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EVALUATION ON THE PERFORMANCE OF AGED ASPHALT BINDER AND MIXTURE UNDER VARIOUS AGING METHODS

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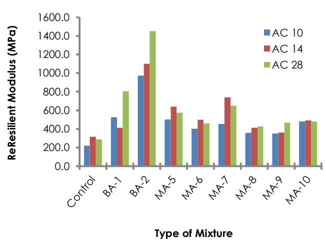
Graphical abstract



Abstract

Hot mix asphalt (HMA) pavement encounter short and long term aging throughout the service life. Laboratory aging is the method used to simulate field aging process of HMA pavement. This study was undertaken to determine the long term effect of different binder and mixture laboratory aging methods on HMA (binder aging and mixture aging). Three types of HMA mixtures were prepared for this study namely Asphaltic Concrete with 10 mm nominal maximum aggregate size (AC 10), Asphaltic Concrete 14 mm (AC 14) and Asphaltic Concrete 28 mm (AC 28). These specimens were conditioned with nine different methods and durations. Resilient modulus test was carried out at 40˚C as an initial indicator of the specimen performance. Permanent deformation of the same specimens was then evaluated by dynamic creep test. Generally, the aged asphalt binder specimens have higher resilient and stiffness modulus compared to aged asphalt mixture specimens. In addition, aged binder specimens have a lower permanent strain which indicates higher resistance to permanent deformation. This study also found that high resilient and stiffness modulus of specimens is attributed by different in heating frequency, temperature, air exposure and binder content of the mixtures.

Keywords: Long term aging, binder aging, mixture aging, HMA, resilient modulus, dynamic creep

1.0 INTRODUCTION

Bitumen or binder undergoes short and long term aging processes throughout the service life. It is extremely complex phenomena because of many factors. Bitumen is exposed to high temperature and high degree of air exposure during the hot mix asphalt (HMA) production (short term aging) before it is exposed to the environment as in-service pavement at a relatively lower temperature for a long duration (long term aging). Loss of volatiles in bitumen during the production phase and progressive oxidation of the in-service pavement are the main reasons why the bitumen becomes harden or stiffen. It also caused an increased in viscosity of bitumen and consequently stiffened the mixtures [1, 2].

Aging might be beneficial since it will harden the mixture and may improve the load distribution properties and resistant to permanent deformation; however, at the same time it may also result in embrittlement which increase the tendency for the pavement to crack and loss of durability in terms of wear resistance [1].Hence, aged HMA mixtures can lead to the development of several types of distresses such as fatigue and thermal crack [3-5].

Laboratory aging is the method used to simulate field aging of HMA pavement (binder aging and mixture aging). Since aging is more relevant to bitumen rather than aggregates, most of the methods specifically designed and developed only for base bitumen [6-8]. Most common and significant aging methods related to bitumen are Thin Film Oven Test (TFOT) and Rolling Thin Film Oven Test (RTFO) for short term aging while Pressurized Aging Vessel (PAV) and Rotating Cylinder Aging Test (RCAT) are specifically for long term aging. Although these methods were developed purposely for bitumen, study conducted by Lu and Isacsson approved that the effect of aging may be different when different methods are used [9]. In addition to artificial binder aging, several methods also exist to simulate the aging process of mixture. According to Airey[10], there are about 16 established aging methods for mixtures as listed in Table 1.

Table 1 Mixture aging methods [10]

Test method	Temperature [°C]	Duration	Specimen condition
Production aging	135	8, 16 , 24 36 hours	Loose
SHRP short term oven aging	135	4 hours	Loose
Bitu test protocol	135	2 hours	Loose
Ottawa sand mixtures	163	Various periods	Compacted
Plancher	150	5 hours	Compacted
Ottawa sand mixtures	60	1200 hours	-
Hugo and Kennedy	100	4 or 7 days	-
Long term aging	60 / 107	2 days / 3 days	Compacted
SHRP long term oven aging (LTOA)	85	5 days	Compacted
Bitu test protocol	85	5 days	Compacted
Kumar and Goetz	60	1, 2, 4, 6, 10 days	Compacted
Long term aging	60	5 to 10days	Compacted
Oregon mixtures	60	0,1 2, 3 5 days	Compacted
SHRP low pressure oxidation (LPO)	60 or 85	5 days	Compacted
Khalid and Walsh	60	Up to 25 days	Compacted
PAV mixtures	100	72 hours	Compacted

Even though there are many established mechanisms or method to artificially aging the HMA, there is very limited study conducted to compare the effect different aging methods. Therefore, this study focused on evaluating the performance of binder and mixture aging methods and the effect of different duration of mixture aging on HMA. 4 aging methods were selected in order to fulfill the objective of the study. The methods were Rolling Thin Film Oven (RTFO), Pressurized Aging Vessel (PAV), Short Term Oven Aging (STOA) and Long Term Oven Aging (LTOA). The details of the aging methods used in this study were further discussed in the next section of the paper.

2.0 MATERIALS AND METHODS

2.1 Materials

80-100 PEN bitumen with average penetration value of 81 PEN was used in this study. The selection of bitumen was based on conventional bitumen grade suggested by the local authority, as stated in Standard Specification for Road Work[11]. The aggregates used in this study were collected from one local asphalt mixing plant in order to control the quality and properties throughout the study.

2.2 Aging methods

In this study, 4 basic aging methods were adopted in order to simulate field aging phenomena. 2 methods applied to simulate the aging process of base bitumen were RTFO and PAV. While another 2 methods implemented to artificially aging the mixture were STOA and LTOA.

2.2.1 Rolling Thin Film Oven (RTFO)

RTFO is the method to simulate the effect of short term aging of base bitumen. The test was conducted based on ASTM D2872 [12]. A total of 8 glass containers (35 g base bitumen per container) were rotated horizontally in the oven with the temperature of 163 °C and airflow at 4000 mL/min for 85 minutes. After the process was completed, the residue was collected and used for next process. Figure 1 shows the specific oven used for RTFO process.

Figure 1 Rolling Thin Film Oven

2.2.2 Pressurized Aging Vessel (PAV)

PAV is a process to simulate the effect of long term aging of bitumen. The test was conducted based on ASTM D6521 [13].A total of 10 pans (50 g RTFO residue) were placed at pan holder before it was placed in the PAV. 2.1 MPa air pressure was applied in the PAV with temperature of 100°C for 20 hours. After the process was completed, the residue was used as a binder for the mixture. Figure 2 shows the PAV and the pan holder used in this study.

Figure 2 Pressurized Aging Vessel

2.2.3 Short Term Aging (LTOA)

Short term oven aging only applies to laboratory loose mixture. This procedure was conducted according to AASHTO R30 [14]. After the bitumen and aggregates were mixed, the mixture was placed in the forced draft oven for 4 hours at a temperature of 135 °C. After 4 hours of aging, the mixtures were compacted and proceed to the next aging process. Figure 3 shows the forced draft oven used for STOA process.

2.2.4 Long Term Aging (LTOA)

According to AASHTO R30 [14], LTOA simulated an aging of HMA for 5 to 7 years of in-service pavement. Through the simulation process, the performance of the mixture can be estimated within the pavement service life. To avoid or minimize slump during the process, compacted specimens were wrapped with a wire mesh. This method facilitated the highest amount of air circulation without allowing for any slump. The specimens were placed in the oven for 5 to 10 days at 85˚C in the forced draft oven. This process was implemented to evaluate the effect of aging at different conditioning time.

Figure 3 Forced draft oven

2.3 Specimen Preparation

Specimens were prepared in a standard Marshall mould with an average height of 65 mm and diameter of 100 mm. Bitumen and aggregates were preheated to the specified temperature and mixed uniformly. The mixing and compaction temperatures were selected from the rotational viscosity test results. Specimens were prepared at optimum binder contents as listed in Table 2.

Table 2 Properties of HMA mixtures

Type of Mixture	Binder Content [%]
AC 10	6.1
AC 14	5.1
AC 28	4.8

Each specimen was compacted with 75 blows per face by automatic Marshall compactor. Specimens were allowed to be cooled overnight before proceed to the test. Figure 4 illustrates the overall flow of the study and Table 3 shows the detail of the specimen and the corresponding aging methods.

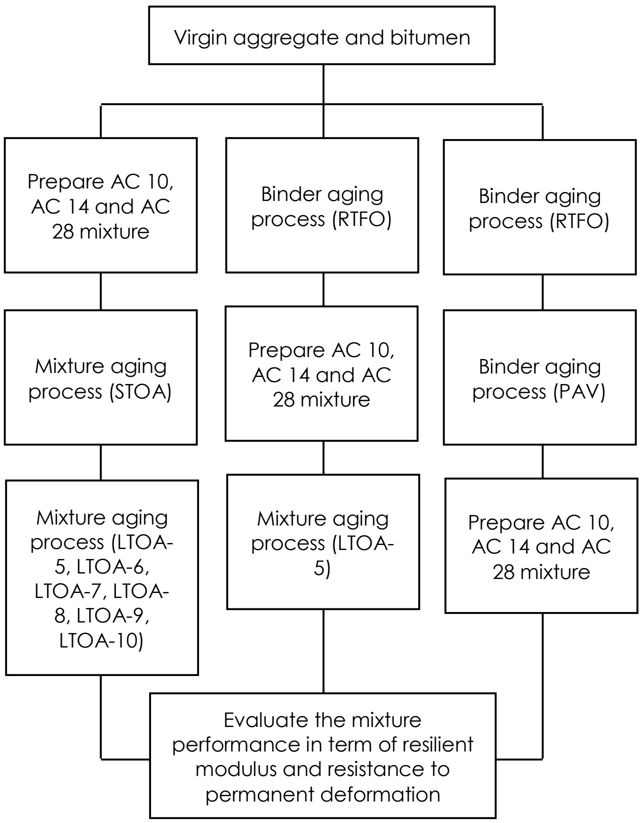


Figure 4 Flow of the study

Table 3 Aging process and the designation of the specimens

Specimen No.	Process of Aging		Flow of Aging	Designation
	Short term	Long Term		
1	-	-	-	Control
2	RTFO	LTO-5	Fresh → RTFO → LTOA-5	BA-1
3	RTFO	PAV	Fresh → RTFO → PAV	BA-2
4	STOA	LTO-5	Fresh → STOA → LTOA-5	MA-5
5	STOA	LTO-6	Fresh → STOA → LTOA-6	MA-6
6	STOA	LTO-7	Fresh → STOA → LTOA-7	MA-7
7	STOA	LTO-8	Fresh → STOA → LTOA-8	MA-8
8	STOA	LTO-9	Fresh → STOA → LTOA-9	MA-9
9	STOA	LTO-10	Fresh → STOA → LTOA-10	MA-10

2.4 Indirect Tensile Resilient Modulus Test

HMA stress-strain relationship, as characterized by elastic or resilient modulus, is an important characteristic in pavement material analysis. Indirect Tensile Test used to determine the elastic or resilient modulus. This non-destructive test is the measurement of dynamic stresses of pavement and the corresponding strain as presented in Equation 1.

$$M_R = \frac{\sigma_d}{\varepsilon_r} \quad \text{(Equation 1)}$$

Where M_R is the resilient modulus; σ_d is the maximum applied load (stress); and ε_r is the strain of the specimen. In this study, all aged and control specimens were tested for resilient modulus by using Universal Testing Machine (IPC UTM-5). Each specimen was tested at 40°C. In accordance with ASTM D 4123-82 [7], the specimens were conditioned at the selected test temperature for 4 hours before they were tested. Resilient modulus test was done on the specimens using repeated load of fixed magnitude and cycle duration to a cylindrical test specimen. A haversine load with 1000 N peak force was applied with three pulse width of 100 ms along with a rest period of 900 ms. All specimens were tested at three different pulse repetition period (1000, 2000 and 3000 ms); 1000 ms indicates high traffic volume while 2000 and 3000 ms indicate medium and low traffic volume. Hence, the specimen received one load cycle per second. After 5 pulse, the resilient modulus can be calculated using the horizontal deformation and an assumed Poisson's ratio. The test procedure then repeated by orientating the specimen at approximately 90 degrees (90 °). All test data were calculated and recorded by specific computer software.

2.5 Dynamic Creep Test

The dynamic creep test is also known as repeated load axial test is an unconfined test conducted using Universal Testing Machine (IPC UTM-5) that applies a repeated pulsed uniaxial stress on specimen. The test was conducted to determine the resistance of the specimen to permanent deformation. The test was performed at 40°C and preloaded for 30 seconds as conditioning stress to ensure that the platen is loaded flat on specimen. The specimen was conditioned at the desired temperature for two hours before commencement of the test. The deviator stress during each loading pulse was 300 kPa. The test was conducted until 3,600 cycles or accumulated axial strain attained 5%, whichever occurred first. The deformations were measured using Linear Variable Differential Transducers (LVDT). Results from the repeated load creep test were presented in terms of the cumulative permanent strain versus the number of loading cycles. The dynamic creep is more simulative to traffic loading than static creep.

3.0 RESULTS AND DISCUSSION

3.1 Effect Of Different Aging Methods On Resilient Modulus Of The Mixtures

Figure 5 shows the resilient modulus values of AC 10, AC 14 and AC 28 mixtures. The test was performed on nine aging condition at 40˚C and the results were averaged based on results of three specimens. Generally, resilient modulus of aged asphalt binder specimens were found to have a significant difference compared to aged asphalt mixture specimens. A similar findings was pointed out by Lu and Isacsson[9]. Based on the graph, BA-2 specimen exhibited highest resilient modulus compared other specimens. This result occurred because BA-2 specimen was experienced high temperature and air pressure of RTFO and PAV compared to other specimens. Meanwhile, MA-7 specimen shows the highest resilient compared to other aged asphalt mixture specimens. Specimens that were aged for more than 7 days (MA-8 to MA-9) show insignificant change on the resilient modulus value.

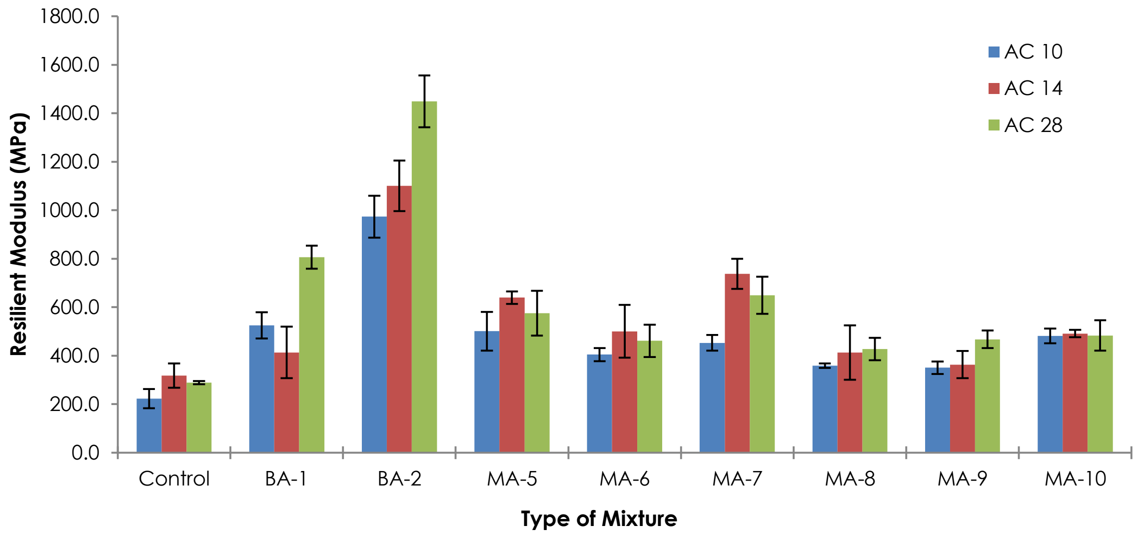


Figure 5 Resilient modulus of aged HMA at 40˚C

3.2 Effect Of Different Aging Methods On Permanent Strain And Stiffness Of The Mixtures

The test evaluated the effect of different aging methods on the permanent deformation of the mixtures at 40˚C. In this study, permanent deformation was assessed based on permanent strain and stiffness modulus of the specimens[1, 2]; the values were calculated and summarized in Table 4 and Table 5. Aged asphalt binder specimens show lower permanent strain and higher stiffness modulus values under the 3,600 cycles loading. Based on the tables, BA-2 specimen exhibited lowest permanent strain and highest stiffness modulus compared to other specimens. MA-7 specimen of AC 10 and AC 14 show the lowest permanent strain and highest stiffness modulus compared to other aged asphalt mixture specimens. Meanwhile, MA-10 exhibits the lowest permanent strain and highest stiffness modulus for AC 28. This result occurred due to the percentage of binder content in AC 10 and AC 14 is slightly higher than AC 28. Since aging is more significant to bitumen; therefore tendency for mixture with high binder content to get aged earlier is higher than the mixture with lower binder content.

Table 4 Permanent strain of mixtures

Type of Mixture	Permanent Strain (Microstrain)		
	AC 10	AC 14	AC 28
Control	49915	46617	10175
BA-1	5913	5640	5035
BA-2	1107	747	1107
MA-5	23085	15805	25740
MA-6	23340	16487	21237
MA-7	21413	8510	27185
MA-8	35785	30923	22690
MA-9	25065	36257	21077
MA-10	25000	20237	11170

Table 5 Stiffness modulus of mixtures

Type of Mixture	Stiffness Modulus (MPa)		
	AC 10	AC 14	AC 28
Control	6.01	6.44	29.48
BA-1	50.73	53.19	59.58
BA-2	271.08	401.80	271.08
MA-5	13.00	18.98	11.66
MA-6	12.85	18.20	14.13
MA-7	14.01	35.25	11.04
MA-8	8.38	9.70	13.22
MA-9	11.97	8.27	14.23
MA-10	12.00	14.82	26.86

4.0 CONCLUSION

The experimental results of this study show the long term effect of different laboratory aging methods and duration on HMA mixtures. Resilient modulus and resistance to permanent deformation of aged mixtures were compared to control mixture to identify the best aging method that can closely simulate the aging of the pavement.

Based on the results, the aged asphalt binder specimens have higher resilient and stiffness modulus compared to aged asphalt mixture and control specimens. In addition, aged binder specimens also have a lower permanent strain. This study found that high resilient and stiffness modulus of aged binder specimens may be attributed by the different heating temperature and air exposure. In term of aged asphalt mixtures, MA-7 is observed to be the best specimen that simulates field aging for AC 10 and AC 14; meanwhile MA-10 is the best specimen simulates field aging for AC 28. The difference in aging duration could be resulted from the variation of binder content in the mixtures.

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