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## Degradation of Asphalt Concrete Stiffness under Dynamic Loading

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### ABSTRACT

*Controlling the degradation of asphalt concrete stiffness modulus throughout its service life is considered an essential issue in the sustainability of the flexible pavement. In the present investigation, asphalt concrete wearing course slab samples are prepared under roller compaction at optimum binder content. Extra samples were also prepared at 0.5 % asphalt above and below the optimum. The beam specimens of 400 mm length and 50 mm height and 63 mm width were extracted from the slab samples. Beam specimens were divided into four sets, the first set was subjected to moisture damage process while the second set has practiced long term ageing process. The third set was tested under various environment temperature of (5, 20, and 30) °C. the fourth set was the control specimens. All the specimens were subjected to the four-point repeated flexural bending beam test. The test was terminated when the beam has reached a 50 percent reduction in stiffness. The flexural stiffness was calculated under three constant micro strain levels of (250, 400, and 750). It was concluded that dynamic modulus ratio degrades by (41, 57, and 69) % under microstrain levels of (250, 400, and 750) respectively. The stiffness declines under microstrain levels of (250, 400, and 750) by (29.3, and 36.7), (34.5, and 39.6), (46.4, and 75.1) when the testing temperature changes from 30 °C to (20 and 5) °C respectively. The stiffness increases under microstrain levels of (250, 400, and 750) by (24.3, 12.3, and 2.8) after long-term ageing process.*

**Keywords:** *Flexural Stiffness, Asphalt Concrete, Micro Strain, Long-term Ageing, Moisture Damage*

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### INTRODUCTION

Asphalt concrete pavement can undergo numerous types of failure under loading and environment impact, so it is necessary to research the behavior of its constituent materials on its performance. Cui et al., [1] assessed the residual fatigue properties of asphalt concrete pavement after long-term field service. Fatigue behavior of pavement specimens with different failure types, traffic load, and service time were collected and evaluated. It was concluded that surface layer has a longer fatigue life under small stress levels, but shorter fatigue life under large stress levels. Longer service time exhibit greater sensitivity to loading stress, while heavier traffic results in shorter fatigue life. A stud by Li et al., [2] was conducted to understand the fatigue properties of asphalt concrete from many aspects, such as influence of asphalt content, occurrence of fatigue, and how to prevent expanding of the fatigue fractures. It was reported that fatigue tests are divided into the simple flexural tests (two-point, three-point, and four-point bending), uniaxial loading test, and diametral loading test. Almeida et al., [3] studied the effect of water and temperature on the rheological behavior, complex modulus and fatigue resistance of an asphalt mixture formulated with a conventional asphalt binder. It was concluded that it was possible to evaluate the effect of the

action of water and temperature on the graphical representation of the complex modulus and on the reduction in the fatigue life of the asphalt mixture. Wahengbam and Rajbongshi, [4] stated that Stiffness modulus of asphalt concrete is a fundamental parameter for its fatigue evaluation. It is evaluated with different considerations like static or dynamic loading, elastic, or visco-elastic material etc. Asphalt being visco-elastic and fatigue being due to dynamic loading, the modulus parameter happens to be time dependent complex variable. Their rate of decay depends upon the relaxation time of mix and is due to material damage. Ahmed et al., [5] revealed that hot-mix asphalt suffers a reduction in stiffness and strength under repeated cyclic loading, and it eventually cracks. Measurements of asphalt fatigue degradation in terms of stiffness modulus and dissipated strain energy have been conducted. Different asphalt mixtures were made from open and dense gradings of limestone and granite aggregates, and with soft and hard binders according to British standards. It was concluded that stiffness modulus degradation rate parameter looks most promising for evaluating and predicting the fatigue performance of asphalt concrete regardless of the test technique and mode. El-hakim and Tighe, [6] tested three conventional asphalt concrete mixtures and a modified one (with asphalt content 0.8% higher than the optimum values). Specimens were evaluated before and after moisture conditioning. The results showed that dynamic modulus displayed a noticeable decrease at low temperatures for the conventional mixtures, but not for the modified mixture. These findings indicated that the additional asphalt content (higher than the optimum) can result in less deterioration of asphalt material due to moisture. Nadkarni et al.[7] studied the resistance to moisture damage of dense-graded, gap-graded, and open-graded mixtures. The results revealed that dynamic modulus ratio which represent the percent retained of stiffness after moisture conditioning of all mixtures decreased after moisture conditioning, the open-graded mixtures showed the largest decay in the dynamic modulus. It was concluded that the dynamic modulus of asphalt mixture is sensitive to moisture, and therefore may be used to evaluate the deterioration of asphalt due to moisture. Nguyen et al., [8] reported that the dynamic stiffness of porous asphalt concrete increases especially at low temperatures which may be attributed to the pore water captured in closed voids.

The aim of the present investigation is to assess the degradation in the dynamic flexural stiffness modulus of asphalt concrete wearing course after practicing long-term ageing and moisture damage with variable testing temperature and binder content.

## **MATERIALS AND METHODS**

The materials implemented in the present investigation are locally available and usually used for pavement construction.

### ***Asphalt Cement***

Asphalt cement of (40-50) penetration grad was implemented in this study. It was obtained from AL-Nasiriya Refinery. The physical properties of asphalt cement are listed in Table 1.

**Table 1. Physical Properties of Asphalt Cement**

<b>Property</b>	<b>Testing condition</b>	<b>ASTM, [9] Designation No.</b>	<b>Value</b>	<b>SCRB, [10] specifications</b>
Penetration	25°c , 100gm 5 sec	D5-06	42	40-50
Softening Point	(ring & ball)	D36-895	49	-
Ductility	25°c ,5cm/mi	D113-99	100 +	>100

Specific Gravity	25°c	D70	1.04	-
<b>After thin film oven test properties D1754-97</b>				
Penetration	25°c , 100gm, 5 sec	D5-06	33	-
Ductility of Residue	25°c ,5cm/mi	D113-99	83	-

### Coarse and Fine Aggregates

Crushed coarse aggregate with a nominal maximum size of 19 mm (retained on sieve No. 4) was obtained from AL-Ukhaider quarry. Mixed crushed and natural sand was used as Fine aggregate (passing sieve No.4 and retained on sieve No.200), was obtained from the same source. The aggregates were air dried and separated into different sizes by sieving. Their physical properties are listed in Table 2.

**Table 2. Physical Properties of Coarse and Fine Aggregate**

Property	Value	ASTM Designation No. ASTM, [9]
<b>Coarse Aggregate</b>		
Bulk specific gravity	2.542	C127-01
Water absorption %	1.076%	C127-01
Wear % (lose Angeles's abrasion)	18%	C131-03
<b>Fine Aggregate</b>		
Bulk specific gravity	2.558	C128-01
Water absorption %	1.83%	C128-01

### Mineral Filler

The mineral filler used in this investigation is limestone dust and was obtained from Karbala governorate. The filler passes sieve No.200 (0.075mm). The physical properties of the filler are presented in Table 3.

**Table 3. Physical Properties of Mineral Filler (Limestone dust)**

Property	Value
Bulk specific gravity	2.617
% Passing Sieve No.200	94

### Selection of Aggregate Gradation

The selected gradation in this study follows SCRB, [10] specification for dense graded wearing course, with 12.5 (mm) nominal maximum size of aggregates. Table 4 present the selected aggregate gradation.

**Table 5: Gradation of Aggregate for Wearing Course SCRB,[10]**

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.75
<b>Selected gradation</b>	100	95	83	59	43	13	7
<b>SCRB, [10] Specification limits</b>	100	90-100	76-90	44-74	28-58	5-12	4-10

### Preparation of Asphalt Concrete Mixture

The coarse and fine aggregates were washed, dried to a constant weight at 110°C, then sieved to different sizes, and stored in plastic containers. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation for wearing course. The combined

aggregates were then heated to 160°C before mixing with asphalt cement. The asphalt cement was heated to 150°C to produce a kinematic viscosity of (170±20) centistokes as recommended by SCRB, [10]. Then, asphalt cement was added to the heated aggregate to achieve the desired amount and mixed thoroughly by hand using a spatula for two minutes until all aggregate particles were coated with asphalt cement. The mixture was subjected to short-term ageing process for 4 hours at temperature of 135 °C. The mixture was stirred every 30 minutes during the short-term ageing process to prevent the outside of the mixture from aging more than the inner side because of increased air exposure, according to AASHTO R-30, [11]. The optimum asphalt content of 4.9% was implemented. Asphalt concrete mixtures were also prepared at asphalt contents of 0.5 percent above and below the optimum, (4.4 and 5.4) %. The optimum binder percentage was determined based on Marshall trial mixes using various asphalt percentages. Details of obtaining the optimum binder content could be found in Sarsam and Al-Lamy, [12].

### **Preparation of Asphalt Concrete Specimens**

The short-term aged mixtures were casted in a slab mold of (40x30x6) cm and subjected to roller compaction to the target bulk density for each binder percentages according to EN12697-33, [13]. The applied static load was 5 kN while the number of load passes depended on the asphalt content in mixture and was determined based on trial-and-error process as 20 passes for 5.4% asphalt content, 30 passes for 4.9% asphalt content, and 60 passes for 4.4% asphalt content. The compaction temperature was maintained on 150 °C. Slab samples were left to cool overnight. Beam specimens of 50±2 mm high, 63±2 mm wide and 400 mm length were obtained from the slab sample using the Diamond-saw. The total number of beam specimens obtained was 20, while the number of casted slabs was 5. Figure 1 shows part of the obtained beam specimens.

### **Long-term Ageing of Beam Specimens**

A group of beam specimens were subjected to oxidation ageing (long-term ageing), beams were stored in an oven for five days (120 hours) at 85°C as per AASHTO R-30, [11] procedure. Specimens were then withdrawn from the oven and stored in the testing chamber for two hours at the required testing temperature of the fatigue test.

### **Conditioning of Beam Specimens for Moisture Damage**

A group of the beams were subjected to moisture damage by conditioning the beams in water bath at 25° C for two hours, the air in the voids was evacuated using a compressor with a vacuum of (3.74 kPa) applied for 10 minutes to obtain 80 % saturation. The beam specimens were then placed in deep freeze at (-18°C) for 16 hours. The frozen specimens were then moved to a water bath and stored for 24 hours at (60°C). Then they were dried and placed in the testing chamber for two hours at 20° C before testing for fatigue life and stiffness.

### **Four-point Repeated Flexural Bending Beam Test**

The repeated flexural bending beam according to AASHTO T321, [14] is implemented to identify the degradation in stiffness modulus of asphalt concrete beam specimens at intermediate pavement operating temperature of 20°C. Part of the specimens were also tested at higher in-service temperature of 30°C to investigate the behavior of stiffness in combination with the possibility of rutting distress. Another group of beam specimen was tested at lower temperatures of 5°C, to investigate its impact on the stiffness in combination with possible thermal cracking distress. During the flexural fatigue test, the beam is subjected to a repeated four-point loading. This testing procedure creates a non-homogeneous stress-

strain field. The load frequency is usually set between 1 and 10 Hz, and the deflection caused by the loading is measured at the center of the beam. The test was terminated when the beam has reached a 50 percent reduction in stiffness. A repeated haversine (sinusoidal) load is applied to the two inner clamps on the beam specimen with the outer clamps providing a reaction load. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). Beams were subjected to a repeated load at a constant strain level. Three different Microstrain levels of 250, 400, and 750 were tried to simulate various modes of loading in the field. Figure 1 demonstrates the four-point bending beam test setup.

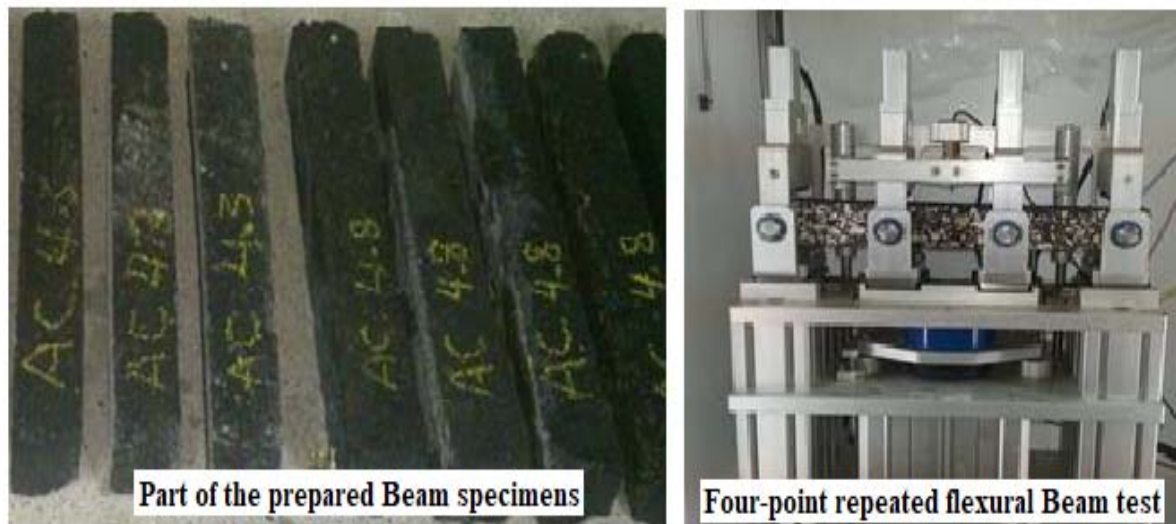


Fig. 1. Testing for Repeated Flexural Beam

## RESULTS AND DISCUSSION

### Influence of Binder Content on Stiffness

Figure 2 exhibit the influence of asphalt binder content on the flexural stiffness of asphalt concrete under three microstrain levels. It can be noted that the stiffness declines as the strain level increases regardless of the binder content. The stiffness decreases as the microstrain increases from 250 to 400 and 750 by (31.2, and 56.5) %, (60.3 and 71.4) %, (54.5 and 70.2) % for mixtures with binder content of (4.4, 4.9, and 5.4) % respectively.

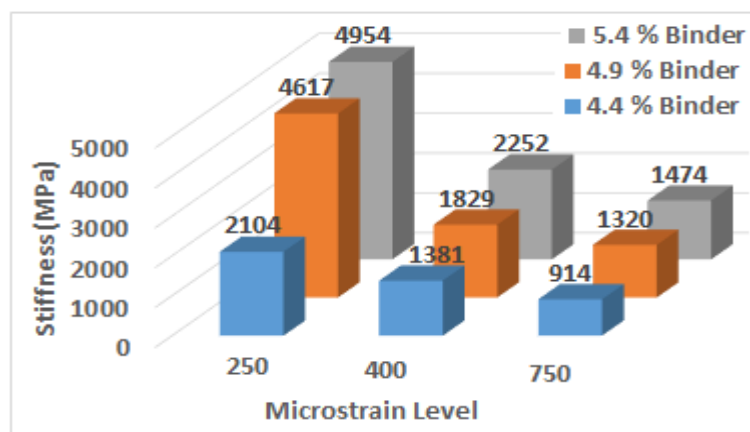
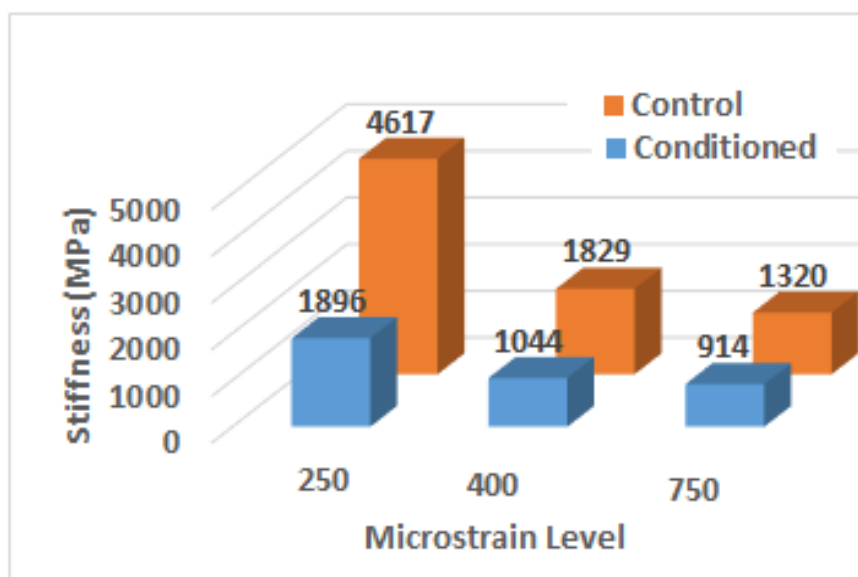


Fig. 2. Influence of Binder Content on Flexural Stiffness

This may be attributed to the reduction in load sustaining capability of the mixtures as the loading increases. However, at microstrain level of 250, 400, and 750, the stiffness increases by (119, and 135) %, (32.4, and 63) %, (44.4 and 61.2) % when the binder content changes from (4.4 to 4.9 and 5.4) % respectively. It was felt that further increment in binder content could decline the stiffness of the mixture. However, the reduction in stiffness will provide an increment in the deformation under repeated loading and decreases the expected fatigue life. Higher asphalt content can positively support the fatigue life. Similar conclusion was reported by Sarsam, [15] and El-hakim and Tighe, [6].

### **Influence of Moisture Damage on Stiffness**

Figure 3 demonstrates the influence of moisture damage process on the stiffness of asphalt concrete under various microstrain levels. The percent retained of stiffness after moisture conditioning which is referred as dynamic modulus ratio degrades by (41, 57, and 69) % under microstrain levels of (250, 400, and 750) respectively for specimens prepared at optimum asphalt content of 4.9 %. Similar behavior was reported by Nadkarni et al., [7]. It can be observed that the stiffness declines by (58.9, 42.9, and 30.7) % after practicing moisture damage for specimens subjected to (250, 400, and 750) microstrain levels respectively.

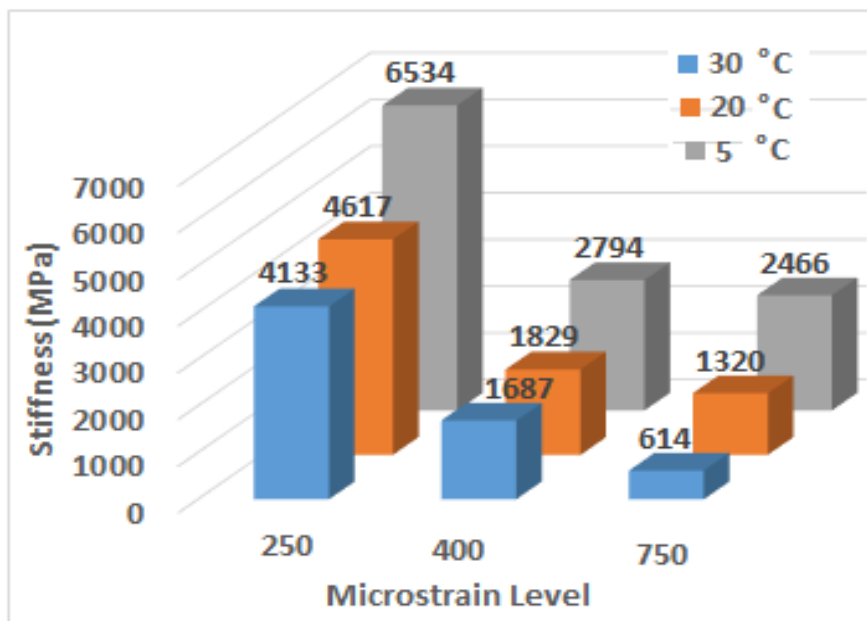


*Fig. 3. Influence of Moisture Damage on Flexural Stiffness*

On the other hand, the significant decline in flexural stiffness can be noted as the microstrain level increases for control and moisture damaged specimens. The stiffness decreases when the microstrain level increases from 250 to 400 and 750 by (60.3, and 71.4) %, (44.9, and 51.7) % for control and moisture damaged specimens respectively. Such finding agrees well with the work reported by Nguyen et al., [8].

### **Influence of Testing Temperature on Stiffness**

as demonstrated in Figure 4, the stiffness declines under microstrain levels of (250, 400, and 750) by (29.3, and 36.7), (34.5, and 39.6), (46.4, and 75.1) when the testing temperature changes from 30 °C to (20 and 5) °C respectively for specimens prepared at optimum asphalt content of 4.9 %.

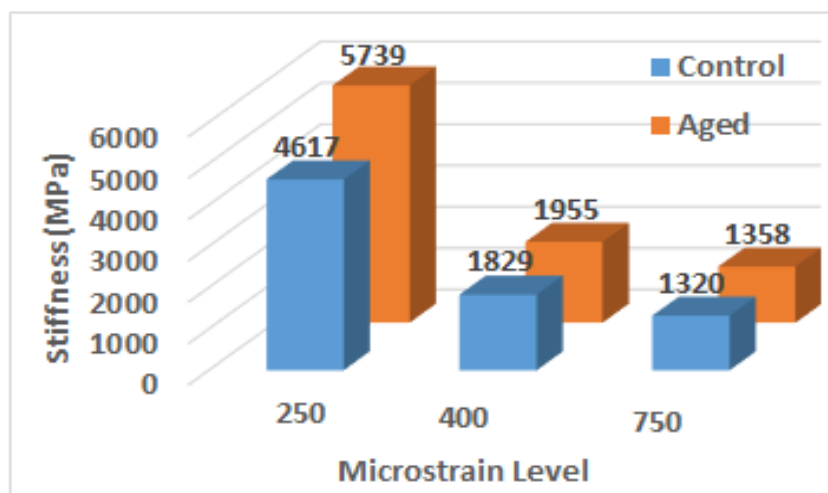


*Fig. 4. Influence of Testing Temperature on Flexural Stiffness*

However, the flexural stiffness declines as the microstrain level increases regardless of the testing temperature. It can be observed that the stiffness declines when the microstrain level increases from 250 to 400 and 750 by (59.1, and 85.1) %, (60.3, and 71.4) %, (57.2, and 62.2) % for (30, 20, and 5) °C testing temperature respectively.

**Influence of Long-term Ageing on Stiffness**

Figure 5 exhibit the influence of practicing long-term ageing on the flexural stiffness for specimens prepared at optimum asphalt content of 4.9 %. It can be noted that the stiffness increases under microstrain levels of (250, 400, and 750) by (24.3, 12.3, and 2.8) after long-term ageing process. On the other hand, the flexural stiffness declines as the microstrain level increases regardless of the ageing process. It can be noted that the stiffness declines when the microstrain level increases from 250 to 400 and 750 by (60.3, and 71.4) %, (65.9, and 76.3) %, for control and aged specimens respectively. Such behavior exhibit susceptibility of the aged mixture to disintegration due to loss of flexibility. Similar findings were reported by Cui et al., [1].



*Fig. 5. Influence of Long-term Ageing on Flexural Stiffness*

## CONCLUSIONS

Based on the limitations of materials and the testing program, the following conclusions may be addressed.

- 1) The stiffness decreases as the microstrain increases from 250 to 400 and 750 by (31.2, and 56.5) %, (60.3 and 71.4) %, (54.5 and 70.2) % for mixtures with binder content of (4.4, 4.9, and 5.4) % respectively.
- 2) At microstrain level of 250, 400, and 750, the stiffness increases by (119, and 135) %, (32.4, and 63) %, (44.4 and 61.2) % when the binder content changes from (4.4 to 4.9 and 5.4) % respectively.
- 3) The dynamic modulus ratio degrades by (41, 57, and 69) % under microstrain levels of (250, 400, and 750) respectively for specimens prepared at optimum asphalt content of 4.9 %.
- 4) The stiffness declines by (58.9, 42.9, and 30.7) % after practicing moisture damage for specimens subjected to (250, 400, and 750) microstrain levels respectively.
- 5) The stiffness declines under microstrain levels of (250, 400, and 750) by (29.3, and 36.7), (34.5, and 39.6), (46.4, and 75.1) when the testing temperature changes from 30 °C to (20 and 5) °C respectively.
- 6) The stiffness increases under microstrain levels of (250, 400, and 750) by (24.3, 12.3, and 2.8) after long-term ageing process.

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