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EFFECTS OF SHORT TERM AGING ON DYNAMIC CREEP PROPERTIES OF ASPHALT MIXTURES

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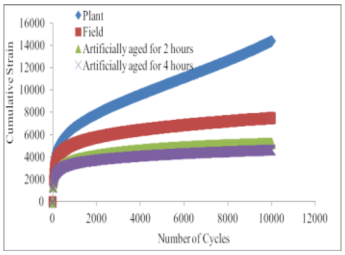
Graphical abstract



Abstract

Many factors affect pavement service life. Aging as one of these factors occurs due to binder volatilization and oxidation. Aging increases binder viscosity and subsequently results in stiffer mixtures. Transportation of asphalt mixture from plant to field may cause variations in the levels of aging. This study attempts to determine the effects of aging on mixture permanent deformation or rutting during transportation from plant to field and to simulate the aging conditions in the laboratory. The rutting parameters evaluated include creep stiffness, cumulative strain, creep modulus and creep rates of mixtures collected from plant, field and samples artificially produced in the laboratory. The results showed that temperature increment significantly changed mixtures rutting properties, while aging during mixture transportation from plant to field has no effect on rutting. It was also found that artificially aging the mixtures by varying aging duration that conducted for this study, cannot exactly simulate the plant and field aging conditions.

Keywords: Asphalt mixture, aging, rutting, dynamic creep

1.0 INTRODUCTION

Rutting is one of the major causes of short pavement service life. Rutting is defined as the progressive accumulation of permanent deformation in each layer due to repeated traffic loads [1]. Tire pressure and wheel load are two factors that adversely affect a pavement structure under repeated traffic loading. The creep test is used to evaluate rutting or permanent deformation of pavement. The test can be used to determine the immediate elastic (recoverable) and plastic (irrecoverable) deformation. In the creep test, load is applied either in static or dynamic mode. It is believed that the dynamic creep test is the more appropriate method to simulate repeated wheel loads. Permanent deformation depends on axle load, number of axle repetitions and temperature. In addition, asphalt binder type, binder content, aggregate type and shape, aggregate gradation, air voids and aging can also affect rutting resistance. Bell *et al*. found that the creep rates for all binders tested reduced significantly at the same time as temperature decreases [2]. Abdullah *et al*. found that excessive asphalt binder content and consequently, reduction in air voids, decrease mixture stiffness hence making the mixture more prone to rutting [3]. According to Kamal *et al*., mixtures prepared using polymer modified binder exhibit less cumulative strain at higher temperatures when compared to conventional asphalt mixtures [4]. Moghaddam *et al*. [5] compared permanent deformation of control and Polyethylene Terephthalate (PET) modified asphalt mixture using dynamic creep test and found that PET remarkably improved permanent deformation characteristics of asphalt mixtures. They also found that the mixture modified by higher amount of PET exhibited better resistance against permanent deformation. Yusoff *et al*. found that nano-silica enhanced rutting resistance of polymer-modified asphalt mixture (PMA) at various aging and moisture conditions [6]. Aging has also received an extensive attention in pavement technology. Hamzah *et al*. found that aging effects on binders' visco-elastic behavior depends on binder type and test temperature. [7]. Baek *et al*. also found that fatigue failure of asphalt mixtures is a function of aging level and test temperature [8]. Hamzah and Omranian studied the impacts of aging during mixture haul, but found no significant effects on pavement air voids [9]. The effects of aging on permanent deformation of asphalt mixture have also been studied. Azari and Mohseni found that temperature, tire pressure, and aging are the main parameters that affect mixture permanent deformation [10]. Hamzah *et al*. indicated that aging increases the creep stiffness but reduces the mixture susceptibility to creep over time [11]. Li *et al*. conducted the creep test to determine the effects of short term and long term aging on plain and polymer-modified asphalt binder for different mixtures and found that for both conditions, the creep rate reduced as aging time increases [12].

Since, pavement resistance to permanent deformation is highly depended on mixture short term aging, this study dwelt upon the creep behavior of dense asphalt mixture subjected to different short term aging conditions. The dynamic creep test was carried out to determine and compare the effects of short term aging on laboratory, field and plant produced samples.

2.0 MATERIAL AND METHODS

2.1 Binder and Aggregate

The binder used in this study was a conventional 80/100 penetration grade (PG-64) supplied by Petronas Ltd. Table 1 shows the conventional properties of the binder. The granite aggregates supplied by Kuad Quarry Sdn. Bhd were used for this study. The median aggregate gradation used was in accordance with the PWD specifications [18] for asphalt mixture type AC14 as shown in Figure 1.

Table 1 Conventional binder properties

Aging Stage	Test Parameters	Value	Standard
Un-aged	Penetration at 25 °C (dmm)	80	ASTM D 5 [13]
	Softening point (°C)	46	ASTM D 36 [14]
	Ductility at 25 °C (cm)	>100	ASTM D 113 [15]
	G*Sinδ at 64 °C (Pa)	1342	ASTM D 7175 [16]
	Viscosity at 135 °C (Cp)	300	ASTM D 4402 [17]
Short Term Aged	G*Sinδ at 64 °C (Pa)	3090	ASTM D 7175 [16]
	Viscosity at 135 °C (Cp)	475	ASTM D 4402 [17]

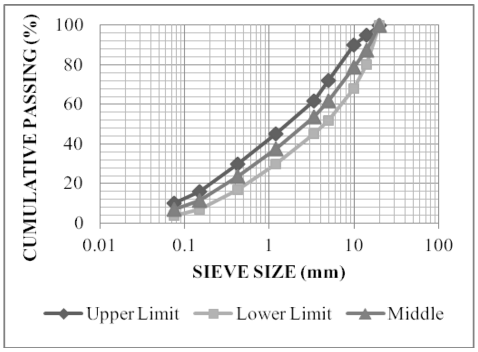


Figure 1 Aggregate Gradation Used in This Study

2.2 Samples Preparation

The loose mixtures were collected from an asphalt mixing plant (Kuad Quarry Sdn. Bhd) and field (Jalan Perda, Utama, Bukit Mertajam). The distance from quarry to field was about 10 km (20 to 30 minutes transportation time depending on traffic density). The collected samples were compacted at 135°C. The laboratory artificially aged mixtures were also prepared based on the quarry procedure. The binder and batched aggregates were mixed together at temperature between 150 to 170˚C. Mixing took about one minute to ensure that aggregates were sufficiently coated with binder. The loose mixtures were then placed inside a conventional oven for either 2 or 4 hours to simulate the mixture short term aging conditions in accordance with procedures outlined by Bell *et al*. [19]. The oven was set at the compaction temperature and the sample was turned upside down after every one hour to ensure the loose mixtures were aged homogeneously. For specimen compaction, the Servopac gyratory compactor was used to better simulate the action of the field roller compactor.

2.3 Test Procedure

The dynamic creep test was conducted to estimate the rutting potential of asphalt mixtures subjected to different short term aging conditions including plant, field and artificially aged samples for 2 and 4 hours, under constant repeated stress. The resistance to rutting and permanent deformation were determined by application of dynamic loading on the specimen. The test was conducted in accordance with NCHRP 9-19 SUPERPAVE [20] procedures using the Universal Testing Machine (MATTA). To conduct the dynamic creep test, cylindrical specimen with approximately 4% air voids was placed in the controlled temperature chamber at 40˚C and 60˚C for at least 4 hours prior to testing. The test parameters used are shown in Table 2. The load was applied to the specimen until it exceeded the specimen bearing load limitation, when it fractured, or when it reached the 10000th cycle. The test was conducted 3 times for each condition (plant, field and artificially produced samples tested at 40 and 60˚C) and the average of three was taken as the result.

Table 2 Dynamic creep test parameters

Parameters	Values
Applied pulse width duration	100 ms
Rest period before next pulse	900 ms
Stress during loading	207 kPa
Stress during rest period	9 kPa
Number of loading	10000 cycle
Temperature	40 and 60˚C

3.0 RESULTS AND DISCUSSION

3.1 Creep Stiffness and Cumulative Strain

Figure 2 illustrates the creep stiffness and cumulative strain temperature dependency for the asphalt mixture samples from field, plant and artificially aged for 2 and 4 hours in the laboratory. Increasing the aging time during sample preparation especially at higher temperature has significant effects on creep stiffness. This is evident from the creep stiffness of 2 hour artificially aged sample, where the creep stiffness is approximately 8% and 42% lower at 40°C and 60°C, respectively, compared to the corresponding values of artificially aged mixture for 4 hours. From Figure 2, aging duration especially at higher temperature, exhibits significant effects on cumulative strain, where cumulative strain of 2 hour artificially aged samples is approximately 8% and 43% lower at 40°C and 60°C, respectively, compared to the corresponding values of artificially aged samples for 4 hours. For all samples tested at elevated temperatures, the creep stiffness decreases, while cumulative strain increases. The creep stiffness at 40°C is approximately 85% higher compared to the corresponding value at 60°C, while the trend reverses for the cumulative strain results. It shows that the rutting potential of all samples increase at higher temperatures.

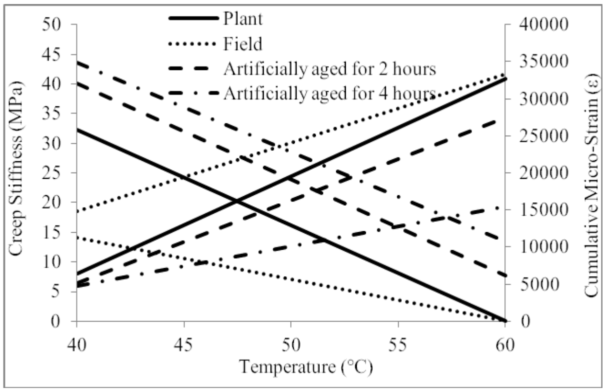


Figure 2 Creep stiffness and cumulative micro-strain versus temperature

Since, field and plant mixtures failed before reaching 10000th cycle at 60°C, Figures. 3 and 4 only present the relationship between cumulative strain and creep stiffness, respectively, versus number of cycles to failure for artificially aged, field and plant produced samples at 40°C. Figure 3 shows that the samples from plant tend to break (progress to tertiary stage) earlier compared to other mixtures. The cumulative strain of 4 hour artificially aged mixture is the lowest compared to other samples. Figure 4 shows that the creep stiffness of plant produced samples is the lowest, while the corresponding values for 4 hours artificially aged mixture is the highest among the tested samples. It indicates that aging duration increment increases mixture stiffness. The results also indicate that mixture resistance to creep increased after haulage from plant to field. It shows that although aging cause's deterioration in pavement service life but, it may increase pavement resistance to rutting.

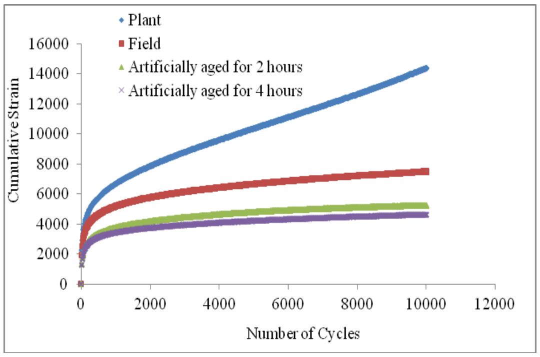


Figure 3 Relationship between cumulative strain and number of cycles to failure at 40 °C

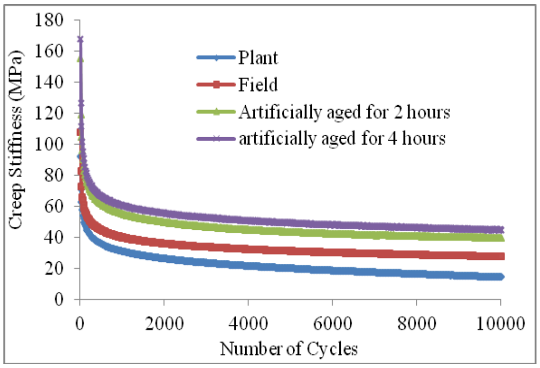


Figure 4 Relationship between creep stiffness at 40°C versus number of cycle

3.2 Creep Modulus

To determine mixture resistance to rutting, the creep modulus is calculated by dividing the applied stress with cumulative axial strain of the samples at secondary stage initiation cycle. To predict the secondary stage initiation cycle number, linear trend lines of primary and secondary stages of creep stiffness are plotted as shown in Figure 5. The cycle at the intersection of these two trend lines is recorded as the cycle that marks the end of the primary creep and the beginning of secondary creep. The results are shown in Table 3. Higher creep modulus indicates higher mixture resistance to permanent deformation. Figure 6 shows that the creep modulus for plant sample is the lowest, while the corresponding values for artificially aged samples for 4 hours are the highest among all samples tested at 40 and 60°C. The creep modulus of plant samples are about 14% and 12% lower compared to the corresponding value of field samples at 40 and 60°C, respectively. The 4-hour artificially aged mixtures exhibit creep modulus by approximately 3.5% and 4.5% higher compared to the creep modulus of samples that were artificially aged for 2 hours tested at 40 and 60°C, respectively. Comparison between the results shows that artificially aged mixtures for 2 and 4 hours exhibit approximately the same creep modulus at 40°C, while their creep modulus discrepancies increase by temperature increment. The results also show that even 2 hours of artificially aging the sample in the laboratory is more than the actual aging that occur when transporting the sample from plant to field. The results also show that temperature increment decreases the creep modulus of all samples. However, the creep modulus differences at 40°C are higher compared to the corresponding values at 60°C.

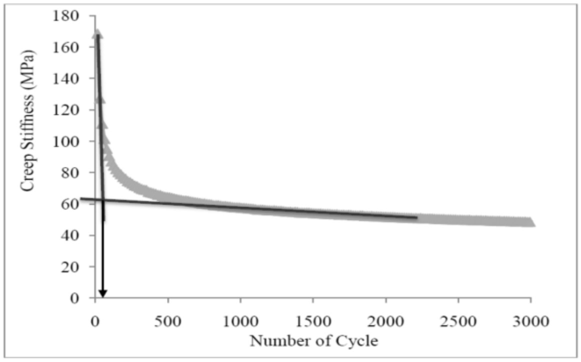


Figure 5 An Illustration of the method used to distinguish between primary and secondary creep

Table 3 Secondary stage initiation cycle

Mixture Type	Secondary Stage Initiation Cycle	
	40°C	60°C
Plant	50	22
Field	55	25
Artificially aged for 2 hours	55	40
Artificially Aged for 4 hours	60	45

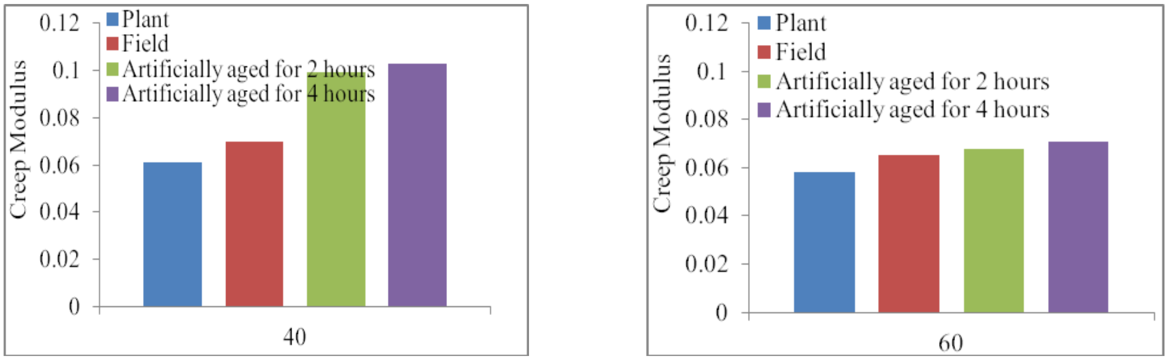


Figure 6 Creep modulus at 40 and 60°C

3.3 Short Term Creep Rate

Short term creep occurs due to traffic over compaction, while the long term creep rate occurs due to the displacement of the aggregates in the mixtures after prolonged traffic loading repetitions. The creep rate is derived from the strain development curve. From Figure 3, it could be seen that the initial strain rates of all mixtures (between 0 to 100 cycles) are high. During this stage, mixtures are densified to resist further densification. Mixture densification stabilises as the strain development rate decreases. Short term creep rate obtained from the gradients of the linear regression equation of cumulative strain versus number of cycles in the range between 100 and 300 cycles. Figure 7 shows that the short term creep rate of artificially aged, field and plant produced mixture at 40°C and 60°C. From Figure 7, the short term creep rate of plant produced mixture is 3.84 and 8.47 when tested at 40°C and 60°C, respectively, which is higher compared to the corresponding results of other mixtures. Artificially aged mixture for 4 hours exhibits creep rate equal to 2.81 and 5.46 at 40°C and 60°C, respectively, which is lower compared to the corresponding results of other mixtures. It implies that artificially aged samples for 4 hours are more resistant to rutting, while plant produced mixture exhibit less resistance to rutting compared to other mixtures. From Figure 7, the creep rate of field produced mixture at 40°C is 3.47, while the corresponding value for 2 hours artificially aged mixture is 3.01, which is approximately 13% higher than creep rate of field produced mixture. It also shows that the creep rate of field produced mixture at 60°C is 7.96, while the corresponding value for 2 hours artificially aged mixture is 6.21, which is approximately 22% higher than the creep rate of field produced mixture. It implies that mixtures artificially aged for 2 hours are more resistant to rutting compared to field and plant produced mixtures. Hence, sample artificially aged for 2 hours cannot exactly simulate the plant and field aging conditions. The results also show that at elevated temperatures, the short term creep rate increases. The short term creep rate at 60°C is approximately 53% higher compared to the corresponding value at 40°C. It shows that the rutting potential increases more than 50% by 20°C temperature increment. It can also be found that extended aging has more influence on rutting resistance at higher temperature compare to lower temperature.

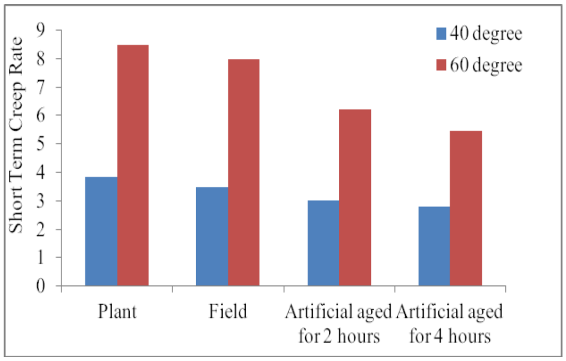


Figure 7 Short term creep rate

An ANOVA is used to statistically determine the effects of temperature on the creep stiffness and cumulative micro-strain as shown in Tables 4. The test is conducted based on 95% significance level. The results show that temperature has significant effects on the changes in mixtures creep stiffness and cumulative micro-strain, which is indicated by P-value less than 0.05. Overall, the results showed that artificially aged samples for 2 hours in terms of short term creep rate and creep modulus at 40 and 60°C, respectively, are in a better agreement with those samples collected from plant and field. However, the artificially aged samples in the laboratory cannot exactly simulate the plant and field conditions. This might be due to exposure of plant and field produced mixtures to various environmental conditions such as humidity and ultra violet, which may increase errors and inconsistency in the experimental analysis. These effects are currently being studied and will be reported in subsequent publication.

Table 4 One-Way ANOVA on effects of temperature

Parameter	Source	DF	SS	MS	F	P
Creep Stiffness	Temperature Conditions	2	1556	778	7.54	0.012
	Error	9	928	103		
	Total	11	2484			
	Std Dev = 10.16	R-Sq = 62.63%		R-Sq(adj) = 54.32%		
Cumulative Micro-Strain	Temperature Conditions	2	758907390	379453695	5.38	0.029
	Error	9	635001017	70555669		
	Total	11	1393908407			
	Std Dev = 8400	R-Sq = 54.44%		R-Sq(adj) = 44.32%		

4.0 CONCLUSION

In order to evaluate the effects of short term aging on pavement, permanent deformation or rutting resistance of asphalt mixture was quantified using dynamic creep test. The results indicate that extending aging duration increase creep stiffness but decrease cumulative strain and short term creep rate. For all samples tested at elevated temperatures, creep stiffness decreases, while accumulated strain and short term creep rate increases. Based on the mixtures creep stiffness and strain, rutting potential is more severe at higher temperature. Higher creep modulus indicates higher mixture resistance to permanent deformation. From creep modulus and short term creep rate results, artificially aged mixture for 4 hours exhibit the highest resistant to rutting compared to other mixtures. The short term creep rate results showed that extended aging exhibits more influence on rutting resistance at higher temperature compared to lower temperature. The overall results showed that the state of aging of the artificially aged mixtures in laboratory is higher compared to the aging severity of the plant and field produced mixtures. Hence, artificially aging the mixtures by varying aging duration cannot exactly simulate the plant and field aging conditions.

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