Then, the specimens were tested in an AMPT to determine dynamic modulus and phase angle. Results of this study were presented by plotting a series of mastercurves obtained from performance testing of the aged specimens. The results showed that aging temperature and duration have significant effects on the viscoelastic properties of asphalt mixtures.

Keywords: Ageing, Asphalt, Mechanical Properties

1. INTRODUCTION

It is well established that the rheological properties of asphalt binders change with time. Asphalt binders get stiffer and become brittle with age [1], which is referred to as asphalt aging or hardening. These altered rheological properties have a direct impact on the performance of asphalt mixtures. Asphalt hardening often leads to fatigue cracking and eventually pavement failure with heavy and repeated traffic loading.

Aging of asphalt binders occurs during the production of asphalt mixtures, and while in service and exposed to the surrounding environment [1-4]. The first stage of aging occurs at a very fast rate when asphalt binder is mixed with aggregates and heated to very high temperatures. This stage is often referred to as short-term aging. The second stage of aging occurs at a slow rate while the mixtures are transported, laid down, and compacted. After construction, aging continues for about 2 to 3 years until the mixture approaches the maximum density, when no further densification occurs. Aging significantly affects the mechanical properties (e.g., stiffness modulus, phase angle, etc.) of asphalt mixture and hence the performance of the asphalt pavement. Therefore, it is required to characterize the aged asphalt mixtures properly for the successful design of asphalt pavements.

Several studies have been conducted to study the influence of aging on the fundamental properties of asphalt binders [5-7]; however, little effort has been devoted to thoroughly understanding and quantifying the effect of aging on fundamental properties of asphalt mixtures [8]. Research studies on aging of asphalt mixtures in the field and laboratory [2, 8-10] illustrate that aging increases the stiffness of asphalt mixtures and accelerates the accumulation of fatigue damage over time. These studies recommended considering these changes while in the design stage to better improve performance analysis of asphalt pavements.

The current practice recommended by the American Association of State Highway and Transportation Officials (AASHTO) [11] is to cure asphalt mixture at short-term aging temperature of 135°C for 4 hrs followed by a long term-aging at 85°C for 5 days. However, this standard protocol does not account for different environmental conditions (e.g., severe climatic conditions like in the Middle East) or mix properties (e.g., air void). Therefore, these protocols may not be appropriate to arid climatic conditions like in Qatar. A research effort has been undertaken at Qatar University to develop a protocol that simulate the aging of asphalt mixtures based on the environmental conditions and construction materials in Qatar.

Dynamic modulus ($|E^*|$) is a key property of the material that is used to calculate stresses and strains in pavement structures. The mechanistic empirical pavement design guide (MEPDG) also recommends $|E^*|$ as one of the fundamental properties for the characterization of an asphalt mixture [12]. The dynamic modulus also has significant correlation with major pavement distresses [13-16] and therefore can be used to forecast the performance of asphalt pavement structure [17].

In this study, a laboratory investigation was carried out to evaluate the effect of short- and long-term aging on the mechanical properties of asphalt mixture. A typical aggregate was mixed with an unmodified binder to prepare cylindrical specimen and tested in Asphalt Mixture Performance Tester (AMPT) system to determine dynamic modulus and phase angle. Details of the material and binder used, specimen preparation, curing technique, testing setup and analysis of test results are presented. This study provides fundamental understanding of the effect of aging on the change in mechanical properties of asphalt mixtures.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials and Mixture Design

This investigation utilized gabbro aggregate which is igneous and relatively hard aggregate in nature. The gabbro rock is imported from the United Arab Emirates and has been widely used in road construction in Qatar. The nominal aggregate size and maximum aggregate size of the gabbro aggregate were 1" and 1½", respectively. The binder used in this experimental investigation was an unmodified binder, namely Pen 60-70 and was supplied by Woqod Inc, Qatar. It had a penetration value of 65 dmm and softening point of 48°C.

A superpave mixture design was used for laboratory experiments. The aggregate gradation is presented in Figure 1. Gabbro aggregates were mixed with Pen 60-70 binder at the optimum binder content determined as 4.3%. A summary of mixture characteristics for 7% air void is given in Table 1.

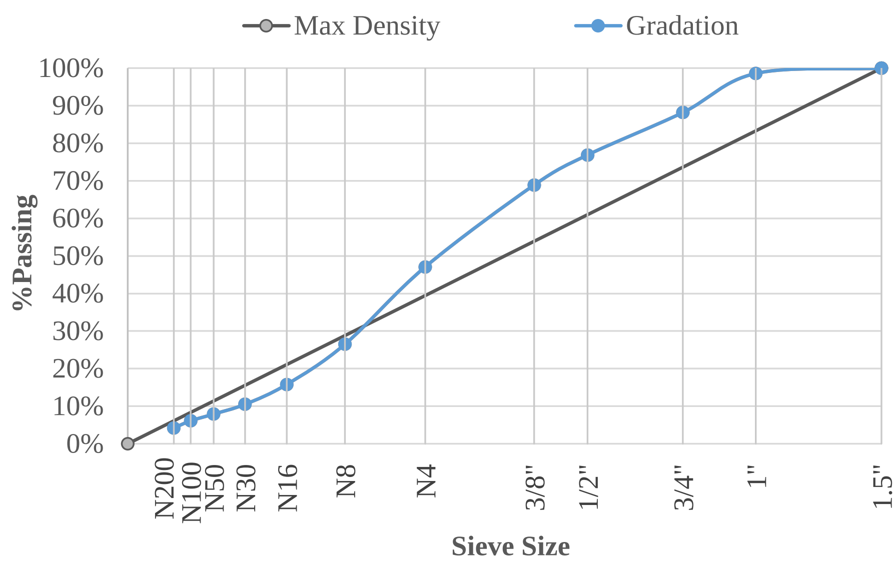

Figure 1. Gradation of aggregate used in the asphalt mixture

Table 1. Summary of Mixture Characteristics

Mixture Properties		**Value**
Binder Content, %	P_b	4.30
Air Voids %	AV	7
Bulk Specific Gravity of Mixture	G_{mb}	2.49
Maximum Specific Gravity of Mixture	G_{mm}	2.689
Bulk Specific Gravity of Aggregate	G_{sb}	2.84
Specific Gravity of Binder	G_b	1.03
Effective Specific Gravity of Aggregate	G_{se}	2.89
Voids in the Mineral Aggregate, %	VMA	16.5
Voids Filled With Asphalt, %	VFA	55.5
Dust Proportion	DP	1.09

2.2 Sample Preparation and Aging Techniques

Based on the mix design discussed in the previous section, required amount of aggregate and binder were calculated to produce test specimens (150 mm diameter and approximately 170 mm height) with an average air void of 7 percent. The mixing and compaction temperatures were determined using consistency test results, and they were 143°C and 135°C, respectively. Therefore loose mixtures were prepared at 143°C in a mixer as shown in Figure 2. After mixing, laboratory short-term aging was conducted in accordance with AASHTO R30 by placing the loose mixtures in a force draft oven at 135°C for three different aging durations (i.e., 2 , 4 and 6 hours).

Figure 2. Mixture preparation

After short-term aging, the asphalt mixtures were compacted to the desired air void level of 7 ± 0.5% by using the Superpave gyratory compactor at a compaction temperature of 135°C. Figure 3 shows a typical compacted specimen. The compacted specimens were then cored to 100 mm in diameter from 150 mm samples using the electric core drill machine. And the cored specimen was then trimmed to produce the final specimen measuring 100 mm in diameter and 150 mm in height.

The final specimens were aged in the forced-draft oven at varying temperatures and durations to simulate the long-term field aging. This investigation assessed three different long-term aging temperatures: 75, 85 and 95°C and four different aging durations: 0, 2, 6 and 10 days. The 0-day specimens were essentially with short term aging only. Table 2 presents a detailed summary of the specimens prepared and tested in this laboratory investigation. Figure 4 illustrates typical changes in the lab specimen due to long-term aging. As can be observed the specimen is getting darker with aging.

Figure 3. Compacted specimen just after compaction

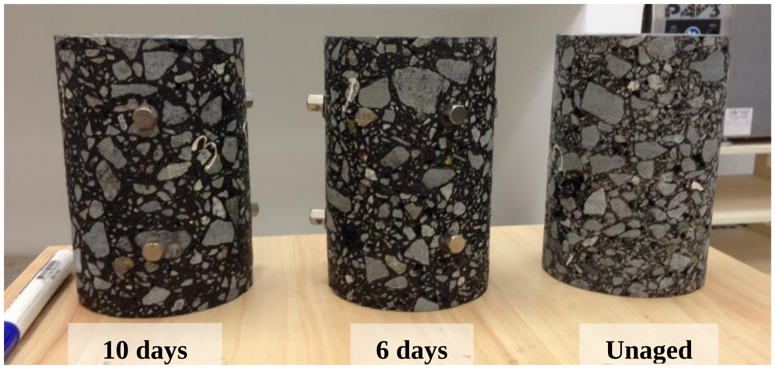

Figure 4. Lab specimens before and after Aging

Table 2. Testing Program for Aging Evaluation

Specimen ID	Short-term aging temp. (°C)	Short-term aging duration (Hours)	Long-term aging temp. (°C)	Long-term aging time (Days)
S135T2L75	135	2	75	0, 2, 6, 10
S135T2L85		2	85	2, 6, 10
S135T2L95		2	95	2, 6, 10
S135T4L75		4	75	0, 2, 6, 10
S135T4L85		4	85	2, 6, 10
S135T4L95		4	95	2, 6, 10
S135T6L75		6	75	0, 2, 6, 10
S135T6L85		6	85	2, 6, 10
S135T6L95		6	95	2, 6, 10

2.3 Dynamic Modulus Testing

The dynamic modulus test was conducted in an AMPT testing system made by IPC Global, Australia. After the appropriate aging as discussed in previous sections, the specimens were tested to determine dynamic modulus ($|E^*|$) and phase angle (δ) at different temperatures and over a range of frequencies. In this test, a sinusoidal axial compressive load is applied under strain-controlled conditions. The testing procedure was as follows: (1) Open the cell and place the specimen on top of the lower end treatment, (2) Mount the axial LVDTs to the gauge points previously glued to the specimen. Adjust the LVDT so that full range is available for the axial deformation measurement (3) Place the upper friction reducing end treatment and platen on top of the specimen, (4) Center the specimen with the load actuator visually in order to avoid eccentric loading and close the cell, (5) Allow the cell chamber equilibrate to the specified testing temperature for a certain period of time specified in AASHTO TP 62-07, and (6) Run a tuning test to determine an initial modulus by applying a maximum load of 1.26 kN. This initial modulus is used as input in the dynamic modulus testing to ensure that axial strains to the specimen remain in between 85 and 115 microstrains without impact in a cyclic manner.
The test is performed at three different temperatures (4, 20, and 40°C), and three loading frequencies (0.1, 1.0, and 10 Hz) for 4°C and 20°C, and at four loading frequencies (0.01, 0.1, 1.0, and 10 Hz) at 40°C. Testing starts from the lowest to highest temperature and from highest to lowest frequency. All the test data are automatically measured and recorded with operation software. Two replicates were prepared and tested for each combination and average of the two test results was used to interpret the data. The applied stress and recorded strain are used to calculate the

dynamic modulus and phase angle. Upon completion of testing, the dynamic modulus master curve is constructed to compare the results of mixtures at different conditions.

The variability of test data and the repeatability of the testing method was evaluated in terms of coefficient of variation (CoV = Standard deviation/mean) of the modulus value. In general, CoVs of 92% of the modulus values obtained at different frequencies and temperatures remained below 10%. Only 8% of the modulus data showed comparatively larger variation (CoV > 10%) with the highest being 21%. Among them, almost 50% of the larger variation was contributed by a single test condition (i.e., at 0.01 Hz frequency and 40 ºC) only. Therefore, it may be concluded that the test data obtained from the testing methods adopted in this study was consistent, reliable and reproducible. However, testing at 0.01 Hz frequency and 40 ºC may lead to increased variability in test results and hence may require additional precautions.

3. TEST RESULTS AND DISCUSSION

Asphalt mixture exhibits viscoelastic behavior i.e., its properties are function of time (or frequency) and temperature. Figures 5 and 6 show the effect of frequency on dynamic modulus and phase angle at different temperatures. As one expects, the dynamic modulus increased with the increase in loading frequency. On the other hand, the phase angle decreased with the increase in frequency at 4 ºC and 20 ºC but had no clear trend (or sometimes increased) at 40 ºC. It is believed that this could be due to the aggregate interlock effects at high temperatures [18]. Also, as expected, dynamic modulus decreased with the increase in testing temperature. This is due to softening of asphalt mixtures at higher temperature.

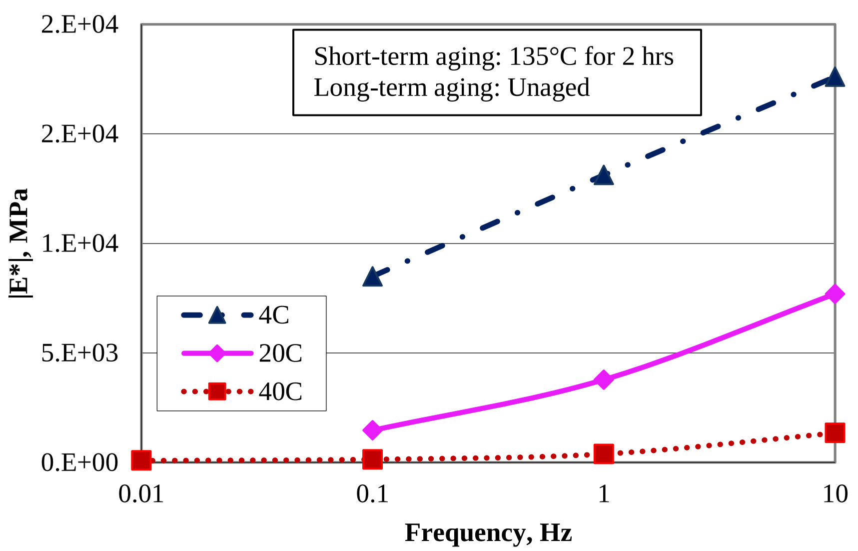

Figure 5. Typical variation in dynamic modulus with frequency and temperature

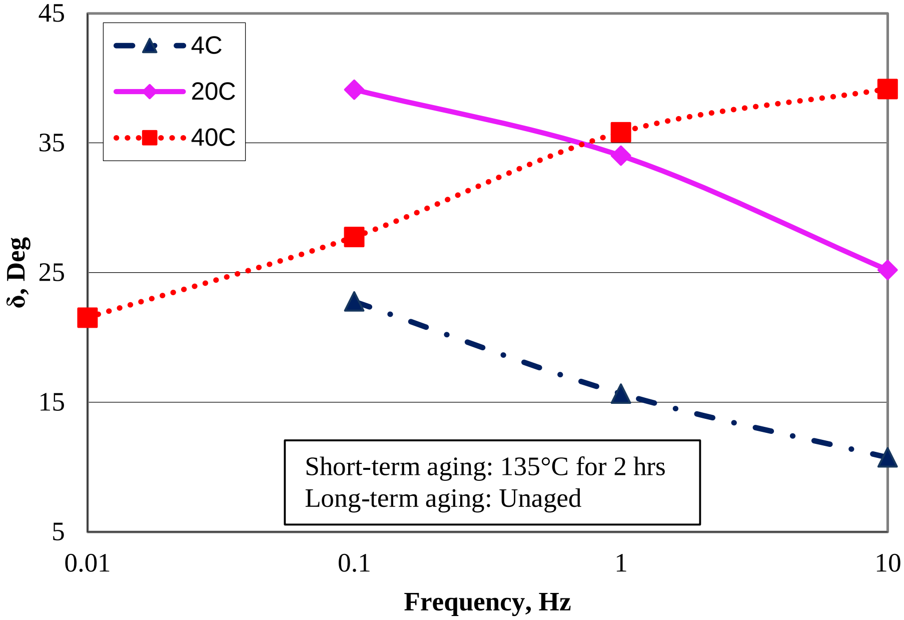

Figure 6. Typical variation in phase angle with frequency and temperature

A master curve is used to describe the viscoelastic property at a reference temperature (i.e. 20°C) and over a range of time and frequency. The master curve allows the estimation of mechanical properties over a range of temperature and times (or frequencies) by utilizing time-temperature superposition principle. A typical master curve is shown in Figures 7.

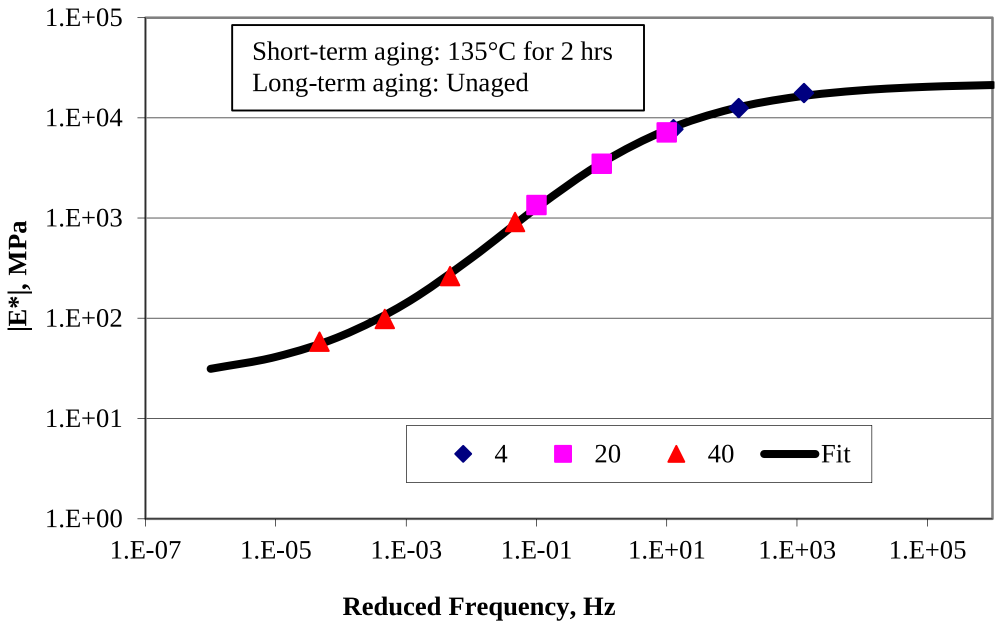

Figure 7. Typical fitted master curve obtained from dynamic modulus testing

A master curve was prepared for each set of specimens and then a comparison study was conducted for better evaluation of effect of aging time and temperature. Figure 8 shows the effect of short-term aging duration on dynamic modulus for 2 days long-term aged specimen at 85°C. It can be seen from Figure 8 that the master curves were shifting towards higher E* values with the increase in short-term aging durations from 2 hrs to 6 hrs. As a result, asphalt mixtures may be more prone to fatigue cracking under repeated wheel load applications.

Aging temperature also has a significant effect on the mechanical properties of asphalt mixture. Figure 9 shows the effect of long-term aging temperature on dynamic modulus for 10 days aged specimens. For increasing in long-term aging temperature from 75°C to 85°C to 95°C, the master curve was shifting towards higher E* values indicating increases dynamic modulus, hence stiffening the materials. Increase in dynamic modulus with increasing long-term aging duration, similar to short-term aging duration was found to be significant. The higher the long-term aging duration is, the greater the dynamic modulus, as seen in Figure 10.

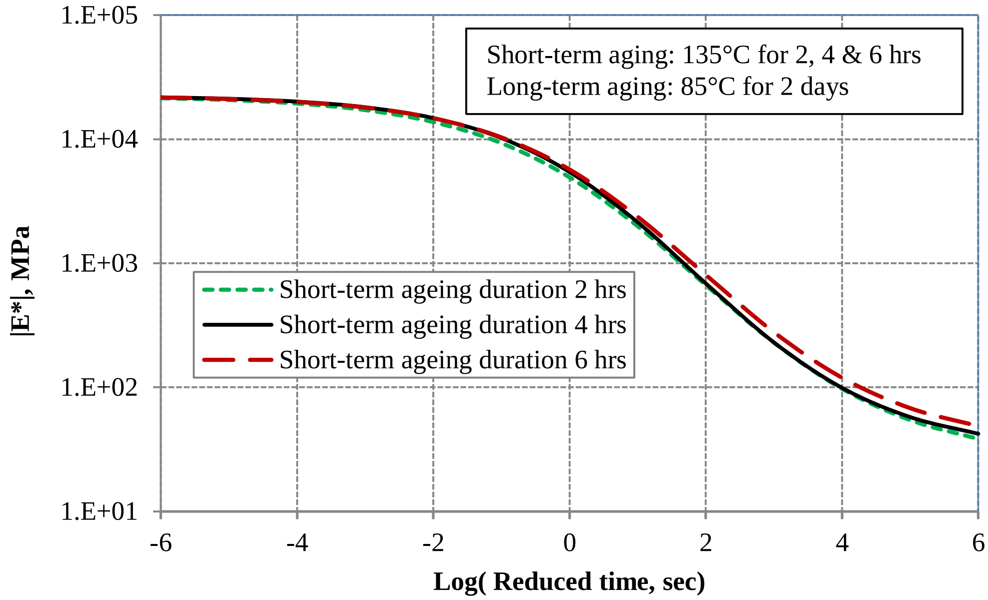

Figure 8. Effect of short-term aging duration on dynamic modulus

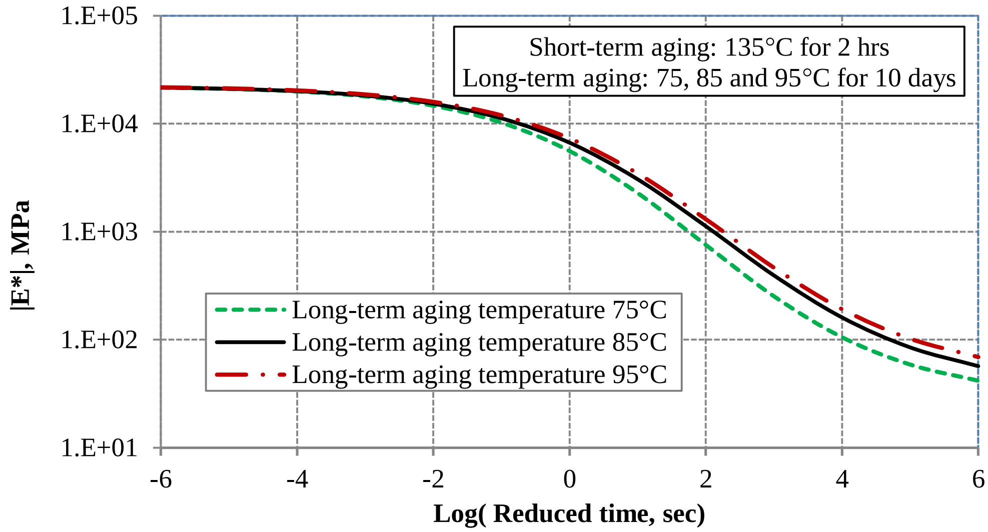

Figure 9. Effect of long-term aging temperature on dynamic modulus

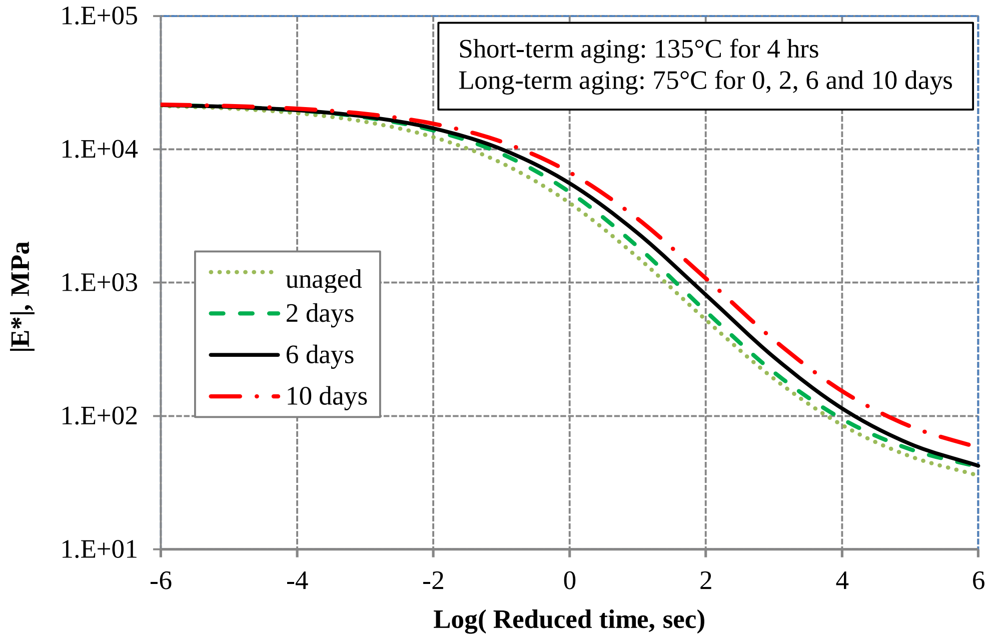

Figure 10. Effect of long-term aging duration on dynamic modulus

8. CONCLUSIONS AND RECOMMENDATION

Asphalt aging is defined as the change in rheological properties with time. It causes several changes in asphalt mix properties in short- and long-runs, and affects the performance of asphalt pavement. The current practice recommended by the AASHTO is to cure asphalt mixtures for a few hours and days for short-term and long-term aging, respectively. However the applicability of these protocols to severe climatic conditions is questionable. With an objective of developing an aging simulation protocol that is representative for the climatic conditions in the Middle East, the researchers conducted laboratory investigation to study the effect of short- and long-term aging on the asphalt mixture properties. This study reports some preliminary findings of comprehensive laboratory and field experiments. The results of this study showed that the duration and temperature of short- and long-term conditioning have significant effect on the measured dynamic modulus and phase angle of asphalt mixtures in the laboratory. Upon completion testing field cores, the authors aim to identify the proper aging parameters (i.e. temperature and duration) in the laboratory to simulate aging of asphalt mixtures in Qatar.

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