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Assessing the Sensitivity of Binder Content in Asphalt Concrete Mixture

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ABSTRACT

Sensitivity of variation in asphalt binder content does not attract the researchers, however, a tolerance of ± 0.5 % of the binder content from the job mix formula is usually allowed by the supervisor engineers in Iraq. In the present investigation, asphalt concrete mixtures for wearing course are prepared at optimum binder content and at ± 0.5 % of the binder content. Asphalt concrete slab samples were prepared using roller compaction. Beam specimens were obtained from the slab samples and tested for dynamic fatigue life with the aid of four-points bending beam at 20ºC environment and under constant strain level of 750. It was noticed that the specimens prepared with optimum binder content exhibit the lowest deformation and phase angle, highest flexural stiffness and dissipated energy when compared with mixtures prepared with the tolerance of ± 0.5 % binder content. It was concluded that the performance of asphalt concrete is greatly sensitive to the variation in binder content. It was recommended that a stringent control measures of binder content should be implemented and verified in the general specification for roads and in the contract documents.

Keywords: Asphalt concrete, Binder content, Flexure, Sensitivity, Phase angle, Deformation, Dissipated energy

1. INTRODUCTION

The fatigue resistance of asphalt concrete mixture is the ability of the mixture to withstand the traffic repetitive loading and the impact of environment without any significant failure such as premature failure or cracking. Such fatigue resistance is dependent mainly on the asphalt binder content. Mandula and Olexa, 2017 assessed asphalt mixture problems which are caused by its inner properties and the behavior of material under dynamical loading. The phase angle was also studied as an indicator of visco-elastic behavior. It was stated that phase angle observation is important for better understanding of structural material behavior. It was observed that the phase angle value became stabilized after one third of the test duration while strong increase in the phase angle started slightly before failure point. It was concluded that sudden increase in the phase angle is one of the indicators of material lifespan ending. Racanel and Burlacu, 2013 addressed that the asphalt

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binder gives an asphalt pavement waterproofing property, supports its flexibility, and binds the aggregate together. However, the binder content is a key mixture design parameter. Roylance, 2001 stated that when a viscoelastic asphalt concrete mixture is subjected to sinusoidal varying stress, a steady state will be reached in which the resulting strain is also sinusoidal, having the same angular frequency but retarded in phase by an angle. This means that the material structure is linear. Abojaradeh, 2013 revealed that dissipated energy is a measure for evaluating the fatigue lifespan of asphalt concrete mixtures. The dissipated energy is calculated for each loading cycle and change in dissipated energy for different cycles can indicate the initial state of failure and cracking of the material. The cumulative dissipated energy is the summary of dissipated energy in every cycle until collapse of the material. Zou et al., 2019 stated that for a viscoelastic material, such as the asphalt concrete mixture, the external work applied to the material is consumed in part by inducing cracking on the surface and in part by inducing flow deformation. The binder content plays a major part in such behavior. Carmo et al., 2021 analyze the structural sensitivity of a flexible pavement, which exhibits variations in its mechanical properties due to the asphalt binder content. A variation of ±0.5% within the optimum asphalt binder contents was used as service tolerance during the asphalt mixture manufacturing process. The indirect tensile strength and the resilient modulus of the mixtures were used for the structure analysis. The results show that the variations in the asphalt binder content influence the mechanical properties and corresponding structural responses of the investigated pavement. Vazquez et al., 2010 stated that the asphalt binder content is considered as one of the most factors affecting the resistance to fatigue cracking of asphalt mixtures. Hence the density and the adequate asphalt binder content should be used in asphalt concrete mixtures to increase the resistance to fatigue cracking. A repeated flexural bending test under the controlled-strain mode of loading was conducted by Karami and Nikraz, 2015 to examine fatigue behavior of the asphalt mixtures for dense graded asphalt concrete mixture. Beam specimens were tested at the temperatures of 20°C and different peak tensile strain. According to the test results and based on the initial flexure stiffness and phase angle values, the elastic and viscous behavior of asphalt concrete could be detected. Zhu et al., 2022 conducted a comparative analysis of flexural-tensile stiffness modulus, residual and initial stiffness modulus, lag angle, and cumulative dissipation energy for evaluation of the fatigue resistance of asphalt concrete mixture. The aim of the present investigation is to assess the sensitivity of asphalt binder content in asphalt concrete mixture and evaluate its influence on flexural stiffness, phase angle, deformation, and dissipated energy.

2. MATERIALS AND METHODS

Asphalt Cement

Asphalt cement binder of penetration grad 40-50 was implemented in this work. It was obtained from AL-Nasiriya oil Refinery. The physical properties of the asphalt binder are listed in Table 1.

Table 1. Physical Properties of Asphalt Cement Binder

Physical properties	**ASTM, 2016 Designation**	**Asphalt cement**	**SCRB, 2003**
Penetration	D5-06	42	40-50
Softening Point °C	D36-95	49	-
Ductility Cm	D113-99	150+	>100
Specific Gravity	D70	1.04	-
Flash Point °C	D92-05	269	>232
After thin film oven test			
Retained Penetration of Residue	D5-06	33	<55
Loss in weight (163^{o}C, 50g,5h) %	D-1754	0.175	-------
Ductility of Residue	D113-99	130 cm	>25

Fine and Coarse Aggregates

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

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Table 2. The Physical Properties of Coarse and Fine Aggregate as per ASTM, 2016

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128).	2.642	2.658
Percent Water Absorption (ASTM C 127 and C 128)	1.07	1.83
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	18 %	-

Mineral Filler

The mineral filler implemented in the present investigation is the limestone dust which was obtained from Karbala. Most of the filler passes sieve No.200 (0.075mm). The physical properties of the mineral filler are presented in Table 3.

Table 3. The Physical Properties of Mineral Filler

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

Selection of Aggregates Combined Gradation

The selected aggregates gradation in the present investigation follows SCRB, 2003 specification for dense graded wearing course pavement layer with 12.5 mm nominal maximum size of aggregates. Table 4 shows the selected aggregate gradation.

Table 4. Aggregates Gradation implemented for Wearing Course as per SCRB, 2003

Sieve size mm	Selected gradation	SCRB, 2003 Specifications
19	100	100
12.5	95	95-100
9.5	83	76-90
4.75	59	44-74
2.36	43	28-58
0.3	12	5-12
0.075	7	4-10

Preparation of Asphalt Concrete Mixture and Specimens

The fine and coarse aggregates were combined with mineral filler to meet the specified gradation for wearing course. The combined aggregates were then heated to 160 ºC before mixing with asphalt cement. The asphalt cement binder was heated to 150 ºC as recommended by SCRB, 2003. Then, the binder was added to the heated aggregate to the desired amount and mixed thoroughly by hand using a spatula for two minutes so that the aggregate particles are coated with a thin film of the binder. The optimum asphalt content of 4.8% was implemented. 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 Sultan, 2015. Extra mixtures with 0.5 % binder above and below the optimum requirement were also prepared. The mixtures were casted in a slab mold of (40 x 30 x 6) cm and subjected to roller compaction to the target bulk density for each binder content according to EN12697-33, 2007. The applied static load was 5 kN while the number of load passes depended on the asphalt content and target density of the mixture and was determined based on trial-and-error process. Details of the compaction process could be referred to Sarsam, 2016. The compaction temperature was maintained to 150 °C. Slab samples were left to cool overnight. Beam specimens of 63±2 mm width and 50±2 mm high, and 400 mm length were obtained from the compacted slab sample using the Diamond-saw. The total number of beam specimens obtained was twelve while the number of casted slabs was three. The beam specimens were tested for fatigue life under repeated flexural bending using the four-point bending beam test at a moderate environment of 20º C. The test was terminated when the stiffness of the mixture declines to 50 % of its original value. The phase angle, cumulative dissipated energy, deformation, and flexural stiffness were calculated after each load repetition. Figure 1 exhibit the roller compactor implemented while Figure 2 exhibit the four-points repeated flexural bending beam test setup.

Figure 1. The Roller Compactor

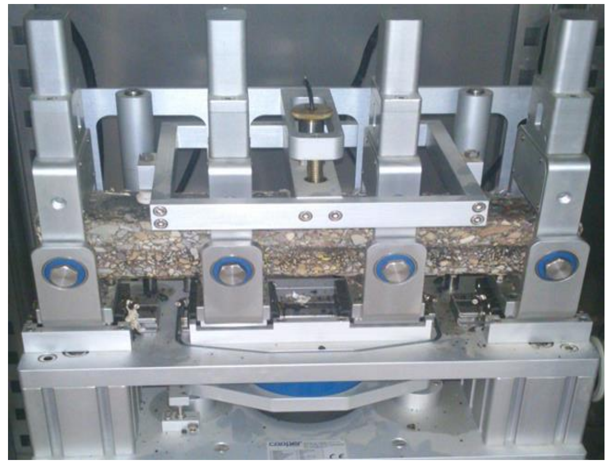

Figure 2. Four-points flexural bending test setup.

3. RESULTS AND DISCUSSIONS

Sensitivity of Deformation

Figure 3 exhibit the sensitivity of deformation of asphalt concrete to the asphalt cement binder content. It can be noticed that the optimum binder content of 4.8 % shows the lowest deformation in microstrain throughout the loading process. However, after 20 repetitions of the flexural stress application, no significant variation in the deformation could be found among various asphalt binder content. This may be attributed to the initiation of microcracks as a start point of failure. On the other hand, higher binder content of 5.3 % exhibit the highest fatigue life at failure of asphalt concrete mixture as compared with lower binder percentages. The optimum binder content exhibit higher fatigue life after the 6th load repetition. Similar behaviour was reported by Racanel C., and Burlacu, 2013.

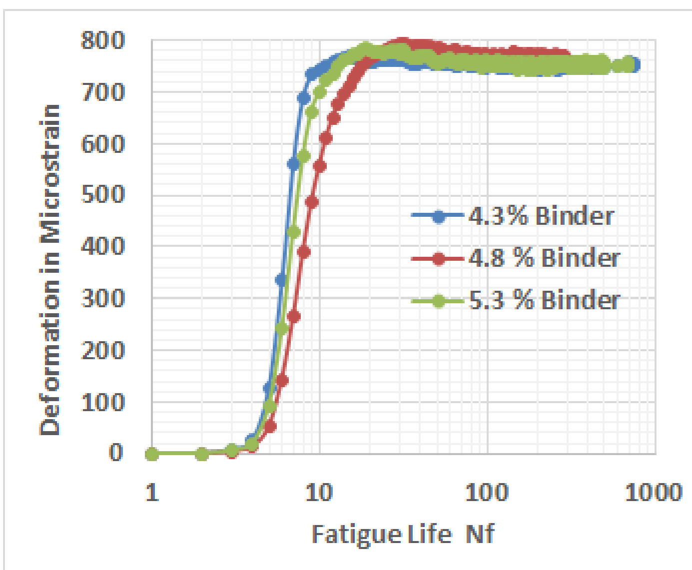

Figure 3. Deformation of Asphalt Concrete under Constant Microstrain of 750

Sensitivity of Flexural Stiffness

Figure 4 demonstrates the sensitivity of flexural stiffness to the variation in binder content. The flexural stiffness decreases in general as the loading proceeds regardless of the asphalt content. This agreed with Mandula and Olexa, 2017. However, the mixture prepared with optimum binder content of 4.8 % shows higher flexural stiffness throughout the fatigue process as compared with mixtures prepared with higher or lower binder percentages. This may be attributed to the fact that the lower binder content below the optimum requirement exhibit lower flexibility of asphalt concrete with a fragile state, while higher binder content may cause

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creep and flow of aggregates due to the lubrication action of excess asphalt binder. Similar conclusion was reported by Carmo et al., 2021.

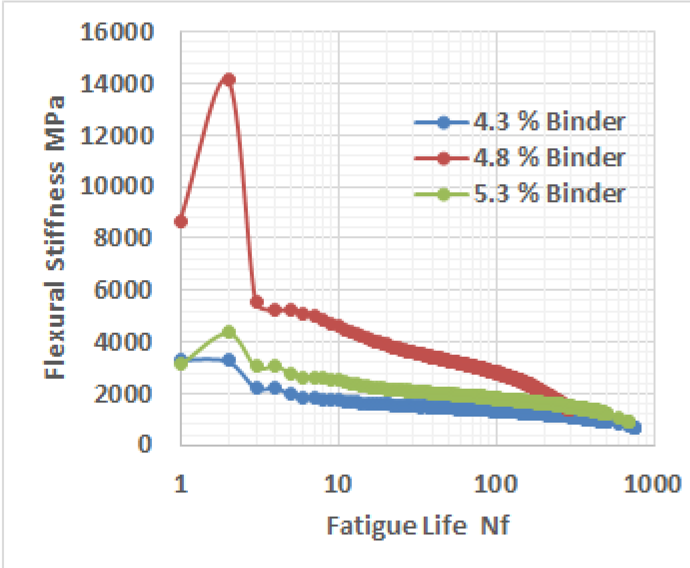

Figure 4. Flexural Stiffness of Asphalt Concrete under Constant Microstrain of 750

Sensitivity of Phase Angle

As demonstrated in Figure 5, the phase angle in the final loading cycle is much higher than that in the initial load cycle. Failure point is the point where the phase angle starts markedly increasing, as can be seen in Figure 5. The sudden change in the phase angle at this point indicates inner structural changes. The cause of these changes was probably the creation of micro-cracks. Based on these facts it could be concluded that the sudden behavior change to viscous state indicates the final stage of the material fatigue life. On the other hand, the asphalt concrete mixtures prepared with optimum asphalt binder content exhibit the lowest phase angle throughout the fatigue process as compared with other mixtures prepared with higher or lower binder content. After practicing 100 flexural stress application, mixture with optimum binder content exhibit a phase angle of 42 º while mixtures prepared with higher or lower binder percentages exhibits a phase angle of (53 and 52) º respectively. Figure 5 also exhibits that the viscoelastic properties in terms of phase angle of the asphalt concrete mixtures are constantly changing throughout the process of the fatigue test. Similar finding was reported by Zhu et al., 2022.

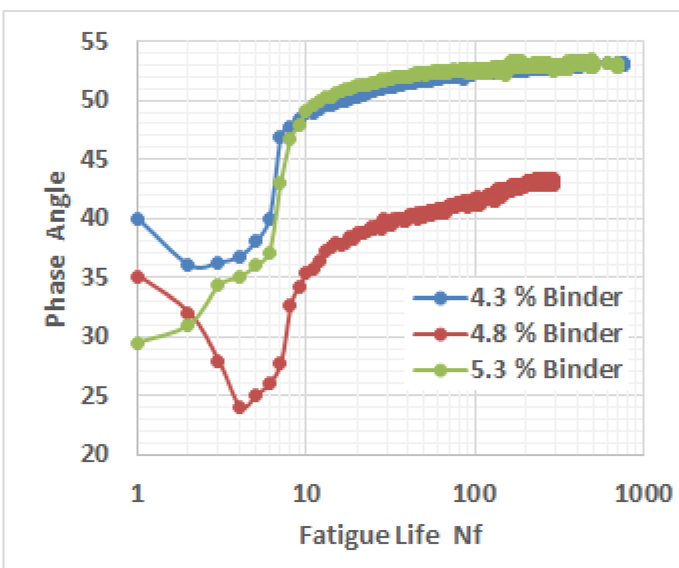

Figure 5. Phase Angle of Asphalt Concrete under Constant Microstrain of 750

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Sensitivity of Dissipated Energy

The dissipated energy during the test was mainly constant until microcracks occurred, and after this point, the dissipated energy started to increase. This fact is illustrated in Figure 6. Similar behavior was reported by Zou et al., 2019. The correlation between fatigue life and the cumulative dissipative energy is considered linear which indicates that higher required accumulated dissipative energy at the damage point of material corresponds to longer fatigue life. It can be detected from Figure 6 that asphalt concrete mixture prepared with optimum binder content exhibit the lowest cumulative dissipated energy as compared with mixtures prepared with higher or lower binder content. The energy is absorbed by the asphalt concrete material causing damage, and the number of loading cycles at failure is related to the amount of energy dissipated during the testing process.

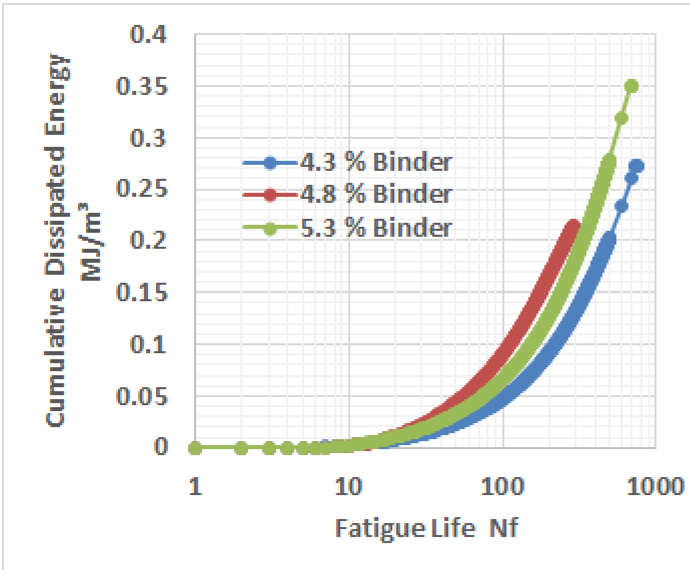

Figure 6. Dissipated Energy of Asphalt Concrete under Constant Microstrain of 750

4. CONCLUSION

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

1- The optimum binder content of 4.8 % shows the lowest deformation in microstrain throughout the loading process. Higher binder content of 5.3 % exhibit the highest fatigue life at failure of asphalt concrete mixture as compared with lower binder percentages.

2- The mixture prepared with optimum binder content of 4.8 % shows higher flexural stiffness throughout the fatigue process as compared with mixtures prepared with higher or lower binder percentages.

3- The asphalt concrete mixtures prepared with optimum asphalt binder content exhibit the lowest phase angle throughout the fatigue process as compared with other mixtures prepared with higher or lower binder content.

4- After practicing 100 flexural stress application, mixture with optimum binder content exhibit a phase angle of 42 º while mixtures prepared with higher or lower binder percentages exhibits a phase angle of (53 and 52) º respectively.

5- Asphalt concrete mixture prepared with optimum binder content exhibit the lowest cumulative dissipated energy as compared with mixtures prepared with higher or lower binder content.

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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