Influence of Aging Time on Asphalt Pavement Performance

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ABSTRACT

Aging of asphalt pavements typically occurs through oxidation of the asphalt and evaporation of the lighter maltenes from the binder. The main objective of this study is to evaluate influence of aging on performance of asphalt paving materials.

Asphalt concrete mixtures, were prepared, and subjected to short term aging (STA) procedure which involved heating the loose mixtures in an oven for two aging period of (4 and 8) hours at a temperature of 135 ^{o}C. Then it was subject to Long term aging (LTA) procedure using (2 and 5) days aging periods at 85 ^{o}C for Marshall compacted specimens.

The effect of aging periods on properties of asphalt concrete at optimum asphalt content such as Marshall Properties, indirect tensile strength at 25 ^{o}C, Resilient Modulus and resistance to permanent deformation were evaluated.

The impact of Short-term and long-term aging on asphalt concrete properties was evaluated. The stiffness of the mixture increases by increasing aging period that lead to increase of Marshall Stability, indirect tensile strength, and the resilient modulus, which leads to increases the resistance of mixtures against permanent deformation. The 8 hr. short term aging causes the Marshall stability, indirect tensile strength at 25 ^{o}C and resilient modulus to be increased by 52%, 34 % , 20% respectively as compared with control mixture while, the permanent deformation decreased by (33 %) as compared with control mixture.

Key words: Marshall Properties, indirect tensile strength, permanent deformation, short-term ageing, long-term aging.

تأثير زمن التقادم على اداء الرصفة الإسفلتية

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الخلاصة

تقادم التبليط الاسفلتي عادة ما يحدث من خلال أكسدة الإسفلت وتبخر المواد المتطايرة من الاسفلت الإسمنتي. الهدف الرئيسي من هذه الدراسة هو تقييم تأثير التقادم الزمني على اداء الاسفلت الاسمنتي ومواد الرصفة الإسفلتية. تم تحضير الخلطات الإسفلتية باستخدام أنواع الاسفلت المختلفة حيث عرضت هذه الخلطات للتقادم القصير الامد والذي يتضمن تسخينها في الفرن لفترات زمنية (4, 8) ساعة عند درجة حرارة 135 درجة مئوية (وهي مفككه) ثم عرضت هذه الخلطات للتقادم الطويل الامد خلال فترات زمنية مختلفة (2 , 5) يوم عند درجة حرارة 85 درجة مئوية بعد رصها الى نماذج. تم دراسة تأثير زمن التقادم على خواص الخلطات (خصائص مارشال , قوة الشد غير المباشر عند 25 درجة مئوية, ومعامل المرونة ومقاومة التشوه الدائم) التي تم تحضيرها عند المحتوى الاسفلتي الامثل .تم تقييم تأثير التقادم قصير الامد وطويل الامد على خصائص الخرسانة الإسفلتية. ان صلابة الخلطة تزداد بزيادة زمن التقادم الذي يؤدي إلى زيادة ثبات مارشال، والشد غير المباشر، ومعامل المرونة، الأمر الذي يؤدي إلى زيادة مقاومة الخلطة ضد التشوه الدائم. ان زمن التقادم بمقدار 8 ساعات يؤدي الى

زيادة كل من قيم ثبات مارشال ومقاومة الشد غير المباشر عند درجة حرارة 25 مئوية ومعامل المرونة الحركي بمقدار 25%, 34%, 20% على التوالي عند المقارنة مع الخلطة المرجعية بينما قل التخدد بمقدار 33% عند مقارنته بالخلطة المرجعية.

الكلمات الرئيسية : خصائص مارشال, قوة الشد غير المباشر, الانفعال الدائم, التقادم قصير الامد, التقادم طويل الامد

1. INTRODUCTION

One of the major problems facing asphalt during its service life is the "aging" process, Aging causes the asphalt to stiffen and become brittle which leads to a higher potential for fatigue and thermal cracking.

Asphalt paving mixtures are used as surface or base layers in a pavement structure to distribute stresses caused by loading and to protect the underlying unbound layers from the effects of water. To adequately perform both of these functions over the pavement design life (age), the mixture must also withstand the effects of air (oxygen) and water, resist permanent deformation, and resist cracking caused by loading and the environment, **Bordea et al., 2002**.

Aging is one of most and important factors that affect performance of asphalt pavement because other factors of failure (moisture damage , thermal cracking ,rutting , and fatigue) affect certain mode of pavement performance while aging factor enters as cause of failure for each mode. It is necessary to study aging effects on asphalt and asphalt aggregate mixture separately for two reasons .First, during mixing and laydown process, asphalt properties are most affected by aging than aggregate; therefore performing aging tests on asphalt only gives ideal about performance of asphalt mixture. Second, the presence of aggregate mixed with asphalt render asphalt behaves in another mode under aging effects, **Sarsam and Lafta, 2014.**

Ageing is primarily associated with the loss of volatile components and oxidation of the bitumen during asphalt mixture construction (short-term ageing) and progressive oxidation during service life in the field (long-term ageing). Bitumen slowly oxidizes when in contact with air (oxygen) increasing the viscosity and making the bitumen harder and less flexible. The degree of viscosity is highly dependent on the temperature, time and the bitumen film thickness. Excessive age hardening can result in brittle bitumen with significantly reduced flow capabilities, reducing the ability of the bituminous mixture to support the traffic and thermally induced stresses and strains, which contribute to various forms of cracking in the asphalt mixture, **Brown et al., 1995**.

2. BACKGROUND

Ageing of bituminous binders in asphalt mixtures is well studied because of its effect on the mechanical performance of the binder and the durability of the asphalt pavement. Since some of the most important rheological properties of bitumen depend on the chemical constitution, **Simpson et al., 1961**, and the ageing mechanism affects the chemical composition it is clear that also the rheological properties of the binder will change. **Jamieson and Bell, 1995**, found a good correlation with aged road mixtures from 14 to 19 years old pavements, when the long-term step was extended from 4 to 8 days. They concluded that the short-term oven aging (STOA) method showed an equivalence of 0-2 years and the long-term oven aging (LTOA) method up to 5-15 years, depending on the climate.

Harvey and Tsai, 1997, conducted a laboratory study to investigate the influence of long-term oven aging on the fatigue of asphalt concrete beam specimens using controlled-strain loading. They used two sources of asphalt AR-4000 and one type of aggregate. Their results show that aging is sensitive to the type of asphalt used and that stiffness increase associated with aging does not necessarily reduce the beam fatigue life. The application of the beam fatigue and stiffness results in the analysis of thin and thick pavement sections indicated that aging prolonged the fatigue life of the pavement structure, **Korsgaard et al., 1996**. Oxidized compacted mix specimens (5% bitumen, 1.1-5.8% air voids) using the pressure ageing vessel (PAV) test developed under the SHRP research program for oxidizing bitumen. They oxidized the mix specimens at 100°C and 2.1 MPa of air for up to 72 hours. The penetration and softening point of the extracted bitumen were measured. They reported that the rate of oxidation of pure bitumen (presumably as 3.2 mm films) was 4 times faster than that of bitumen in the mix.

Hachiya et a.,l 2003, prepared compacted slabs of dense mix and cut them into 20x40x250 mm beams. They oxidized these in an oven at 70°C for up to eight hours and measured the flexural strength, strain at failure and stiffness of the mix at –10° to 30°C. They also carried out oxidation experiments at 60°C in a pure oxygen atmosphere for up to 20 days. The laboratory results were compared with data from samples exposed outdoors for up to five years, showing similar trends (though with quantitative differences); and conclude that a combination of the two oxidation methods would be most suitable. Their data seem to show that measured flexural properties were relatively insensitive to oxidation time (as opposed to test temperature). Though the authors do not correlate laboratory oxidation time to field ageing period, their data suggest that five days' exposure to pure oxygen at 60°C is approximately equivalent to 3 years' field ageing, based on flexural properties over 0°C.

3. MATERIAL CHARACTERIZATION

The materials used in this work, namely asphalt cement, aggregate, and fillers were characterized using routine type of tests and results were compared with State Corporation for Roads and Bridges Specifications (**SCRB, R/9 2003**).

3.1 Asphalt Cement

The asphalt cement used in this work is a 40-50 penetration grade. It was obtained from the Dora refinery, south-west of Baghdad. The asphalt properties are shown in **Table 1.**

3.2 Aggregate

The aggregate used in this work was obtained from Al-Nibaie quarry; it consists of crushed quartz, hard, tough, grains, free of injurious amount of clay, loam or other deleterious substances. This aggregate is widely used in Baghdad city for asphalt concrete mixes. The coarse and fine aggregates used in this work were sieved, and recombined in the proper proportions to meet the wearing course gradation as required by specification (**SCRB, R/9 2003**). The physical properties and selected gradation curve for the aggregate are presented in **Table 2.** and **Fig. 1.**

3.3 Filler

The filler is a non-plastic material that passing sieve No.200 (0.075mm). In this work, the control mixes were prepared using ordinary Portland cement (from Tasluga factory) as a mineral filler at a content of 7 percent, this content represent the mid-range set by the **SCRB, 2003** specification for the type IIIA mixes of wearing course. The physical properties of the filler are presented in **Table 3.**

4. PREPARATION OF MIXTURES

Three types of mixtures have been prepared in the study using Marshall Method, control mixture; short and long- term aged mixtures.

4.1 Preparation of Control Mixture

The efficiency of mixing procedure depends on providing homogenous mix and uniform coating of aggregate with asphalt. Asphalt mixtures were prepared in this investigation as follows: The aggregates are washed, dried to a constant weight at 110 ºC, and then sieved. The combined aggregate was heated to a temperature of (160 ºC) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150 ºC) to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement was added to the heated aggregate to achieve the desired amount, and mixed thoroughly by hand for 2 minute until all aggregate particles are coated with asphalt cement. The Marshall Mold assembly were (101.6 mm) in diameter and (63.5 ±1.27 mm) in height. Spatula and compaction hammer were heated on a hot plate to a temperature between (90-150 ^{o} C). The asphalt mixture was placed in the preheated mold and it was then spaded vigorously with the heated spatula 15 times around the perimeter and 10 times in the interior. The temperature of the mixture immediately prior to compaction was between (140-150^{o} C). Then, 75 blows on the top and bottom of the specimen were applied with a compaction hammer of 4.535-kg sliding weight, and a free fall of (457.2 mm). The specimen in mold was left to cool at room temperature for 24 hours and then it was removed from mold by using sample extractor. The asphalt concrete was prepared as per **AASHTO, 1994** procedure.

4.2 Preparation of Aged Mixture

Aging of mixture was conducted in accordance to **AASHTO**, **SP2 2002**. The short-term mixture conditioning for the mechanical property testing procedure is designed to simulate the plant-mixing and construction effects on the mixture. The long-term mixture conditioning for the mechanical property testing procedure is designed to simulate the aging the compacted mixture will undergo during seven to ten years of service.

4.2.1 Short-term aging

The same procedure to prepare the control mixture was adopted; but after preparation of the mixture, the loose mix was placed in a pan, and spread to an even thickness ranging between 25 and 50 mm. the mixture in pan was placed in the conditioning oven for (4, 8) hr. at a temperature of 135 °C and Stir the loose mix every 60 minutes to maintain uniform conditioning. After aging process, the loose mix was removed from the forced-draft oven. The conditioned mixture is compact by Marshall Hammer in the same procedure as that of virgin sample.

4.2.2 Long-term aging

In order to simulate long-term aging of HMA that occurs during the pavement service life, Marshall sized compacted specimens prepared from mixtures exposed to short-term aging were placed in a forced-draft oven at 85°C for (48,120) h. At the end of the aging periods, the oven is switched off and left to cool to room temperature before removing the specimens. The specimens were not tested until at least 24 h after removal from the oven.

5. EXPERIMENTAL WORK

The experimental work was started by determining the optimum asphalt content for all the asphalt concrete mixes using the Marshall mix design method .**Table 4** shows that the optimum asphalt content (O.A.C) for asphalt concrete mixture of 4.7% and the performance properties.

5.1 Marshall Test Method

This method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to **ASTM (D 1559).** Marshall Stability and flow tests were performed on each specimen. The cylindrical specimen was placed in water bath at 60 ˚C for 30 minutes, then inserted into the testing device and then compressed on the lateral surface at constant rate of (50.8mm/min) until the maximum load (failure) was reached. The maximum load resistance and the corresponding flow value were recorded. The bulk specific gravity and density **ASTM (D 2726),** theoretical (maximum) specific gravity of void-less mixture were determined in accordance with **ASTM (D 2041).** The percent of air voids was then calculated.

5.2 Indirect Tensile Strength Test

Specimens were prepared by Marshall Method and tested for indirect tensile strength according to **ASTM (D 4123).** The prepared specimens were cooled at room temperature for 24 hours, immersed in a water bath at different testing temperatures (25 and 40 ˚C) for 30 minutes. Then they were tested by Versa-Tester using a 1/2 in. (12.5 mm) wide curved, stainless steel loading strip on both the top and bottom, running parallel to the axis of the cylindrical specimen which was loaded diametrically at a constant rate of 2 in/min. (50.8 mm/min.) until reaching the ultimate loading resistance. The indirect tensile strength (ITS) was calculated, as follows:

$$\mathbf{ITS} = \frac{2P}{\pi\, t\, D} \qquad (1)$$

where:

ITS = indirect Tensile Strength, MPa

P = ultimate applied load (N).

t = thickness of specimen (mm),

D = diameter of specimen (mm).

5.3 Indirect Tension Repeated Load Test

The Indirect Tension repeated loading tests were conducted for cylindrical specimens, 101.6 mm in diameter and 63.5 mm (2.5 inch) in height, using the pneumatic repeated load. In these tests, repetitive compressive loading with a stress level of 20 psi was applied in the form of rectangular wave with a constant loading frequency of 1 Hz (0.1 sec. load duration and 0.9 sec. rest period) and the axial permanent deformation was measured under the different loading repetitions. All the uniaxial repeated loading tests were conducted at 40°C (104°F). The specimen preparation method for this test can be found elsewhere, **Albayati, 2006**. The permanent strain (εp) is calculated by applying the following equation:

$$\varepsilon p = \frac{pd * 10^6}{h} \qquad (2)$$

where

εp= axial permanent microstrain

pd= axial permanent deformation

h= specimen height

Also, throughout this test the resilient deflection is measured at the load repetition of 50 to 100, and the resilient strain (ε_r) and resilient modulus (Mr) are calculated as follows:

$$\varepsilon_r = \frac{rd}{h} \qquad (3)$$

$$Mr = \frac{\sigma}{\varepsilon_r} \qquad (4)$$

where
εr= axial resilient microstrain
rd= axial resilient deflection
h= specimen height
Mr= Resilient modulus
σ = repeated axial stress
εr= axial resilient strain

The permanent deformation test results for this study are represented by the linear log-log relationship between the number of load repetitions and the permanent micro-strain with the form shown in Eq.6 below which is originally suggested by **Monismith et. al., 1994, and Barksdale 1972.**

$$\varepsilon p=aN^b \tag{5}$$

where
εp= permanent strain
N=number of stress applications
a= intercept coefficient
b= slope coefficient

6. RESULTS AND DISCUSSION

6.1 Effects of Aging Time on Marshall Properties

The variation of Marshall Properties with aging time is shown in **Fig.2** which is based on the data presented in **Table 5.** Marshall Stability gives the indication about the resistance of asphalt mixture to permanent deformation; a High value of Marshall Stability indicates increased Marshall Stiffness. Figure (2-a) shows the effect of short and long term aging periods on Marshall Stability of asphalt mixture, and it can be observed that the short and long term aging of asphalt mixture increase the Marshall Stability values. The Marshall stability after 8 hr short aging is higher than that of control mixture by 52.2%. In the case of long term aging of 5 day, the stability increase by 66% as compared to control mixture. This may be attributed to the loss of volatiles which makes the asphalt concrete more stiff and can resist the deformation. From fig (2-a) it found that Marshall stability for mix that exposed to 8 hr short aging is equivalent to that at 2 day long aging. Figure (2-b) shows the effect of short and long term aging periods on Marshall Flow asphalt mixture. It can be observed that the short term aging of asphalt mixture reduced the Marshall Flow values, and also the flow value for long term aging reduced more than short term aging. these reduction may be related to that the aging process make the mixture more stiffer than control mixture and also may be related to the good interlocking offered by asphalt binder and coarse aggregate particles and the reduction in fluidity of the binder.
Air void in the mixture is an important parameter because it permits the properties and performance of the mixture to be predicted for the service life of the pavement and percentage of air voids is related to durability of asphalt mixture. Figure (2-d) shows the effect of short and long term aging on voids in total mix (VTM) percent's for asphalt mixture investigated .It is clear from Figure that the air void is increased with increased aging time and the 8 hr. short term aging have VTM more than 2 day long term aging but less than 5 day aging. This may be related to the loss of volatiles and reduction in asphalt volume. Test results agrees well with **Sarsam, 2007**.

6.2 Effect of Aging Time on Indirect Tensile Strength Test

The indirect tensile strength test is used to determine the tensile properties of the asphalt concrete, which can be further related to the cracking properties of the pavement. **Fig. 3** shows Effect of aging times on ITS @25 ^{0}C for asphalt mixture. Results indicated that indirect tensile strength was 1471 KPa, these value increased during short term aging process. For 8 hr. aging, the ITS shows (34.1%) increment more than that of control mixture. While After 2 day aging the ITS give lower value than 8 hr. aging by 3.5% ,this indicate that 8 hr. aging have more severity than 2 day aging ,ITS was increased by (13.4%) at 5 days aging when compared to 2 days aging . Results agrees well with **Sarsam, 2007,** and **Sarsam and Lafta 2014** work.

6.3 Effect of Aging on Resilient Modulus Test

Table 6 shows Resilient Modulus value for mixture with asphalt cement. It was observed that the resilient modulus increased with increased aging period , such increment may be related to increase in stiffness. Higher resilient modulus results will generate great rutting resistance development in the asphalt pavements.

6.4 Effect of Aging on Resistance to Permanent Deformation

The result of permanent deformation tests is shown in **Fig.4** which is based on the data presented in **Table 7.** The analysis of permanent deformation in this study is based on intercept, slope parameters. The slope of control mixture was higher than that of mix with 8 hr. short term aging by approximately 3.3%, and higher than 5 day long term aging by approximately 9.3% as compared with control mix. From the table below, the intercept value is decreased as the aging time increases for various type of asphalt, this mean that the aging have lower micro-strain at first load cycles. Results are in agreement with, **Sarsam and AL-Zubaidi, 2014** findings.

7- CONCLUSIONS

1. The aging of asphalt concrete mixture lead to changes in the mixture properties, the 8 hr. short term aging causes the Marshall stability, indirect tensile strength at 25 ^{o}C and resilient modulus to be increased by 52.2%, 34.1%, and 20.6% respectively as compared with control mixture. The permanent deformation decreased by (33.4%) as compared with control mixture.

2. The 5 day long term aging causes, the Marshall stability, indirect tensile strength at 25^{o}C, and resilient modulus to be increased by 66%, 46.7%, and 40% respectively as compared with control mixture while, permanent deformation decreased by(53.6%) as compared with control mixture.

3.The 8 hr. short term aging period has an equivalent effect on the properties of asphalt concrete as compared to that of 2 day long term aging.

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Table 1. Physical properties of asphalt cement.

Property	Unit	ASTM Designation	Test Result	SCRB, 2003 Specifications
Penetration (25˚C, 100 gm, 5sec)	0.1 mm	D 5	41	40-50
Softening point (ring & ball).	°C	D 36	49.4	--------
Ductility (25˚C, 5 cm/min).	cm	D 113	>100	>100
Flash point (cleave land open cup)	°C	D 92	275	>232
Residue from thin film oven test		D-1754		
Retained Penetration of Residue	%	D 5	66	>55%
Ductility of Residue	cm	D 113	87	>25%
Loss on Weight %	%	D 1754	0.3	< 0.75

Table 2. Physical properties of aggregates.

Property	Value	ASTM Designation No.
Coarse aggregate		
Bulk specific gravity	2.584	ASTM C 127
Apparent specific gravity	2.608	ASTM C 127
water absorption %	0.57%	ASTM C 127
Wear % (Los Angeles abrasion)	13.08%	ASTM C 131
Fine aggregate		
Bulk specific gravity	2.604	ASTM C 128
Apparent specific gravity	2.664	ASTM C 128
% water absorption	1.419%	ASTM C 128

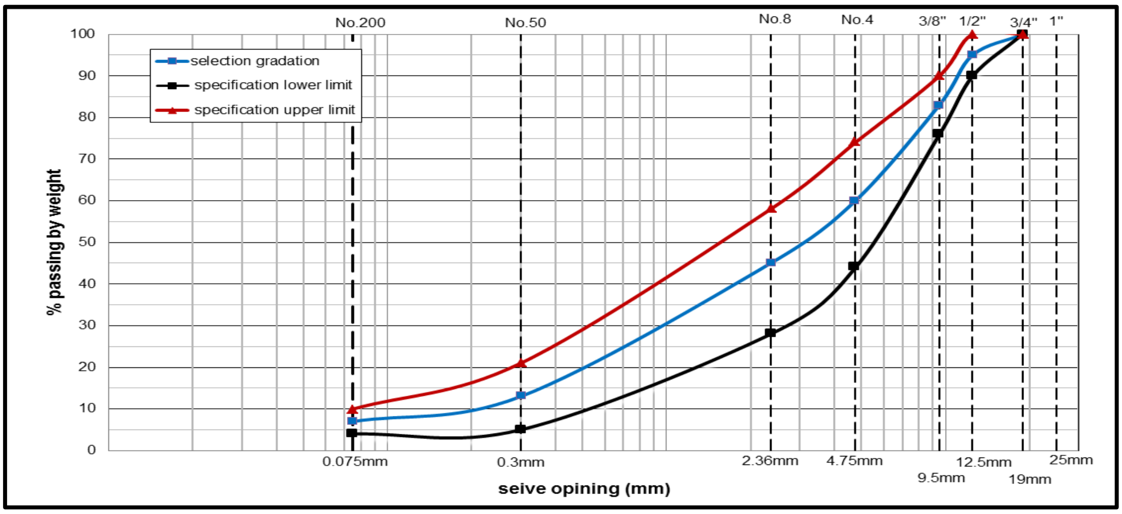


Figure 1. Selected aggregate gradation and specification limits.

Table 3. Physical properties of portland cement.

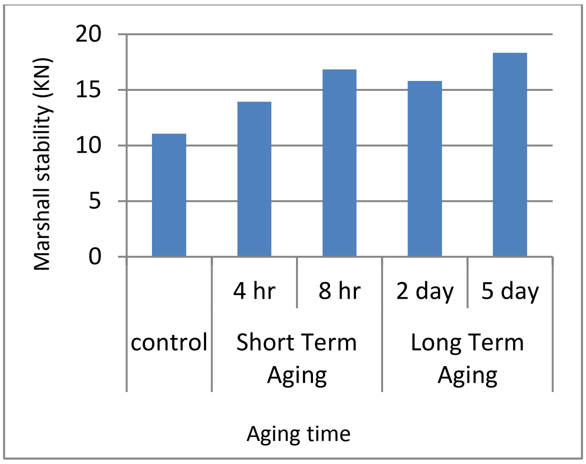
Property	Physical properties
% Passing Sieve No. 200	96%
Specific Gravity	3.14

Table 4. Properties of asphalt mixture with the optimum asphalt content.

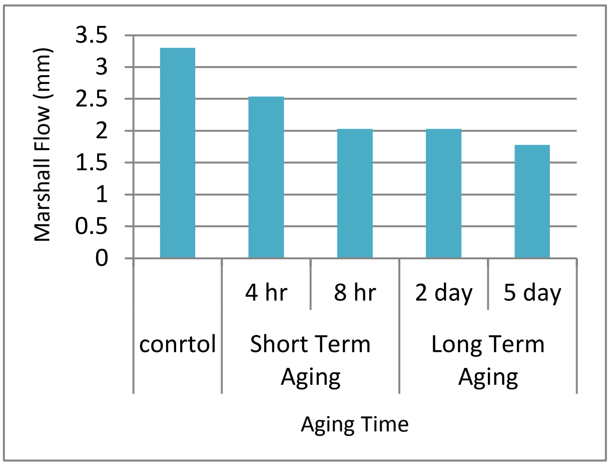
Marshall properties	value	SCRB, 2003 Specification limit
Optimum asphalt content %	4.7	----
Stability KN	10.87	8 KN min.
Flow mm	3.21	2-4 mm
Bulk density gm/cm^3	2.351	-----
Air void in total mix %	3.549	3-5%
VMA %	14.724	14 % min.
VFA %	73.88	----

Table 5. Summary of the Marshall Properties of asphalt concrete mixes at optimum asphalt content.

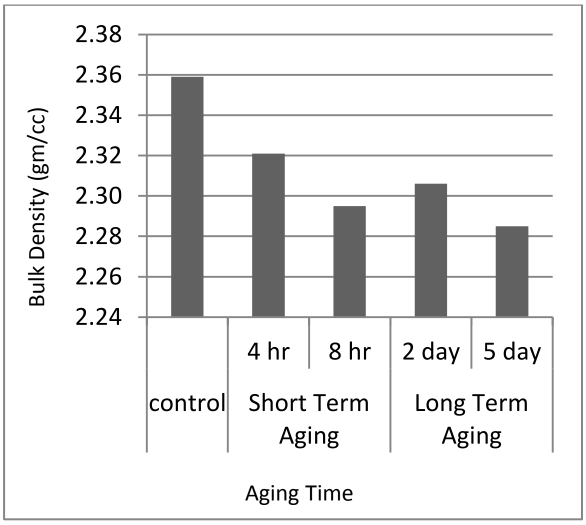
Aging Type	Aging Time	Marshall Stability KN	Marshall (mm)	Bulk Density (gm/cm^3)	VTM (%)	VFA (%)	VMA (%)
Control		11.05	3.302	2.359	3.8	73.3	14.4
Short term a time (hours)	4 hr.	13.93	2.54	2.321	4.4	72.0	15.8
	8 hr.	16.82	2.032	2.295	5.6	66.3	16.7
Long term a Time (days)	2 day	15.79	2.032	2.306	5.21	68.1	16.3
	5 day	18.31	1.778	2.285	5.8	65.7	17.1



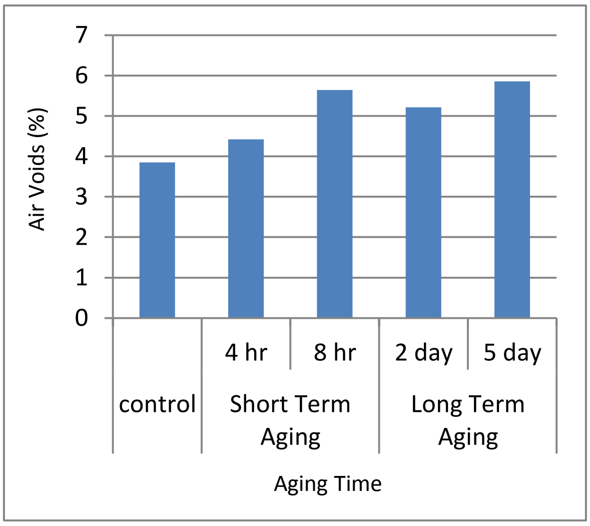
A-Marshall Stability



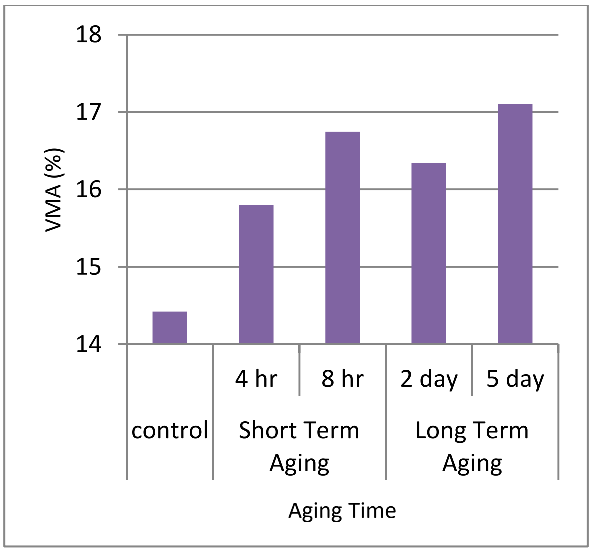
B- Marshall Flow



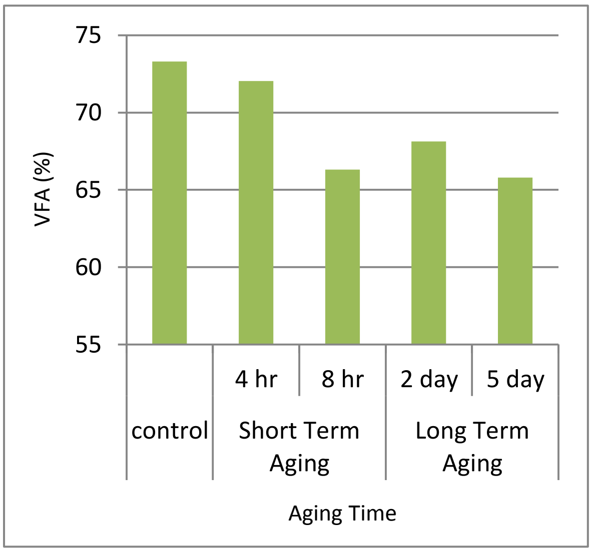
C – Bulk Density



D- Air Void



E – VMA



F – VFA

Figure 2. Effect of aging time on Marshall Properties.

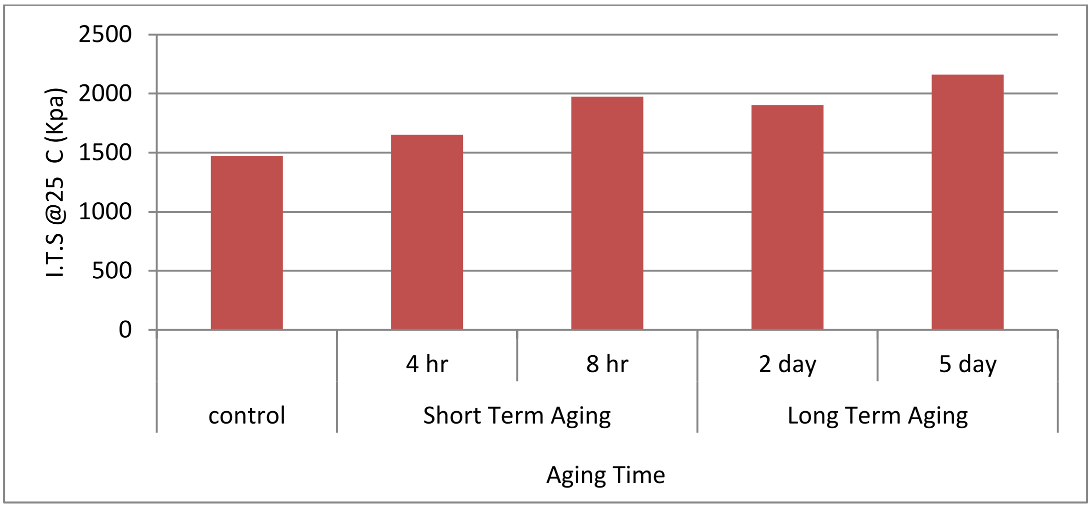


Figure 3. Effect of aging times on ITS @25 ^{0}C for asphalt mixture.

Table 6. Effect of aging time on resilient modulus value.

Aging time	Control mixture	Short term aging		Long term aging	
		4 hr.	8 hr.	2 day	5 day
Mr (psi)	31373	32653	33823	34043	37209

Table 7. Effect of aging time on permanent deformation test results.

Aging time	Control mixture	Short term aging		Long term aging	
	0 hr.	4 hr.	8 hr.	2 day	5 day
Intercept	268.15	241.77	198.31	190.55	167.22
Slope	0.4617	0.4571	0.4465	0.4369	0.4188

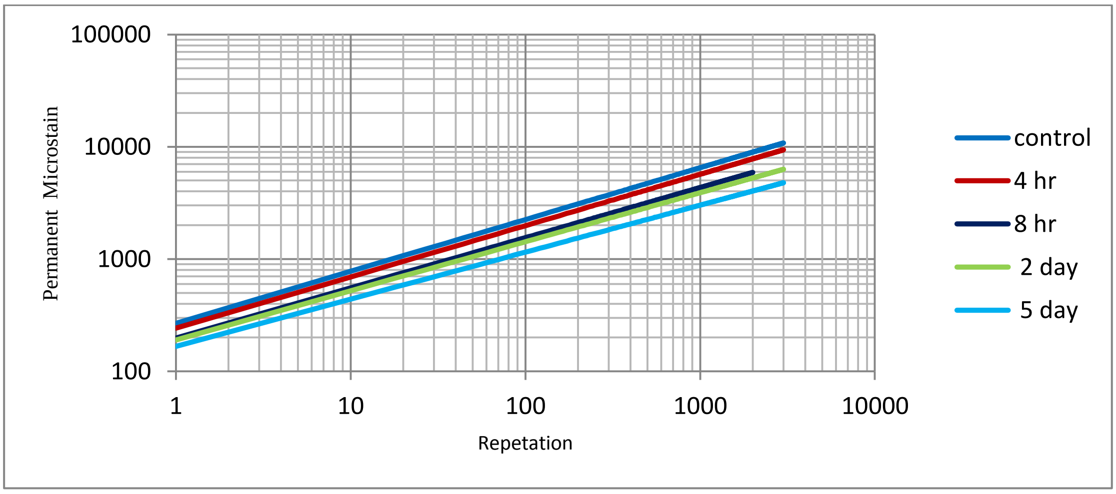


Figure 4. Effect of aging time on permanent deformation.