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Research Article

Monitoring the Durability Issues of Asphalt Concrete Mixtures

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Keywords

Asphalt concrete, Ageing, Durability, fatigue life, Moisture damage, stiffness.

Abstract

The asphalt concrete mixture is prone to environmental issues such as moisture damage and ageing. This may exhibit a great significance in the service performance of asphalt concrete pavement mixtures which may be more susceptible to many types of early distresses throughout its fatigue life. In the present investigation, asphalt concrete mixtures were prepared and compacted with the aid of laboratory roller compaction into a slab samples. optimum binder content was implemented. Extra samples were prepared at higher and lower binder content of 0.5 % (above and below the optimum). Asphalt concrete beam specimens were obtained from the prepared slab samples with the aid of a diamond saw. Part of the Asphalt concrete beam specimens were tested under four point's repeated flexural stresses after practicing moisture damage while another part was subjected to long term ageing. The rate of change in the flexural strength was monitored and compared among the various testing conditions at 20 °C environment and under constant micro-strain level of 750. It was observed that the lower flexural strength was observed for moisture damaged specimens while higher flexural strength could be detected for aged specimens as compared with the control mixtures. The binder content exhibits a significant influence on flexural strength of the asphalt concrete specimens since it declines significantly at higher or lower binder content as compared with that of specimens prepared at the optimum.

1.Introduction

The Fatigue life assessment of asphalt concrete is susceptible to environmental conditions which must be incorporated into the assessment to ensure an accurate prediction of the service life of the pavement. Chauhan and Narayan, (2019), [1] reported that the changes in fatigue characteristics of asphalt concrete after moisture conditioning can be evaluated by conducting four-point beam fatigue tests on dry and moisture conditioned beam specimens. The fatigue test was conducted at four different strain amplitudes of 200, 400, 600 and 800 micro-strains. The test results were compared with the fatigue test results obtained with dry beam specimens. It was revealed that the conditioning reduces both the initial flexural stiffness and the fatigue life of the beam specimens. Sarsam, (2020), [2] investigated the influence of short and long term ageing of laboratory beam specimens. Specimens were tested for fatigue life under the influence of three levels of micro strain (250, 400, and 750) at various testing environments after and before practicing long-term aging. It was observed that the fatigue life of asphalt concrete decreases by after increasing the applied microstrain. The fatigue life increases when the asphalt content increases. Yang et al., (2021), [3] evaluated the effect moisture damage and ageing on fatigue cracking of asphalt concrete. It was observed that the material properties of hot mix asphalt mixtures changed after practicing aging and moisture damage. The service life of the pavement was reduced by approximately (40–80) % owing to moisture damage, whereas ageing had a greater impact on fatigue life as the service life increased. Aljubory et al., (2017), [4] stated that data regarding the influence of moisture or ageing on the fatigue susceptibility of asphalt concrete mixtures are scarce and scattered. The susceptibility of asphalt concrete mixtures to fatigue damage incorporating ageing and moisture conditions was assessed using indirect tensile stiffness and fatigue modulus test in strain controlled mode. It was revealed that after moisture conditioning, the stiffness of control asphalt mixes increased significantly. However, a decline of the control and aged asphalt mixtures fatigue life due to moisture effects was detected. Moreno-Navarro and Rubio-Gámez, (2016), [5] addressed that fatigue failure is considered as one of the main distresses which is responsible for the decline in the service life of asphalt concrete pavements. The fatigue phenomena are important for enhancing the durability of the pavement. It was revealed that the permanent deformations of asphalt concrete can influence its mechanical response of materials. Carmo et al., (2021), [6] studied the strength sensitivity of asphalt concrete pavement, which exhibits variations in its mechanical properties due to the changes of asphalt cement binder content. A variation in the binder of ± 0.5% within the optimum asphalt contents was implemented as a service tolerance during the asphalt mixture preparation process. Test results reported that the variations in the asphalt binder content can influence the corresponding changes in the mechanical properties and structural responses of the investigated flexible pavement. Rahmani et al., (2017), [7] had addressed that the stiffness of asphalt concrete mixture may be increased by four folds after the ageing process based on the binder type. However, such behavior may exhibit a stiff and brittle asphalt concrete mixture, and it will be susceptible to fatigue cracking and disintegration at low temperatures. Al-Khateeb and Alqudahaims, (2018), [8] assessed the impact of laboratory ageing on the fatigue-life performance of asphalt concrete mixtures. The asphalt concrete mixtures have practiced the short and long-term ageing process, and then tested for fatigue using the repeated indirect tensile stresses test at various initial strain levels. It was noticed that the short-term ageing process exhibits an increase in the fatigue-life. Testing also showed that the fatigue-life of asphalt concrete increases as the testing temperature increase. Sarsam, (2016), [9] investigated the impact of the ageing process on the flexural stiffness of asphalt concrete mixture through the fatigue process. It was addressed that the stiffness of the mixture is significantly susceptible to ageing. It was revealed that the stiffness

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of the asphalt concrete mixture is significantly susceptible to the changes in the asphalt cement binder content; high asphalt binder content may exhibit a negative influence on the stiffness of asphalt concrete.

The aim of the present work is to assess the change in the flexural stiffness of asphalt concrete after practicing the durability issues such as moisture damage and ageing using variable binder percentages. Roller compacted slab samples will be prepared in the laboratory at optimum binder content. Extra samples will be prepared at 0.5 % binder above and below the optimum. Asphalt concrete beam specimens will be obtained from the slab samples and subjected to four point's repeated flexural stresses after practicing moisture damage and long term ageing. The rate of change in the flexural strength among variation in the binder content, practicing moisture damage, and practicing ageing will be monitored and compared among the various testing conditions at 20 °C environment and under constant micro-strain level of 750.

2. Materials and Methods

The materials used in this study are selected from the quarries that are currently used for road paving construction in Iraq.

2.1. Asphalt Cement

Asphalt cement of (40-50) penetration graded was used in this study. It is obtained from AL-Nasiriya oil refinery; Table 1 presents the physical properties of asphalt cement.

Table 1.Physical properties of asphalt cement

Property	Testing condition	ASTM, 2015, [10] Designation	Test result
Penetration (0.1 mm)	100 gm, 5 seconds, 25 °C	D-5	42
Softening point (°C)	Ring and ball	D-36	49
Specific gravity	25 °C	D-70	1.04
Ductility (Cm)	5 Cm/Minute, 25°C	D-113	136
Flash point (°C)	Cleveland open cup	D-92	256
	After thin film oven test		
Penetration (0.1 mm)	100 gm, 5 seconds, 25 °C	D-5	33
Ductility (Cm)	5 Cm/Minute, 25°C	D-113	83
Mass loss (%)	5 Hours, 163°C, 50 gm	D-1754	0.35

2.2. Coarse and Fine Aggregates

Crushed coarse aggregate (retained on sieve No.4) was obtained from AL-Ukhaydir- Karbala quarry. Crushed sand and natural sand combination is used as Fine aggregate (particle size between sieve No.4 and sieve No.200). The physical properties of aggregates are shown in Table 2.

Table 2. Physical properties of **Course and Fine** aggregates

Property	Value	ASTM. (2015), [10] Designation No.	Value	ASTM, (2015), [10] Designation No.
Coarse Aggregates			Fine Aggregates	
Bulk specific gravity	2.542	C127-01	2.558	C128-01
Apparent specific gravity	2.554	C127-01	2.563	C128-01
Water absorption %	1.076	C127-01	1.83	C128-01
Wear % (los Angeles abrasion)	18%	C131-03	-----	-----

2.3. Mineral filler

Limestone dust was obtained from lime factory at Karbala and used in this work; the physical properties of the filler are presented in Table 3.

Table 3. Physical properties of mineral filler

Property	Test value
Passing sieve No. 200 (%)	94
Bulk specific gravity	2.617

2.4. Selection of Aggregates Combined Gradation

The aggregate gradation as per SCRB, (2003), [11] Specifications for wearing course, with 12.5 (mm) nominal maximum size have been considered. Figure 1 shows the selected aggregate gradation.

2.5. Preparation of Asphalt Concrete Mixture

The aggregates were washed, dried to constant weight at 110°C, and sieved to different sizes. Aggregates were combined with mineral filler to meet the specified gradation. The combined aggregate was heated to a temperature of 160 °C before mixing with asphalt cement. The asphalt cement was also heated to a temperature of 150 °C then, the predetermined amount of asphalt cement was added to the heated aggregate, and mixed thoroughly in mixing bowl by hand using a spatula for two minutes until all aggregate particles were coated with thin layer of asphalt cement. The asphalt concrete mixture had practiced the short-term ageing process at which, the loose mixture was aged for 4 hours at temperature of 135 °C as recommended by AASHTO R-30, (2013), [12]. The optimum asphalt content was 4.8 % and extra specimens with (4.3 and 5.3) % binder content was prepared. Details of obtaining the optimum asphalt content are found at Sarsam and Alwan, (2014), [13]. The short-term aged mixture was compacted in a steel slab mold of (30 x 40 x 6) cm using a laboratory roller compactor to the target bulk density for each binder content percentage as per EN12697-33, (2007), [14]. The applied static load was 5 kN while the number of roller passes were based on the target bulk density of the mixture and the asphalt content in the mixture. Details of the compaction process are presented at Sarsam, (2005), [15]. The temperature of compaction was maintained to 150 °C. The slab samples were left to cool overnight. Beam specimens of 5± 2 cm height, 6.3± 2 cm width, and 40 cm length were extracted from the compacted slab sample with the aid of the Diamond-saw. The total number of the obtained beam specimens was fifteen, while the number of prepared slab samples was three. The prepared beams for each binder content were divided into three groups, the first group represents the control mix; the second group was subjected to the long term ageing process. The third group includes the beams that practiced moisture damage process.

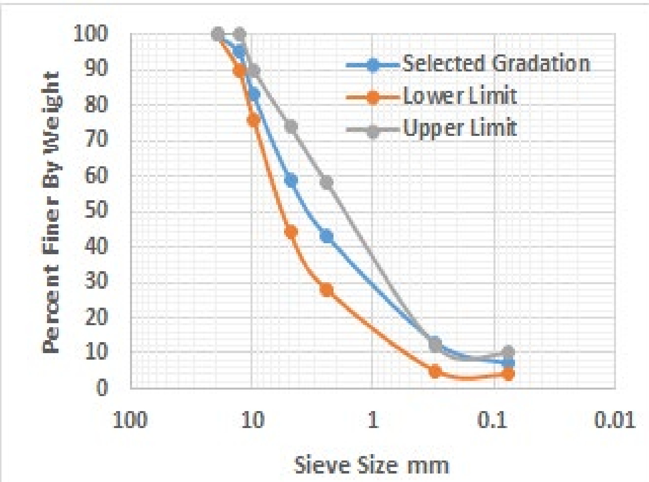

Figure 1. Aggregates Combined Gradation for Wearing Course According to SCRB, (2003), [11].

2.6. Moisture Damage Process

The beam specimens were immersed in a water bath for 120 minutes at 25° C. A compressor with a vacuum of 3.74 kPa applied for 10 minutes to obtain 80 % saturation was implemented for evacuating the air in the voids. The beam Specimens were placed in a freezer at -18°C ± 1°C for a minimum of 16 hours then removed from the freezer and placed into water bath for 24± 1 hour at a 60± 1°C. Beam specimens were removed from the water bath and were placed in another water bath at 25 ± 0.5 °C for about 2 hours, and then they were tested according to AASHTO, (2013), [16]. The only deviation of this procedure from that described in AASHTO, R-30, (2013), [12] is that the tested specimen is a beam and not a cylindrical specimen.

2.7. Long-Term Aging Process

Part of the asphalt concrete beam specimens had practiced oxidation ageing (long-term ageing). The beam specimens were stored in an oven for (120 hours) at 85°C as recommended by AASHTO R-30, (2013), [12] procedure. Afterwards, Specimens were withdrawn from the oven and stored in the testing chamber for 120 minutes at the testing temperature of 20°C for the fatigue test.

2.8. Repeated Flexural Bending Beam Test

The repeated flexural bending stresses were applied through the four-point repeated flexural bending beam test apparatus according to the procedure recommended by AASHTO T-321, (2007), [17]. The influence of asphalt cement binder content was monitored on the flexural stiffness and fatigue life of asphalt concrete beam specimens. The testing was implemented at a temperature of 20 °C, and under constant micro strain level of 750, which simulate heavy traffic mode of loading in the field. Beam specimens were subjected to dynamic four-point loading. The frequency of loading was set to 5 Hz. A repeated sinusoidal (compression-tension) load was applied to the beam specimen. Figure 2 exhibits the dynamic flexural bending beam test setup.

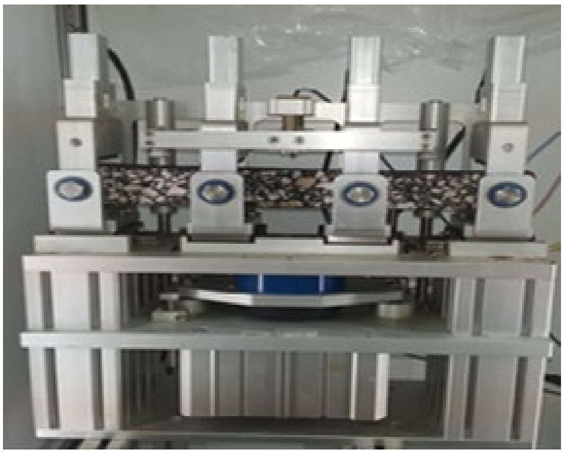

Figure 2. The dynamic flexural bending beam test setup.

3. Results and Discussions

3.1. **Durability issues at optimum binder content**

Figure 3 exhibit the durability issues of asphalt concrete mixture prepared with optimum binder content of 4.8 %. The flexural stiffness of the mixtures prepared at optimum binder content is two folds of that at higher or lower binder content. This can be related to the proper flexibility generated in the asphalt concrete at optimum binder content. Similar trend of decline in the flexural stiffness through the fatigue life could be noticed. However, the long term aged mixture exhibit significant improvement in the flexure strength as compared with other mixtures. After the first load repetition, the flexural stiffness of moisture damaged mixture decline by 57.8 % as compared with the control mixture while the aged mixture does not show significant variation. On the other hand, at failure, the aged mixture exhibit thirteen folds higher flexural stiffness than other mixtures. It can be detected that mixture prepared with optimum binder content exhibit higher flexural stiffness after 30 repetitions of the flexural stresses as compared with control specimens. This may be attributed to the fact that optimum binder content provides the required binder film thickness to resist the stripping after exposure to the moisture conditioning. Similar findings were reported by Racanel and Burlacu, (2013),[18] as the asphalt binder provides waterproofing property to the asphalt concrete, binds the aggregate together, and supports its flexibility.

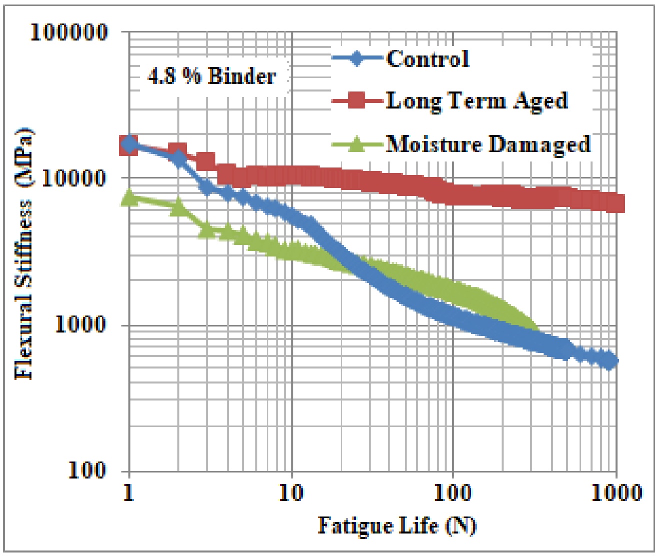

Figure 3. Durability issues at optimum binder content

3.2. Durability issues at 5.3 % binder content

As exhibited in Figure 4, the flexural stiffness declines in general, while the repeated flexural stresses proceeds when high binder content of 5.3 % is implemented. The moisture damaged beam specimens exhibit sharp decline in the stiffness after 10 repetitions of flexural stresses as compared with other specimens. The flexural stiffness of moisture damaged mixture declines by 16.6 % after the first load repetition while it decline by 64.7 % at failure. This could be attributed to the stripping action of the binder. On the other hand, the long term aged mixture exhibits a significant increment in the flexural stiffness as compared with other mixtures. The flexural stiffness of aged mixture increases by 233 % after the first load repetition while it increases by 35.4 % at failure. This may be attributed to the stiffening of the binder after ageing. However, the maximum flexural stiffness of the mixtures does not exceed 10000 MPa. This could be attributed to higher flexibility generated due to the high asphalt binder content. Since the asphalt binder content is considered as a key parameter in the mixture design, higher binder content exhibit higher flexural stiffness at failure as compared with mixtures prepared with lower binder content regardless of the conditioning process of asphalt concrete. Such behavior is in agreement with Rondón-Quintana et al., (2021), [19].

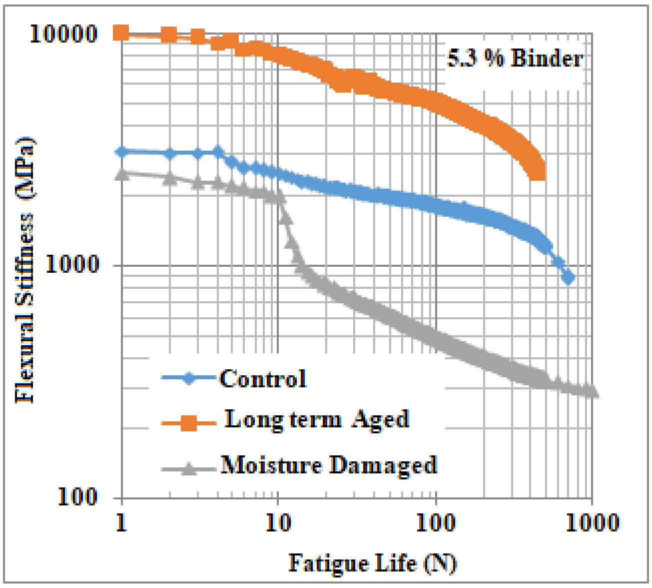

Figure 4. Durability issues at 5.3 % binder content

3.3. Durability issues at 4.4 % binder content

Figure 5 exhibits the deterioration of flexural stiffness through the fatigue life of asphalt concrete mixture prepared at lower than optimum binder content of 4.3 %.

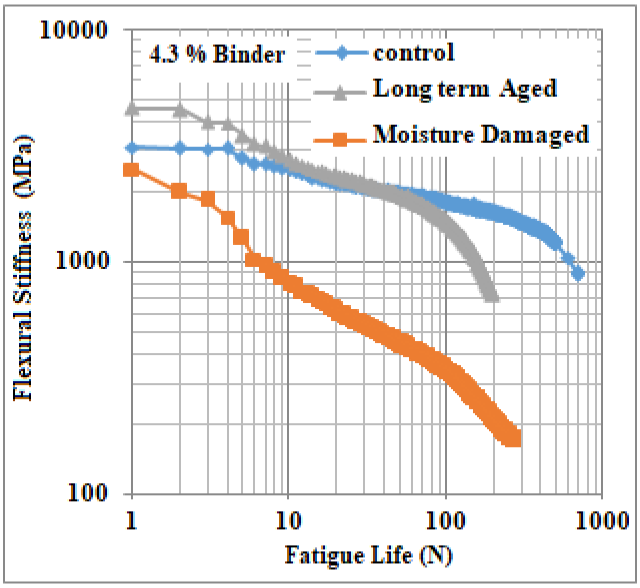

Figure 5. Durability issues at 4.3 % binder content

A significant decline in the flexural stiffness could be noticed after practicing the moisture damage process than the control mixture. However, the flexural stiffness increases significantly after practicing the long term ageing process. The flexural stiffness of moisture damaged mixture declines by 16.6 % after the first loading cycle while it declines by 75 % at failure as compared with the control mixture. On the other hand, the flexure stiffness increases by 50 % after the first loading cycle while the rate of increase in flexural stiffness decline gently until it vanishes after 30 repetitions of flexural stresses. This may be attributed to the stiffening of the mixture and the loss of the required flexibility due to ageing. At failure, the aged mixture exhibits a decline in the flexural stiffness by 17.6 %. Bessa et al., (2019), [20] have observed similar behavior.

3.4. Influence of binder content on the fatigue of asphalt concrete

There was different viscoelastic behavior at different binder content. The fatigue life for mixture with optimum binder content of 4.8 % was higher than that at higher or lower binder content by 42.8 % for control mixture. However, after practicing the long term ageing process, the fatigue life decline by (50 and 80) % for mixtures prepared at higher or lower binder content respectively as compared with the control mixture. This may be attributed to the stiffening of the mixtures due to ageing. On the other hand, higher binder content exhibits higher fatigue life for moisture damaged mixtures. This could be related to the thicker binder film which can sustain the quality against stripping. Long term ageing processes of asphalt concrete exhibit higher flexural stiffness as compared with the control mixture regardless of the binder content. This was in agreement the statement revealed by Rahmani et al., (2017), [7] that the stiffness of asphalt concrete may increase by four folds after the ageing process based on the binder type. However, this may create a stiff and brittle mixture which will be susceptible to disintegration and fatigue cracking at cold environment. Ageing process can stiffen the asphalt cement binder and negatively affects the viscosity; it makes the pavement more prone to various types of distress, such as raveling and cracking as reported by Tauste et al., (2018), [21].

4. Conclusions

The following conclusions could be addressed based on the limitations of testing program and materials.

1- The flexural stiffness of the control mixtures prepared at optimum binder content is two folds higher than that prepared at higher or lower binder content.

2- At failure, the aged mixture prepared at optimum binder content exhibit thirteen folds higher flexural stiffness than other mixtures.

3- The flexural stiffness of aged mixture prepared at high binder content increases by 233 % after the first load repetition while it increases by 35.4 % at failure.

3- The flexural stiffness of moisture damaged mixture declines by 16.6 % after the first loading cycle while it declines by 75 % at failure as compared with the control mixture.

4- After practicing the long term ageing process, the fatigue life decline by (50 and 80) % for mixtures prepared at higher or lower binder content respectively as compared with the control mixture.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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