Influence of Aging, Temperature and Moisture Damage on the Stiffness of Asphalt Concrete through the Fatigue Process

Saad Issa Sarsam

Professor of Transportation Engineering, Department of Civil Engineering, College of Engineering, University of Baghdad, Baghdad, Iraq

Corresponding Author: Email: saadisasarsam@coeng.uobaghdad.edu.iq

Received 19 March 2016; Accepted 24 November 2016

Abstract. The stiffness of asphalt concrete is considered as a key element in the fatigue process under load repetitions. In this study, an investigation was made in order to better understand the influence of long term aging, moisture damage, low testing temperature, asphalt content, and Microstrain level on the stiffness through the fatigue process of asphalt pavement. Repeated four-point flexure bending beam test in controlled strain mode has been implemented using Nottingham apparatus. Asphalt concrete mixtures were prepared using different percentages of asphalt cement, (optimum and 0.5% above and below the optimum). Asphalt concrete slab samples of (300x 400x 60) mm were prepared using roller compaction, beam specimens of (400x 50x 60) mm were cut from the slab samples. Beam specimens were divided into four groups, the first group was tested for fatigue life under the influence of three levels of micro strain (750, 400, and 250). The second group was tested at 30, 20, and 5 °C, while the third group was subjected to long-term aging, before testing for fatigue life. The fourth group was subjected to moisture damage impact, and then tested for fatigue life. The changes in stiffness per load cycles have been monitored. It was concluded that the stiffness is susceptible to moisture damage and aging, the increase in Microstrain level leads into a remarkable decrease in initial and failure stiffness’s. The stiffness is susceptible to the testing temperature and asphalt content, lower testing temperature of 5º C exhibits higher stiffness value, while higher binder content has a negative impact on the stiffness.

Keywords: Aging, Asphalt concrete, fatigue, moisture damage, stiffness, temperature.

1. INTRODUCTION

Different types of distresses appear in asphalt concrete pavement such as moisture damage, rutting and fatigue cracking. Fatigue failure is the result of flexural cracking of asphalt bound layer and there are a lot of factors affecting the fatigue mechanism such temperature, loading rate and aging, (SHRP, 1994; Sarsam and AL-Lamy, 2015; and Sarsam and Alwan, 2014-a). It has been generally accepted that fatigue is a process of cumulative damage and one of the major causes of cracking in asphalt concrete pavement. The traditional fatigue approach assumes that damage occurs in a specimen from dynamic repetitive loading that leads to fatigue failure of the specimen. The number of load repetitions to failure equal to the fatigue life, and can be calculated based on stress, or strain, (Adhikari, and Zhanping, 2010; Van Dijk, 1975; and Sarsam and AL-Lamy, 2016). The current failure criterion of flexible pavement assumes linear elastic material response under single loading level to relate the number of load repetitions to fatigue life.

Aging has long been recognized as a contributing factor to fatigue distress of asphalt concrete pavement. Aging causes the asphalt to stiffen and become brittle, which leads to a higher potential for cracking, (Sarsam, 2005). With the increase of the aging degree, the asphalt mixture would become brittle gradually, with its ultimate tensile strain decreases gradually, while the tensile strength increases gradually.

The ultimate tensile strain shows the digressive trend monotonously. When exceeding a certain aging degree, the tensile strength will be fallen instead, (Zheng et al, 2007). Oxidative aging of asphalt concrete mixtures has been studied by (Sarsam and Muayad, 2014). Both long and short term oxidation processes were tried, then mathematical models have been obtained which correlates the impact of aging on Marshall Properties. The effects of aging on the linear viscoelastic and damage properties have been investigated by (Kim et al, 2012). It was found that the stiffness of an asphalt mixture increases with aging time and a statistically significant effect on the
Influence of Aging, Temperature and Moisture Damage on the Stiffness of Asphalt Concrete through the Fatigue Process

Dynamic modulus exists due to the laboratory aging procedures. With respect to damage properties, it is found that the damage properties of aged asphalt mixtures and fatigue failure in the asphalt mixture are a function of temperature as well as aging level, (Kim et al, 2012). The study by (Sarsam and Alwan, 2014-b) had shown that the asphalt concrete material undergoes stiffening because of oxidative hardening. Asphalt concrete exhibits viscoelastic material behavior at most of its service temperatures. Stiffness at 250 and 750 Microstrain levels shows higher values for the long term aging as compared with short term aging mixes by (+7%, +54%) respectively. When asphalt concrete is subjected to moisture damage process, it shows lower values of stiffness for condition mix as compared with unconditioned mix by (-62%, -16%) respectively. Stiffness decreases at conditioned mix by 62 % as compared to unconditioned mix, (Sarsam and Alwan, 2015). The results of repeated four point flexural fatigue beam testing indicated that fatigue life decreases by 70 percent after subjecting asphalt concrete to moisture damage. For a Microstrain range from 250 to 400, the fatigue life decreases by 87 percent as compared to reference mixture, (Sarsam and Alwan, 2014-c).

The aim of this investigation was to better understand the influence of long term aging, moisture damage, low testing temperature, asphalt content, and Microstrain level on the stiffness of asphalt concrete through the fatigue process of asphalt pavement.

2. MATERIALS AND METHODS

Locally available materials currently used in road construction in Iraq, have been implemented in this investigation.

2.1. Asphalt Cement

Asphalt cement of penetration grade (40-50) was obtained from AL-Nasiriya Refinery, south of Iraq. The properties comply with the specifications of State commission for Roads and Bridges (SCRB 2003). The physical properties of asphalt cement are shown in Table 1.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration</td>
<td>25°C, 100gm 5 sec (ring &amp;ball)</td>
<td>D5-06</td>
<td>42</td>
<td>40-50</td>
</tr>
<tr>
<td>Softening Point</td>
<td></td>
<td>D36-895</td>
<td>49</td>
<td></td>
</tr>
<tr>
<td>Ductility</td>
<td>25°C, 5cm/mi</td>
<td>D113-99</td>
<td>136</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td>25°C</td>
<td>D70</td>
<td>1.04</td>
<td></td>
</tr>
<tr>
<td>Flash Point</td>
<td>Cleveland open cup</td>
<td>D92-05</td>
<td>256</td>
<td>&gt;232</td>
</tr>
</tbody>
</table>

After thin film oven test properties D1754-97

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Penetration</td>
<td>25°C, 100gm, 5 sec</td>
<td>D5-06</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Ductility of Residue</td>
<td>25°C, 5cm/mi</td>
<td>D113-99</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>Loss on Weight</td>
<td>163°C, 50g, 5 hr.</td>
<td></td>
<td>0.35</td>
<td></td>
</tr>
</tbody>
</table>

2.2. Coarse and Fine Aggregate

Crushed coarse aggregate (retained on sieve No.4) was obtained from AL-Ukhaider- Karbala quarry. Crushed sand and natural sand usually used as Fine aggregate (particle size distribution between sieve No.4 and sieve No.200), were brought from the same source. It consists of hard, tough grains, free from loam and other deleterious substances. The physical properties are listed in Table 2.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
<th>ASTM Designation No. (ASTM, 2009)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Aggregate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>2.542</td>
<td>C127-01</td>
</tr>
<tr>
<td>Apparent specific gravity</td>
<td>2.554</td>
<td>C127-01</td>
</tr>
<tr>
<td>Water absorption %</td>
<td>1.076%</td>
<td>C127-01</td>
</tr>
<tr>
<td>Wear % (Los Angeles abrasion)</td>
<td>18%</td>
<td>C131-03</td>
</tr>
<tr>
<td>Fine Aggregate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bulk specific gravity</td>
<td>2.558</td>
<td>C128-01</td>
</tr>
<tr>
<td>Apparent specific gravity</td>
<td>2.563</td>
<td>C128-01</td>
</tr>
<tr>
<td>Water absorption %</td>
<td>1.83%</td>
<td>C128-01</td>
</tr>
</tbody>
</table>
2.3. Mineral Filler

The mineral filler is mostly passing sieve No.200 (0.075mm). The filler used in this work is limestone dust obtained from a factory in Holly Karbala governorate. The physical properties of the filler are presented in Table 3.

2.4. Selection of Aggregate Gradation

The selected gradation in this study follows the SCRB Specification (SCRB, 2003) for wearing course, with 12.5 (mm) nominal maximum size of aggregates. Fig.1 shows the selected aggregate gradation.

![Fig. 1: Selected Aggregate Gradation and Specification Limits as per SCRB, 2003](image)

2.5. Preparation of Asphalt Concrete Mixture (control Mixture)

The aggregate was washed, dried to a constant weight at 110ºC, and then sieved. Coarse and fine aggregates were combined with mineral filler to meet the specified gradation. The combined aggregate was then heated to a temperature of (160°C) before mixing with asphalt cement. The asphalt cement was heated to a temperature of (150°C) 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 using a mechanical mixer for three minutes until all aggregate particles were coated with asphalt cement. The mixture was subjected to short term oven aging for 4hrs at temperature of 135 °C as per (AASHTO, 2013). The mix was stirred every 30 minutes during the short term aging process to prevent the outside of the mixture from aging more than the inner side because of increased air exposure, according to (AASHTO PP2, 1999). Asphalt concrete mixtures were prepared at optimum asphalt content of 4.9% and at asphalt contents of 0.5 percent above, and 0.5 percent below optimum, (4.4 and 5.4) %. The process of finding the optimum asphalt content was based on Marshall Properties (AASHTO, 2013), the details was published elsewhere, (Sarsam and Alwan, 2014-a). The mixture was casted in a slab mold of 40x30x6 cm, and subjected to roller compaction to the target bulk density according to (EN12697-33, 2007). The static load applied was (5 kN) while the number of load passes depended on the asphalt content in mix 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. Beam specimens of 50±6 mm high, 63±6 mm wide and 400 mm length were obtained from the slab using the Diamond-cutter. The total number of beam specimens obtained was 36, while the number of casted slabs was 9. Fig. 2 shows part of the beams obtained.

2.6. Long term aging of beam specimens

A group of beam specimens were subjected to oxidation aging (long term aging), beams were stored in an oven for five days (120 hours) at 85°C as per AASHTO procedure (Sarsam and Muayad, 2014; Sarsam and Alwan 2014 –b; and AASHTO, 2013). Specimens were withdrawn from the oven and stored in the testing chamber for two hours at the required testing temperature of the fatigue test.
2.7. Conditioning 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 hour at 20°C before testing for fatigue life and stiffness. Fig. 3 demonstrates part of the water conditioning process of the beam specimens.

2.8. Repeated Flexural Beam Fatigue Testing

Asphalt concrete beams (400 x 50 x 60 mm) obtained from the slab sample were placed in a 4-point loading machine. The standard flexure fatigue beam test procedure as per (AASHTO, 2010), was implemented to determining the Fatigue Life of Compacted Hot-Mix Asphalt beams Subjected to Repeated Flexural Bending. The flexural fatigue test is performed by placing a beam of asphalt concrete in the repetitive four points loading chamber at a specified strain level. During the test, the beam is held in place by four clamps and a repeated haversine (sinusoidal) load is applied to the two inner clamps 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). The number of loading cycles to failure can then give an estimate of a particular mixture’s fatigue life. Beam fatigue testing is performed at intermediate temperatures, usually 20°C, because fatigue cracking is thought to be a primary HMA distress at these intermediate temperatures. Higher in-service temperature of 30°C was tried for another set of beam specimens to investigate the behavior of stiffness in combination with the possibility of rutting distress. While a third group was tested at lower temperatures of 5°C, to investigate its impact on the stiffness in combination with possible thermal cracking distress. 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. Fig. 4 shows the four point bending beam test setup.

Test stiffness test results were monitored and recorded at each load cycle and the test was terminated when the beam has practiced 50 percent reduction in its stiffness. Test results are completed in a Microsoft Access database application which reports the result, as show in Fig.5, while the output of the test is presented in Fig.6.
3. RESULTS AND DISCUSSIONS

3.1. Influence of long term aging on stiffness

Fig. 7 exhibits the stiffness response of control mix under various Microstrain levels. After few load repetitions of 5-6, the mixture loses its stiffness under the Microstrain levels applied, further increase in load repetitions beyond 100 load cycles causes more reduction in the stiffness. Failure occurs at 24000, 800, and 750 load repetitions for 250, 400, and 750 Microstrain levels respectively, and the stiffness at
Influence of Aging, Temperature and Moisture Damage on the Stiffness of Asphalt Concrete through the Fatigue Process

failure was in the range of (76-500 MPa), (failure criteria is the reduction of the stiffness by 50% of its original value). As demonstrated in Fig.8, the tested beams were subjected to long term aging before testing. Lower Microstrain level of 250 exhibit gentle reduction in the stiffness through the fatigue process, the stiffness was in the range of 1000 to 10000 MPa throughout the process. The fatigue life was 4100 load repetitions and is higher than other strain levels. When higher Microstrain level of 400 MPa was introduced, a sharp drop in the stiffness at an early stage of fatigue life (within 10 load repetitions) could be observed (in a range of 100 to 1000 MPa) and a reduction in the fatigue life was also obtained. Similar behavior was detected when the Microstrain level was increased to 750, and shorter fatigue life was obtained. This behavior may be attributed to the loss of asphalt cement volatiles during the long term aging process, the mixture loses its flexible property and gets stiffer. It could be concluded that after subjecting the pavement to long term aging, it will be able to sustain lower frequency of loading, and the pavement is susceptible to higher wheel load repetitions. Similar findings have been reported for core and Marshall Size specimens by (Sarsam and Alwan, 2014 –a; Sarsam, 2005; Sarsam and Muayad, 2014; Kim et al, 2012).

Fig. 7: Behavior of control mixtures

Fig. 8: Behavior of long term aged mixtures

3.2. Influence of moisture damage

Fig.9 shows that at 250 Microstrain, the stiffness of moisture damaged beam specimens decreases in a smooth rate within a range of (10000 to 1000 MPa). The specimen failed after 760 load repetitions with a residual stiffness of 2074 MPa. When 400 or 750 Microstrain levels were implemented. The stiffness decreases sharply within the few load repetitions, then the rate of reduction was slow and the fatigue life was 305 and 1300 load repetitions with residual stiffness of 992 and 120 MPa respectively. It can be noted that the stiffness is susceptible to moisture damage at early stages of load repetitions when the test results are compared with those of control mix. On the other hand, Fatigue life was lower for the moisture damaged beam specimens. Such finding agrees well with the work reported by (Sarsam and Alwan, 2014-c; and Sarsam and Alwan, 2015).

3.3. Influence of micro strain level

Another group of beam specimens were tested under three different Microstrain levels, Fig.10 demonstrates the variation in stiffness through the fatigue process at 5 ° C. The stiffness decreases gradually under load repetitions when tested at 250 Microstrain level. On the other hand, implementation of 400 and 750 micro strain levels exhibits sharp reduction in the stiffness at initial load repetitions, then the rate of reduction is slow. It can be noted that as the Microstrain level increases, the fatigue life decreases and also the stiffness at failure decreases, such results are in agreement with (Sarsam and Alwan, 2014-a; Adhikari, and Zhanping, 2010; and Van Dijk, 1975) work.
3.4. Influence of testing temperature

A group of Beam specimens were stored at the testing chamber for two hours at the specified testing temperature of (5, 20 and 30) ºC before execution of the fatigue test. Beam specimens were tested at moderate Microstrain level of 400. Fig. 11 shows that the testing temperature had a great influence on asphalt concrete stiffness. A sharp reduction in the stiffness could be detected at the early stage of load repetitions for all of the testing temperatures tried, then the rate of change of the stiffness was smooth up to the initial stiffness at 100 load repetitions, then it sharply decreases again. This behavior may be attributed to the possible relaxation of asphalt concrete after the early loading cycles. It can be observed that as the testing temperature increases, the stiffness decreases. Similar findings were reported by (Dave et al, 2010).

3.5. Influence of asphalt content

Asphalt concrete specimens were constructed using optimum asphalt content of 4.9% and 0.5% asphalt content above and below the optimum (i.e. 4.4 and 5.4 %). Fig. 12 shows the behavior of stiffness of asphalt concrete mixtures under 250 micro strain. The stiffness decreases sharply at the early stage of loading for all of the asphalt binder percentages. On the other hand, the rate of change of the stiffness was smooth up to the initial stiffness at 100 load repetitions, and then it sharply decreases again. The optimum asphalt percentage and 0.5% of asphalt above have low stiffness values, but exhibits longer fatigue life. It can be noted that higher binder content is positively supporting the pavement fatigue life while it has a negative impact on the stiffness.

4. CONCLUSION

Based on the testing program, the following conclusions could be obtained.

1- After subjecting the pavement specimens to long term aging, it was able to sustain lower frequency of loading (250 Microstrain), while the pavement is highly susceptible to higher wheel load repetitions.

2- The stiffness is susceptible to moisture damage when the test results are compared with those of control mix. Implementation of 400 and 750 Microstrain levels for the moisture damaged specimen’s exhibits sharp reduction in the stiffness at initial load repetitions.
3- In general, the increase in micro strain level leads into a remarkable decrease in the value of fatigue life, initial and failure stiffness’s.

4- Higher binder content is positively supporting the pavement fatigue life while it has a negative impact on the stiffness.

5- The stiffness is susceptible to the testing temperature, lower testing temperature of 5º C exhibits the higher stiffness value and shortest fatigue life as compared to those at higher testing temperature.

REFERENCES


Prof. Saad Issa Sarsam was born in Baghdad (1955), got his BSc. in Civil Engineering (1977), Post graduate diploma in Transportation Engineering (1978); MSc in Transportation Engineering (1980).

He worked as senior material Engineer for NCCL (1982-1992); He joined the academic staff at University of Mosul (1992-2005) and got the Assistant Professor degree at (2002); He joined the academic staff at University of Baghdad (2005 until now) and got the Professor degree at (2007).

Areas of specialization and interest: (Roller compacted concrete; modified asphalt concrete; Asphalt stabilized embankment Models; Road user characteristics).