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RESEARCH ARTICLE

Effect of Superpave Short-Term Aging on Binder and Asphalt Mixture Rheology

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Abstract
This study aimed to evaluate the effect of Superpave short term aging period length and type of additive used in modifying the asphalt binder on the creep behavior of asphalt binder and asphalt mix. Hot-mix asphalt (HMA) specimens were prepared at optimum asphalt content using unmodified asphalt, or asphalt with 4% by weight of SBS or PE. The Universal Testing Machine was used to conduct dynamic creep tests. Tests results indicated that the effect of extending the aging period on creep deformation is highly dependent on type of additive used in preparing the asphalt mix. Extending the aging period more than three hours caused insignificant effect of creep behavior of control asphalt mixes. On the other hand, extending the aging period more than one hour caused insignificant effect of creep behavior of asphalt mixes prepared using SBS additive. While for mixes prepared using PE, the creep deformation continues to decrease as aging period increase.

Keywords
asphalt, mix, rheology, creep, additives, aging

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1 Introduction

Superpave laboratory short term aging for asphalt mixtures was developed in an effort to simulate the aging in the field during mixing, transportation and construction.

While Superpave laboratory long term aging was developed to simulate the asphalt mixture aging over about 10 years of the pavement service life. Several traffic and environmental factors affect the deterioration of roads. A substantial part of the damage on flexible pavements is caused by rutting of the pavement.

Rutting is associated mainly with heavy traffic loads. Rutting of pavements is complex phenomena caused by cumulative deformation of binder, surface, base, subbase, and subgrade layers. Rutting distress leads to poor pavement structural and functional performance, which in turns increases maintenance as well as road user cost.

Long and expensive tests are required to assess the mechanical characteristics of bituminous mixtures for the purpose of pavement design and performance prediction. When the mechanical characteristics are called for, the effect of short and long term aging on these properties should be considered.

Although asphalt constitute small part of the HMA, it significantly affect the performance of flexible pavement. In pavement, asphalt exposed to two aging processes. The short term aging process occurred during mixing, laydown and compaction of HMA. During this process the asphalt expose to high temperature leading to loss of volatile and oxidation of asphalt.

As a result harder asphalt will be produced. The asphalt long term aging take place as the pavement in service expose to the environment at a relatively lower temperature and longer duration. In this process polymerization, oxidation, and loss of volatile oils are the main cause of aging.

Due to continuously increasing traffic volumes, axle loads and the effects of temperature cycling, pure asphalt pavements are subjected to stress cracking and rutting. Therefore, under certain circumstances, base asphalt need to be modified with some additive to meet the requirements of local authorities.

2 Literature Review

Molenaar et al. (2010) investigated the effect of known short-term and long-term laboratory aging procedures on the rheological characteristics and chemical composition of binders and compared them with those for the field aged binders. Results showed laboratory procedures were not capable to simulate long-term field aging, and at best two years field aging could be simulated.

Daniel et al. (2013) conducted a study on how will the addition of already aged asphalt binder affect the overall properties and performance of the mixtures. The conclusions of the study were that the reclaimed asphalt pavement (RAP) mixtures stiffen due to laboratory aging at a slower rate than original mixtures, and the impact of the presence of (RAP) on material properties decreased with aging time.

In another study, the laboratory short-term and long-term aging were evaluated and compared to those take place in the field. The short-term aging of bitumen binders in the laboratory using the thin film oven (TFO) and the rolling thin film oven (RTFO) test methods. The long-term aging was simulated by using a pressurized aging vessel (PAV) under constant conditions of pressure and temperature. Test results showed differences between actual aging and laboratory aging (Behera, 2013).

A study performed by Abo-Qudais and Molqi (2006) was aimed to develop new, low cost, chemical antistripping additives. To achieve this objective, HMA specimens were prepared using limestone aggregate, asphalt with 80/100 penetration, and different types of chemical antistripping compounds. The effect of HMA stripping was evaluated using the modified Texas Boiling Test. The results indicated that out of the 28 evaluated combinations of additive type and amount, 11 additives combinations showed a positive effect on stripping resistance. Five of these 11 additive showed a high positive improvement in the stripping resistance (increase in coating areas was greater than 20%). However, of these 11additives, only one (Aluminium mono-stearate) showed strong positive impact on stripping resistant with a small reduction in ductility and an insignificant change in penetration.

In another study, Abo-Qudais and Alshwiely (2007a) investigated the effects of conditioning and aggregate properties on the creep and stripping behavior of hot-mix asphalt (HMA). Two types of aggregates evaluated in this study were limestone and basalt. The percent of increase in static creep strain of HMA due to conditioning was utilized in this study to assess the stripping. Test results indicated that, after conditioning, mixes prepared using basalt were less resistant to creep strain than those prepared using limestone aggregate. Percent absorbed asphalt was found to be directly related to stripping resistant. Also, the results of the calculated adhesion work were able to detect the effect of stripping on creep behavior for mixes prepared.

The effect of stripping on the hot mix asphalt (HMA) creep behavior was evaluated using static creep. Part of the prepared specimens was exposed to freezing–thawing conditioning, according to AASHTO T283, before creep test. The findings of this study indicated that conditioning of HMA specimens has a significant effect on the increase of creep deformation. This is especially true for open graded aggregate gradation mix (Abo-Qudais and Al-Shweily, 2007b).

In another study, Abo-Qudais and Al-Suliman (2005) found that ultrasound pulse velocity (UPV) can be used to estimate the fatigue life and crack healing of hot-mix asphalt.

Hugo et al. (2007) investigated the effect of using calcareous fillers (hydrated lime and limestone filler) on aging properties of bituminous mixes. Obtained results showed some advantages of incorporating Calcareous fillers into bituminous mixes.

The effect of aging on bitumen binder using different filler materials was reviewed by Harshad and Gundaliya (2014). Studies have shown that the modified bitumen binder has less effect of aging than the virgin bitumen.

Yero and Roslitlainin (2012) investigated the aging properties of modified bitumen performance grade PG 76-22 (binder). The aging was simulated using the rolling thin film oven (RTFO) and pressure aging vessel (PAV) for short-term and long-term aging during production and lying of asphalt mixtures. Results indicated that aging resulted in oxidation of the bitumen with increase in the stiffness of the binder.

Pilat and Krol (2008) analyzed the influence of short and long term aging processes on polymer dispersion in the polymer modified bitumen. The polymer used was SBS. Microstructure changes of polymer dispersion were tested using fluorescent. It has been shown that the phase separation of SBS modified binders is influenced by the base bitumen and the characteristics and microstructure after aging.

Recasens et al. (2005) investigated the effect of filler on aging of bitumen when the filler was being incorporated by volume not by weight. Results showed that an increase in filler produces an increase in the breaking load and a decrease in the maximum deformation.

Harvey and Tsai (2007) studied the effect of long-term oven aging on the initial stiffness and fatigue of asphalt concrete. The results indicated that the tested mixes exhibited an increase in initial stiffness with long-term oven aging periods of up to six days and the sensitivity of beam fatigue life to long-term oven aging depends on the asphalt.

3 Problem Statement

The mechanical behavior of both binder and asphalt mix is significantly affected by aging, The Superpave specification requires exposing the binder to short term aging by exposing the binder to a temperature of 163^{o}C, accompanied with air blowing for 80 minutes. This aging can be accomplished using the Rolling Thin Film Oven (RTFO).

The Superpave specification, also, requires exposing the asphalt mix to Short term aging by exposing the loose mixture samples to short term aging before compacting it using Superpave gyratory compactor. This short term aging is performed by placing the mixture in a forced draft oven at 135° C for two or four hours. The two hours of aging is recommended when the volumetric properties of asphalt mixture with low absorption aggregate (less than 2.5 percent) is considered. While four hours of aging is recommended when the volumetric properties of asphalt mixture with high absorption aggregate is considered, or when the asphalt mixture will be tested using indirect tensile tester and Superpave shear tester (Superpave Asphalt Technology Program, 2015). No short term aging period was recommended for other mechanical tests such as creep and fatigue testing.

Asphalt binder modification has been practiced for past years to achieve many goals as improving pavement durability and lower life cycle costs. Nowadays numerous binder additives are available in the market with different categories as polymers, chemical modifier, fibers and fillers, etc. The manner in which the aging affect the mechanical behavior of binder and asphalt mix might be significantly affected by type of used additives.

4 Objectives

Based on the above, the main objective of this study was to evaluate the effect of short term aging period on the creep behavior of asphalt mixture and asphalt binder at different temperatures. Asphalt additives were used to modify the binder.

5 Materials and Research Approach

To satisfy the objectives of this study, asphalt mix specimens were prepared without additives or using polymers additives added at 4% to modify the binder used in preparing the specimens. Those polymers were the SBS or the PE.

Asphalt mix specimens were prepared at optimum asphalt content according to Marshall Mix design procedure (ASTM D1559). Before compaction, the loose specimens were oven aged at 1,2,3, and 4 hours.

A control specimen (without aging) was also prepared for the purpose of comparing the effect of aging. Limestone aggregate complying with the Superpave system requirements along with virgin asphalt (before modifying) with PG 64-10 (60/70 penetration) were used in preparing HMA specimens.

Dynamic creep tests were performed on the prepared Marshall specimens to evaluate the effect of short term aging period and type of additive on rutting based on the accumulated strain and resilient modulus. Also, the unmodified binder was tested using Dynamic Shear Rheometer (DSR) to evaluate the effect of aging period length on asphalt binder shear modulus and phase angle. Fig. 1 summarizes the research approach followed to achieve the objective of this study.

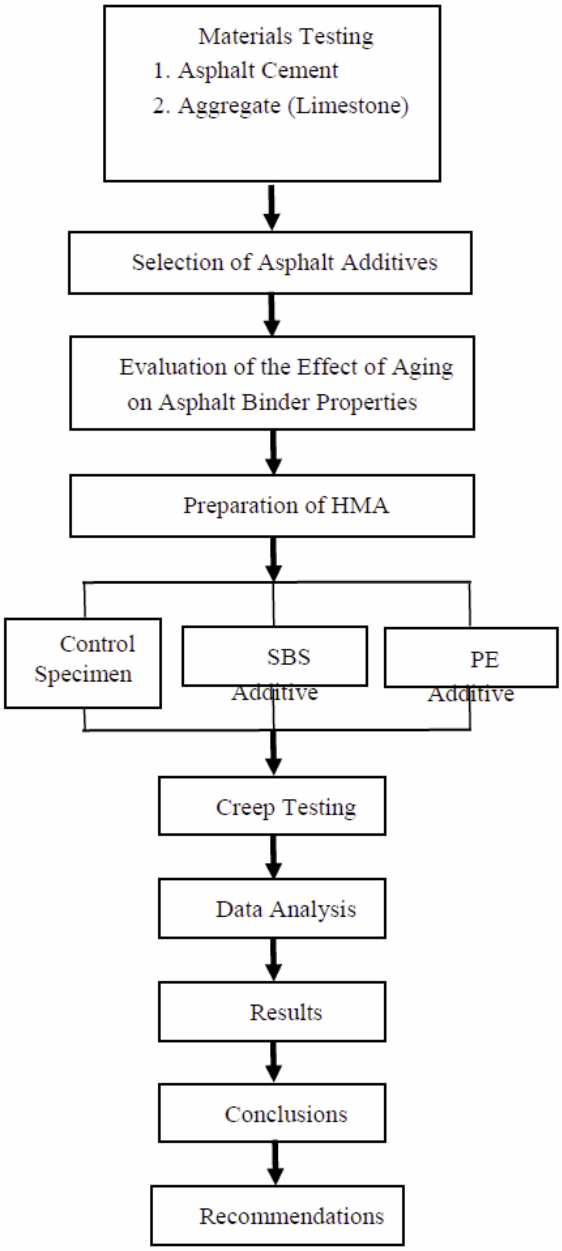


Fig. 1 Research frame work

5.1 Materials Used

5.1.1 Aggregate

The aggregate used in this study was crushed limestone aggregate. The limestone was obtained from Al Dogara quarries in the middle part of Jordan. Table 1 summarizes the physical properties of the aggregate. The used gradations followed was the recommended one by Superpave system, with a maximum nominal aggregate size equal to 19 mm. The aggregate gradations are presented in Fig. 2.

5.1.2 Asphalt

Asphalt cement having a performance grade (PG) of 64-10 (penetration of 60/70) was used in preparing HMA specimens. This asphalt was obtained from the Jordan Petroleum Refinery in Zarqa city. Table 2 summarizes the physical properties of the asphalt.

Table 1 Properties of Aggregate used in Preparing the Asphalt Mix Specimens

Aggregate	ASTM Test Designation	Dry Bulk Specific Gravity	Apparent Specific Gravity	Absorption (%)	Abrasion Value (%)	Angularity	Sand Equivalent	Flat and Elongated Aggregate
Coarse	C127	2.424	2.573	3.1	34.1	96/95 (95/90)*	-	0.5% (10%)*
Fine	C128	2.485	2.590	4.6	-	46% (45%)*	65% (45%)*	-
Mineral Filler	C128	2.552	2.625	5.1	-	-	-	-

*Values between parentheses represent values specified by Superpave for medium traffic (10-30 million Equivalent Single Axle Load)

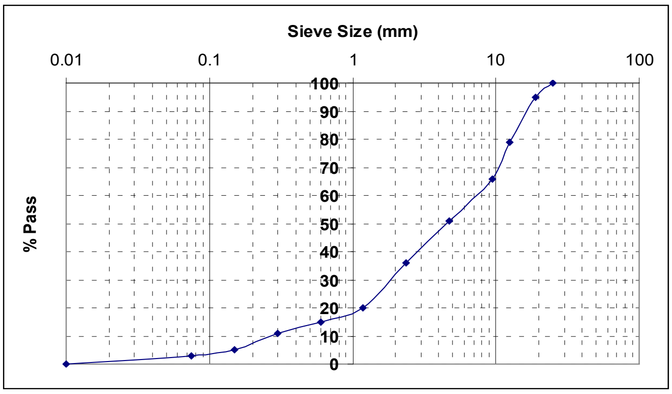


Fig. 2 Radation of Used Aggregate

Table 2 Properties of Asphalt Cement used

Test	ASTM Test Designation	Value
Ductility at 25 °C (cm)	ASTM D 113	100 +
Penetration at 25 °C, 100gm (0.1 mm)	ASTM D 5	64
Softening Point (°C)	ASTM D 36	50
Flash Point (°C)	ASTM D 92	319
Fire Point (°C)	ASTM D 92	325

5.1.3 Binder Additives

In order to modify the asphalt binder, two basic types of polymers were used: Elastomers and plastomers. Elastomers polymers (or rubber) are materials with high yield strain compared with other materials where plastomers polymers are those materials deform in a plastic or viscous manner and becomes hard and stiff at low temperatures. In this study, two of the commonly used additives to improve the binder and asphalt mix performance was used. One Elastomers polymer and one Plastomers polymer were used to investigate its effect on the creep behavior under different conditions. Styrene Butadiene Styrene (SBS) (Elastomers) and Polyethylene (PE) (Plastomers) were used as asphalt modifiers. SBS and PE are commonly used additives to improve the binder and asphalt mix performance. SBS is a block copolymer. It is made of backbone chain that consists of three long chains of polystyrene, polybutadiene, and polystyrene. The polymer is a high molecular weight, random block copolymer consisting of about 30% styrene and 70% butadiene in mole ratio.

Polyethylene is a thermoplastic polymer obtained by the polymerization of ethane. It is a semi-crystalline material consists of long chains of repeated small molecules produced by combination of the ingredient monomer ethylene.

The optimum percentage of the polymers is 4% by weight as recommended by researches (King and King, 1986).

5.2 Dynamic Shear Rheometer Test

The effect of accelerated short term aging period on the rheological properties of unmodified and modified asphalt binder was evaluated. A standard Rolling Thin Film Oven Test (RTFOT), at 163 °C for 0, 80, 160, or 240 minutes, was used to accelerate the aging of the binder. The rheological properties of the binder were measured using Dynamic Shear Rheometer (DSR), according to AASHTO T 315.

A one millimeter DSR plate gap was used in the study. The tests were run using a sinusoidal wave at a frequency of 10 rad/sec which simulate one cycle of loading due to 55 mph traffic. The tests results were presented by complex shear modulus (G*) and phase angle (δ). The value of G* presents the asphalt binder stiffness, while δ represent its elasticity. The G* and δ were measured at 58, 64, 70, 76, 82, and 88 °C.

5.3 Determination of Optimum Asphalt Content

Optimum asphalt content by weight of total mix was determined using the Marshall Mix design 50 blow procedures (ASTM D 1559). The optimum asphalt content was calculated as the average of asphalt contents that meet the maximum stability, maximum unit weight, and 4.0% air voids. The resulting optimum asphalt content was 5.0%.

5.4 Dynamic Creep Test

A repeated stress test was conducted by applying a cyclic compressive stress of 100 KPa with a 0.1 second loading followed by a 0.4 second rest period. The Universal Testing Machine (UTM), shown in Fig. 3, was used for this purpose. The machine is an electro-hydraulic test system.

The loading frame was housed in an environmental chamber to control temperature during a test. The desired load level, rate and duration were controlled by a computer. The deformation of the specimen was monitored through linear variable differential transducers (LVDTs).

The LVDTs were clamped vertically on the diametrical side of the specimen as shown in Fig. 3. The test was terminated 10,000 cycles. Three specimens were tested at the same additive, aging period, and testing temperature.

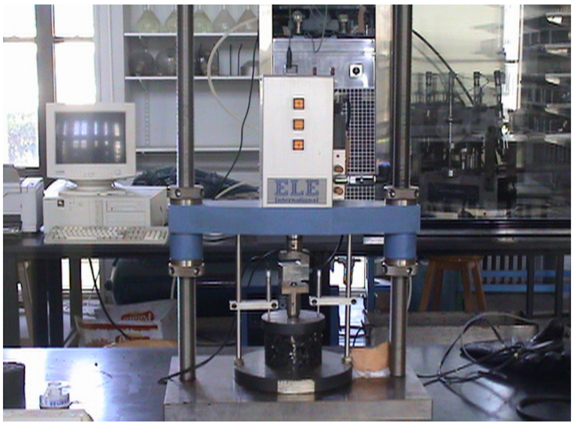


Fig. 3 Dynamic Creep Test Setup

6 Test Results and Discussion

The main objective of this study is to evaluate the effect of short term aging on rheological behavior of both binder and asphalt mix.

To achieve this objective, the effect of short term aging on unmodified (control) and modified HMA specimens tested at different temperature was evaluated. The results are summarized in the below sub-sections.

6.1 Effect of Short Term Aging Period on Creep Behavior

The effect of short term aging period used in preparing control specimens is shown in Figs. 4 through 6. These figures indicated that as the short term aging period increase, the creep microstrain (m/m x 10^{-6}), generally, decreased. A similar trend was noticed regardless type of additives used in preparing the hot mix asphalt. This behavior can be explained by the fact that increasing the short term aging period increase the mix stiffness and so increase its resistance to creep deformation.

The impact of aging period length was found to be highly dependent on the additives used in preparing the hot mix asphalt. For control (unmodified) asphalt mix specimens, gradual and small reduction in creep deformation was noticed, as aging period increase, (see Fig. 4).

For SBS modified asphalt mix, large increase in creep resistance was noticed as the aging period increase from 0 to 1 hour, while small increase in creep resistance was noticed as the aging period increased from 2 to 4 hours. On the other hand, when PE additive used in preparing the mix, gradual increase in creep resistance was noticed as the aging period increase from 0 to 4 hours. The rate of increase in creep deformation as loading cycles increase was high for specimens prepared using PE compared to those of control specimens or specimens prepared using SBS.

For control hot mix asphalt (prepared using unmodified binder), the average creep microstrain after 10,000 loading cycles were 0.114, 0.107, 0.103, 0.084, and 0.082 microstrain for mixes exposed to 0, 1, 2, 3, and 4 hours of short term aging, respectively.

While for hot mix asphalt prepared using SBS additive, the average creep microstrain after 10,000 loading cycles were 0.076, 0.039, 0.038, 0.034, and 0.028 microstrain for mixes exposed to 0, 1, 2, 3, and 4 hours of short term aging, respectively. For asphalt mix prepared using PE additive, the average creep microstrain after 10,000 loading cycles were 0.050, 0.043, 0.034, 0.025 and 0.020 for mixes exposed to 0, 1, 2, 3, and 4 hours of short term aging, respectively.

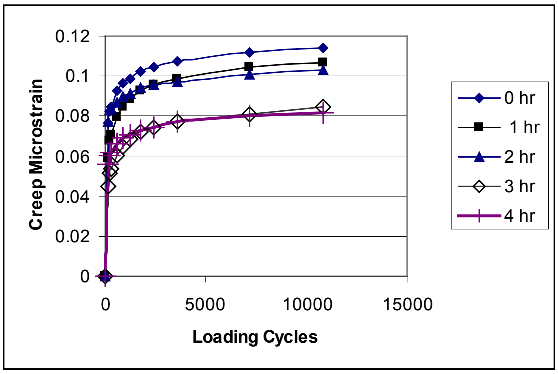


Fig. 4 Creep of specimens prepared without additives at different short term aging periods

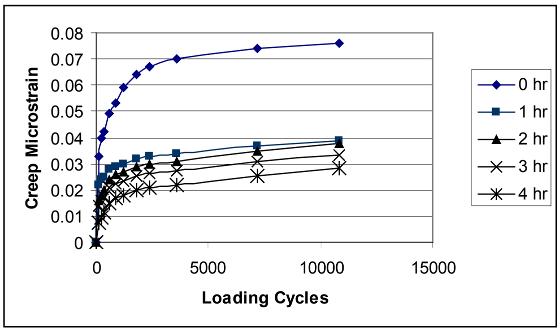


Fig. 5 Creep of specimens prepared using SBS additives at different short term aging periods

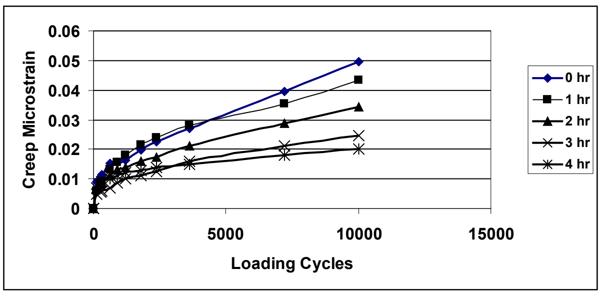


Fig. 6 Creep of specimens prepared using PE additives at different short term aging periods

6.2 Effect of Additives on Creep Deformation

Unmodified and modified (using either SBS or PE) asphalt mix specimens were prepared. In order to compare the effect of additives on creep behavior, the prepared specimens were tested using dynamic creep test. The results of tests performed on asphalt mix control specimens were compared to those of specimens prepared using modified binder.

Figs. 7 through 11 show the relationship between accumulated microstrain (m/m x 10^{-6}) and time, at same aging period, for unmodified and modified asphalt mix tested at 25 °C. Through the 10,000 loading cycles, used in this study, the control (unmodified) mixes had the highest creep deformation, followed by the mixes prepared using SBS additive. While, the mixes prepared using PE additive show the lowest creep deformation. A similar trend was noticed for all used short term aging periods. The resulted creep deformation of unaged asphalt mix specimens was the largest for control asphalt mix followed by those for asphalt mix prepared using SBS.

The smallest creep deformation was for asphalt mix prepared using PE. While for aged asphalt mix specimens, again, the largest creep deformations were for control asphalt mix. The creep deformations of asphalt mix specimens prepared using SBS and PE were close to each other and less than those of control specimens.

This might be due to the fact that SBS additive is Elastomers polymers (or rubber) with high yield strain compared with other materials. While, PE is plastomers polymers are those materials deform in a viscous manner and becomes harder and stiffer as temperature decrease.

The average creep microstrain of specimens not exposed to short term aging, after 10,000 loading cycles were 11367, 9984, and 9044 for control mixes, mixes prepared using PE additives, and those using SBS additives, respectively. While the average creep microstrain of specimens exposed to four hours of short term aging, after 10,000 loading cycles were 11367, 9984, and 9044 for control mixes, mixes prepared using PE additives, and those using SBS additives, respectively.

The enhancing of asphalt mix mechanical behavior, after SBS modification, was caused by the presence of the dispersed phase; and the swelling of the polymer. The strength and elasticity of asphalt mix specimens prepared using SBS were resulted from physical and cross linking of the molecules through the binder into a three dimensional network. These networks reinforce the binder, and the interaction between them forms critical networks that cause a sharp increase in the binder complex modulus. The polystyrene end blocks provide the asphalt mix with the strength, while, polybutadiene rubbery matrix blocks provide the mix with needed viscosity (Al-Hadidy and Tan, 2011; Chen et al., 2002).

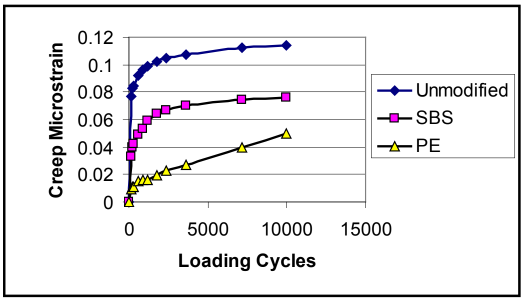


Fig. 7 Creep of specimens prepared using different types of additives at 0 hour short term aging period

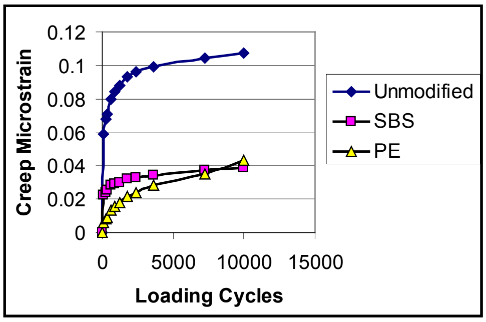


Fig. 8 Creep of specimens prepared using different types of additives at 1 hour short term aging period

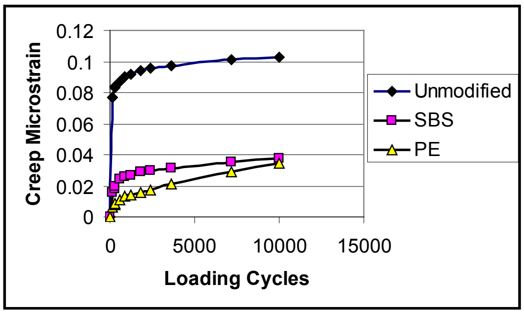


Fig. 9 Creep of specimens prepared using different types of additives at 2 hour short term aging period

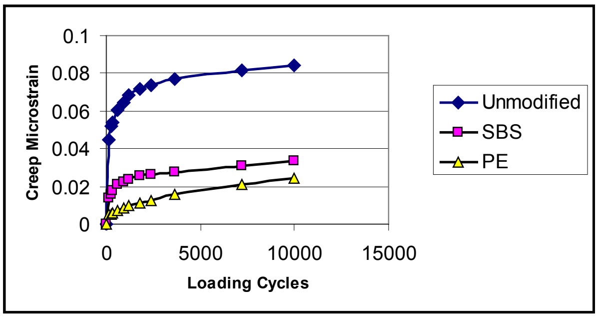


Fig. 10 Creep of specimens prepared using different types of additives at 3 hour short term aging period

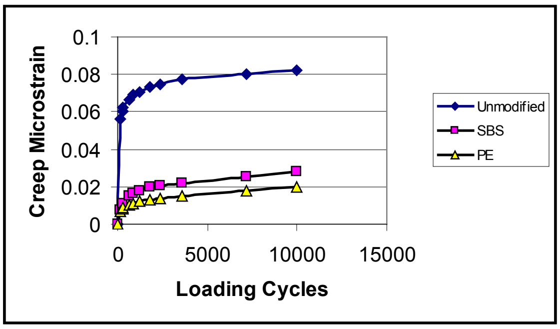


Fig. 11 Creep of specimens prepared using different types of additives at 4 hour short term aging period

6.3 Effect of Testing Temperature

In order to evaluate the effect of aging period length, the control mix specimens (without additives) and those modified with SBS were tested at two temperatures, 25 and 40 °C.

Fig. 12, 13, and 14 show the relationship between accumulated strain (microstrain) (m/m x 10^{-6}) and time for hot mix asphalt control specimen tested at different temperatures.

Based on these figures, it can be seen that at the beginning of the creep test the deformation of asphalt mix specimens tested at 40 °C, were close to those tested at 25 °C. However, after around 7000 cycles, specimens exposed to short term aging period of two hours or less and tested at 40 °C, entered the tertiary creep stage, where sharp increase in the microstrain were noticed.

Asphalt mix specimens exposed to three and four hours of aging and tested at the same temperature did not enter the tertiary creep stage for the tests applied loading cycles (10,000 cycles).

For asphalt mix modified by SBS and PE, the specimens tested at 40 °C experienced much higher creep accumulated strain compared to those tested at 25 °C. This difference has been reduced as aging period increase. After 10,000 loading cycles, asphalt mix specimens modified by SBS and tested at 40 °C, showed creep microstrain equal to about 1.5 to 3 times of those for specimens tested at 25 °C. Asphalt mix specimens modified by PE and tested at 40 °C, showed creep microstrain, after 10,000 loading cycles, equal to about 2 to 3.5 times of those for specimens tested at 25 °C.

For unmodified asphalt mix, the accumulated creep microstrain, after 10,000 loading cycles, for specimens exposed to 0 hour aging and tested at 25 °C was 0.114. While it was 0.381, for those tested at 40 °C.

As the same asphalt mix exposed to 4 hours of aging, the accumulated creep microstrains were 0.082 and 0.092, for specimens tested at 25 °C and 40 °C, respectively.

The reduction in the effect of temperature on the creep deformation as the aging period increase can be explained by the fact that the aging reduce the temperature susceptibility of asphalt, and this will produce higher asphalt viscosity and mix stiffness at 40 °C.

6.4 Effect of Short Term Aging Period on Asphalt Binder Properties

The effect of short term aging period on the unmodified asphalt binder rheological behavior, at different testing temperature, was evaluated using Dynamic Shear Rheometer (DSR).

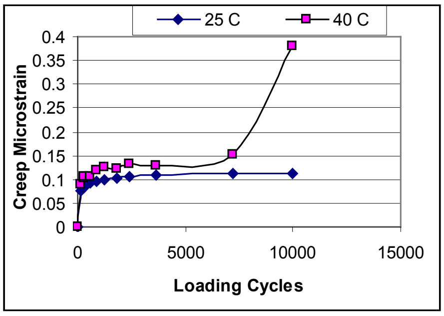
Summary of the tests results are shown in Fig. 15. This figure indicated that as the aging period increased, a huge increase in the ratio of complex shear modulus to the phase angle (G*/sin δ) was noticed. Also, the magnitude of G*/sin δ decreased as testing temperature increased. At 58 °C the value of G*/sin δ for unaged asphalt was 1.14 KPa. As the aging increased to 80, 160, and 240 minutes, the G*/sin δ increased by 4.7, 12.2, and 65.5 times the value at 0 hours of aging. At different testing temperature, the average increase in the magnitude of G*/sin δ are 4.8, 9.6, and 62.0 times the value at 0 hours of aging as the aging increased to 80, 160, and 240 minutes, respectively.

Comparing the increase in asphalt binder G*/sin δ to the increase in creep stiffness as aging period increase indicated that the effect of aging period has much more significant effect on the asphalt binder than that on the asphalt mixture. For unmodified asphalt, the average increase in the magnitude of G*/sin δ, at different testing temperature, were 4.8 and 9.6 times the value at 0 hours of aging as the aging increased to 80 and 160 minutes, respectively. While, for the control asphalt mixtures tested at 40 °C, the magnitude of creep stiffness were about 1.1 and 4.1 times the value at 0 hours of aging as the aging increased to 2 and 4 hours, respectively. It was expected that the aging impact will be more significant in the case of asphalt binder, as the asphalt mixture testing temperature was less than binder testing temperature, and as the main constitute of asphalt mixture is the aggregate, which is not affected by the aging. However, the difference in the impact of aging on the asphalt binder and asphalt mixture was extremely large, which raise the questions: Does the aging of asphalt mix and aging of binder have similar impact on the rheological behavior of asphalt mix. And if the answer is no, which of short term aging techniques (asphalt binder aging and asphalt mix aging) more simulate the field short term aging. These questions can not be answered without extracting the asphalt from asphalt mixtures prepared in the field and in laboratory, compared its G*/sin δ values to each other and to those of binder aged using RTFOT.

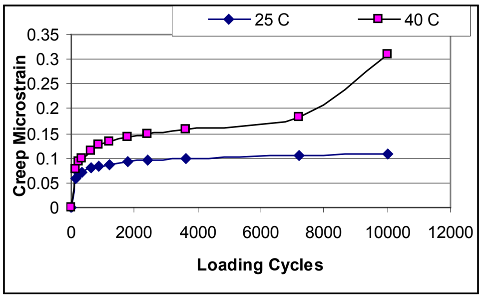
7 Conclusions

This study evaluated the effects of aging duration, type of additive, and testing temperature on creep behavior. Based on the results, the following conclusion can be drawn.

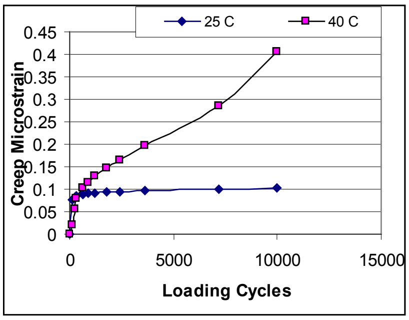
1. Extending the aging period improve the rutting resistance (reduced the creep deformation). Asphalt mix prepared using SBS showed high reduction in creep deformation as aging period increase from 0 to 1 hour, after which small drop in creep deformation was noticed as aging period



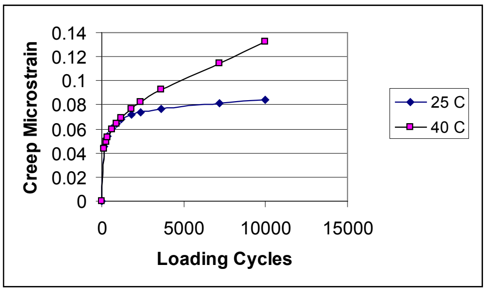
a) Without (0 hours) aging



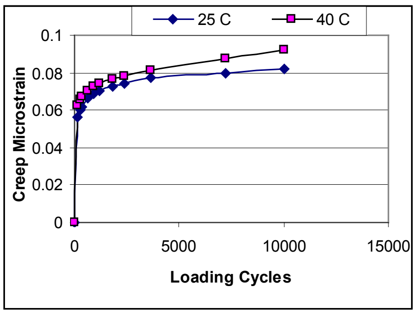
b) One hour of aging



c) Two hours of aging

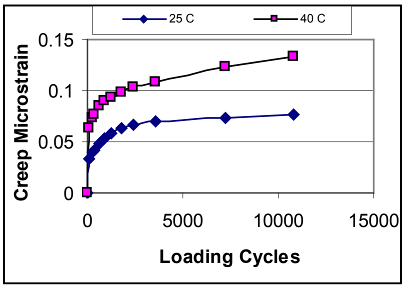


d) Three hours of aging

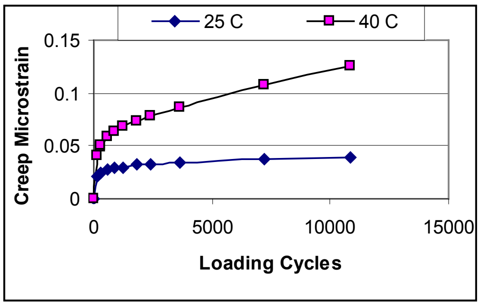


e) Four hours of aging

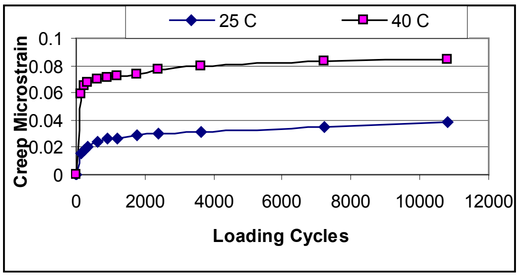
Fig. 12 Creep of control asphalt mix (without additives) specimens exposed to different short term aging periods and tested at different temperatures



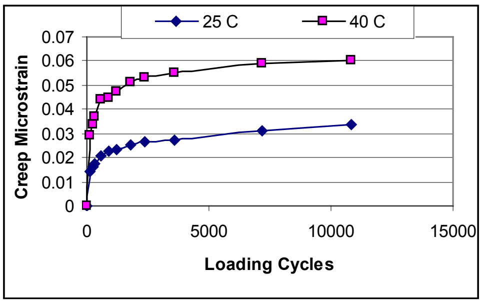
a) Without (0 hours) aging



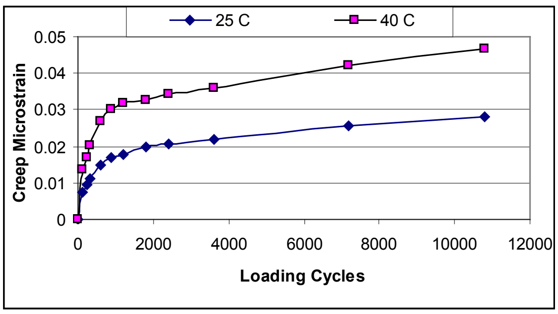
b) One hour of aging



c) Two hours of aging

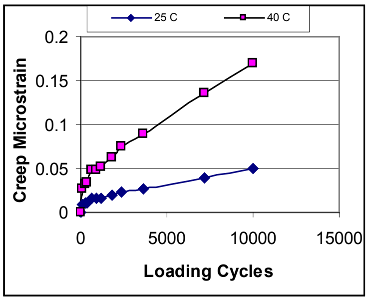


d) Three hours of aging

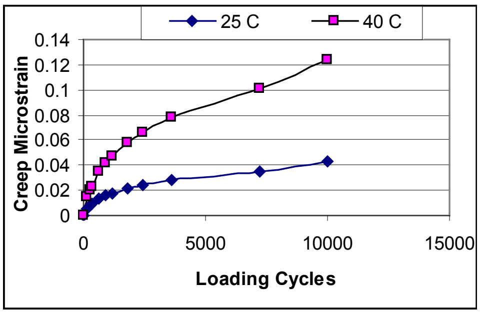


e) Four hours aging

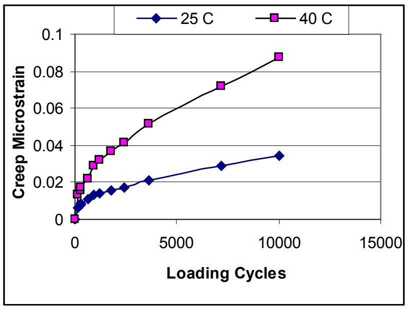
Fig. 13 Creep of Asphalt Specimens prepared using SBS additives and exposed to different short term aging periods and tested at different temperatures



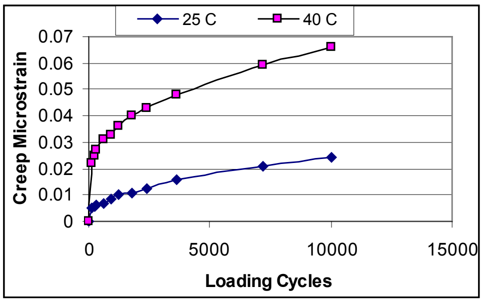
a) Without (0 hours) aging



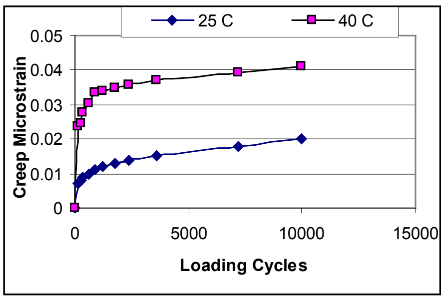
b) One hour of aging



c) Two hours of aging



d) Three hours of aging



e) Four hours aging

Fig. 14 Creep of Asphalt Specimens prepared using PE additives and exposed to different short term aging periods and tested at different temperatures

extended. While mixes prepared using PE show uniform drop in creep deformation as aging period increased.

2. The impact of aging period on the creep behavior was found to be strongly depends on the additives used in preparing the hot mix asphalt.
3. The creep deformation was found to be significantly affected by the testing temperature. This effect was found to be more significant at shorter aging period.
4. Modifying the binder with SBS and PE reduced the creep deformation (improve the rutting resistance).

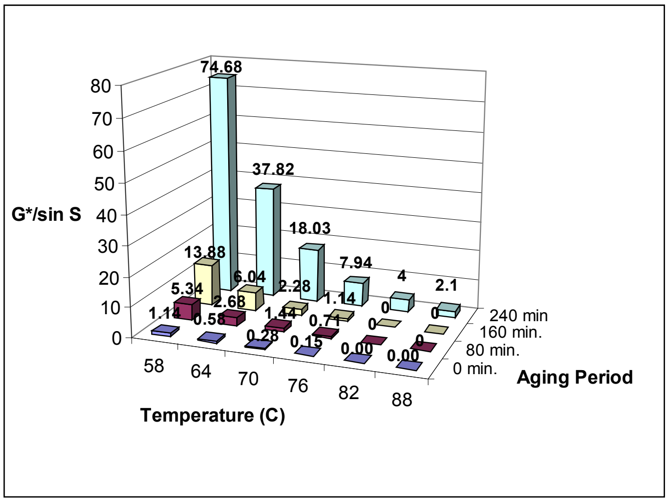


Fig. 15 Effect of short term aging on the magnitude of asphalt shear modulus over phase angle (G*/sinδ)

8 Recommendations

Based on the findings of this research, It is recommended to:

1. Evaluate the effect of aging period using different asphalt types and aggregate types and gradations.
2. Evaluate the effect of different field aging periods (including mixing, transportation, and construction periods) on the creep behavior of asphalt mixes.
3. Assess the effect of aging period on creep behavior at wide ranges of testing temperatures.
4. Comparing the G*/sin δ value of binder aged using RTFOT to the values of binder extracted from asphalt mixtures prepared in both the field and the laboratory.

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