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(Research Article)

Detecting the Role of Fly Ash Additive in Enhancing the Fatigue Life of Asphalt Concrete

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Abstract

Enhancing the fatigue life of asphalt concrete by implication of coal fly ash additive was investigated in this work. Asphalt concrete mixtures have been prepared with optimum binder requirements; additional mixtures were also prepared with ±0.5 % binder above and below the optimum. Coal fly ash was implicated into the asphalt cement binder in the wet process. The mixtures were compacted using laboratory roller compaction into a slab mold. Beam specimens were obtained from the prepared slab samples and tested for fatigue life at 20 ℃with the aid of dynamic bending beam test and three constant strain levels of (750, 400, and 250) microstrain. Specimens were subjected to the long term ageing process before conducting the dynamic test. It was observed that implication of coal fly ash in the asphalt concrete exhibit longer fatigue life regardless of the implemented constant strain level. It was concluded that the coal fly ash exhibit negative influence on the fatigue life of asphalt concrete after ageing as compared with the control mixture.

Keywords: Coal fly ash, asphalt concrete, fatigue life, flexural stress, ageing

1. Introduction

The influence of using coal waste powder as an active mineral filler material in asphalt concrete was investigated by Modarres and Rahmanzadeh, [1]. It was detected that implementing the coal waste and its ash have resulted in higher Marshall Stability and resilient modulus. On the other hand, the combination of coal waste and limestone powders in equal proportion had resulted in a desirable asphalt concrete mix with high water resistance. It was revealed that the asphalt concrete mixture containing coal waste powder showed more flexible behavior than the reference mix. Sarsam and AL-Lamy, [2] revealed that fatigue in asphalt concrete mixture is a process of cumulative damage and one of the major causes of cracks in the flexible pavement. The traditional fatigue approach assumption is that the expected damage occurs in a specimen due to the dynamic repetitive loading which leads to fatigue failure of the specimen. It was revealed that the number of load repetitions to failure is equal to the fatigue life, and can be calculated based on strain or stress. The fatigue life and fatigue properties of asphalt concrete mixtures were evaluated by Golchin and Mansourian, [3] using the four-point bending beam. It was addressed that the asphalt mixtures tested at lower strains level, exhibited higher stiffness and the fatigue life of mixture increased, when the level of test strains declined. Shafabakhsh et al., [4] studied the influence of using different additives on the fatigue life parameters of asphalt concrete mixtures. Positive impact of these additives on improving fatigue behavior of asphalt mixture was detected through the test results. Cui et al., [5] studied the fatigue properties of asphalt concrete mixture after practicing long-term field service. The fatigue behavior of asphalt concrete pavement mixture with different service time, failure types, and traffic load were monitored and evaluated. It was addressed that surface layer of asphalt concrete pavement has a longer fatigue life under small stress levels. However, it exhibit shorter fatigue life under large stress levels. The longer service time of the pavement exhibits greater sensitivity to loading stress, while heavier traffic exhibits shorter fatigue life. Sarsam, [6] stated that the flexural stiffness of asphalt concrete mixture increases by (63.6) %, when 4 % of fly ash was implemented in the mixture and tested under 400 microstrain level. However, the fatigue life of asphalt concrete increases by (220.6) %, when 4 % of fly ash was implemented, under 400 microstrain level. It was revealed to implement fly ash in the asphalt cement binder to enhance the stiffness of the binder. Tahami et al., [7] assessed the potential of using two waste byproducts namely the rise husk ash and the date seed ash, as partial replacement of mineral filler in the asphalt concrete mixture. The role of the rise husk additive in the mechanical properties of asphalt concrete mixtures was evaluated using the stiffness modulus value, and the four point bending beam fatigue tests. It was addressed that such additives exhibited higher Marshall Stability and stiffness modulus as compared

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with the control mixture, while such fillers had enhanced the fatigue life and rutting resistance of asphalt concrete mixtures. The influence of active fillers on the fatigue behavior and rheological properties of cold bitumen emulsion mastic was assessed by Al-Mohammedawi and Mollenhauer, [8]. Such fillers include cement, limestone, silica fume, and ladle slag. The investigation was supported by chemical analysis for the filler-bitumen emulsion. The test results exhibit that the fatigue damage resistance and the rheological performance depend not only on the filler inclusions but also on filler chemistry and filler type. Sarsam, [9] stated that the additives in the asphalt concrete mixture may change the strength properties and can influence the viscoelastic positive behavior of asphalt concrete. Fly ash and silica fumes were introduced into the asphalt concrete mixture. It was revealed that the flexural stiffness and the fatigue life of asphalt concrete declines after implication of such additives. It was concluded that the silica fumes additives had a significant impact on the viscoelastic properties of asphalt concrete as compared with that of the fly ash treated mixtures. Asphalt concrete mixtures with fly ash were characterized by Joumblat et al., [10]. Fly ash was added as partial substitute for the mineral filler, and subjected to evaluation of the performance in comparison with the control mix. The dynamic modulus was expressed for measurement of the stiffness of the mixture. The test results concluded that the use of fly ash in asphalt concrete mixtures as mineral filler substitution was able to increase the resistance to low temperature cracking as higher than 25%, and increase the rutting resistance of asphalt concrete up to 50%. Woszuk et al., [11] investigated the variation in the properties of asphalt concrete mixture where the traditional limestone filler was replaced by fly ash of class C and class F. It was noticed that the water resistance was (104-96) % while the frost resistance was (104-102) %, for the samples with the addition of class F and class C fly ash. It was revealed that both classes of fly ash can be implemented as the alternative mineral filler substitute. Khan et al., [12] assessed the influence of different type of fillers on some properties of asphalt concrete mixtures. Two filler types, marble dust and silica fumes were studied to investigate the impact of filler/asphalt ratio on the characteristics of asphalt mixtures. It was revealed that the mixtures with 50% marble dust and 50 % silica fume exhibit greater stability than all the other percentages used in a Marshall mixture. All other percentages of filler exhibit lower stability and voids which are out of range. Asphalt concrete mixture having 50% marble dust and 50% silica has only 13.5 mm flow value which is greater than all other percentages.

The aim of the present work is to detect the role of coal fly ash additive in enhancing the fatigue life of asphalt concrete. Asphalt concrete mixtures will be prepared with optimum binder requirements; additional mixtures will also be prepared with ±0.5 % binder above and below the optimum. The mixtures will be compacted using laboratory roller compaction into a slab mold. Beam specimens will be obtained from the prepared slab samples and tested for fatigue life at 20 ℃ with the aid of dynamic bending beam test and three constant strain levels of (750, 400, and 250) microstrain. Specimens will also be subjected to the long term ageing process before conducting the dynamic test.

2. The Materials and the Testing Methods

2.1 Asphalt cement: Asphalt cement with a softening point of 49℃, penetration grade of 42, and ductility of 150 Cm, which was obtained from AL-Nasiriya oil Refinery was implemented in the present work. After implementing the thin film oven test, the ductility and penetration declines to 83 Cm and 33 respectively while the softening point increases to 53℃. The test of physical properties of binder was conducted according to the ASTM, [13] procedures.

2.2 Fine and coarse aggregates: Crushed coarse aggregates have been obtained from AL-Ukhaider quarry. A mixture of crushed and natural fine aggregates was obtained from the same quarry of aggregates. Both aggregates type were washed, and then air dried and separated to different sizes by sieving. The bulk specific gravity of the fine and coarse aggregates is (2.558 and 2.542) respectively while the water absorption was (1.83 and 1.076) % for fine and coarse aggregates respectively.The test of physical properties of aggregates was conducted according to the ASTM, [13] procedures.

2.3 Mineral filler: The limestone dust was obtained from Karbala quarry and implemented as mineral filler. Testing for physical properties shows that the bulk specific gravity of the mineral filler was 2.617. However, 94 % of the filler passes sieve No.200 (0.075mm).

2.4 Coal fly ash: Coal fly ash of class F was obtained from local market. The specific surface area was 650 m^2/Kg while the specific gravity of the fly ash is 2.645. The major chemical composition of the coal fly ash is 28.82 % of Al_2O_3, 61.95 % of SiO_2, 2.67 % of Fe_2O_3.

2.5 Selection of the combined aggregate gradation for preparation of asphalt concrete mixture: The dense gradation of wearing course pavement layer was selected in the present assessment. It follows SCRB, [14] specification. The aggregates gradation exhibit 12.5 mm of nominal maximum size of aggregates. Figure 1 demonstrates the selected combined gradation with its tolerance for wearing course.

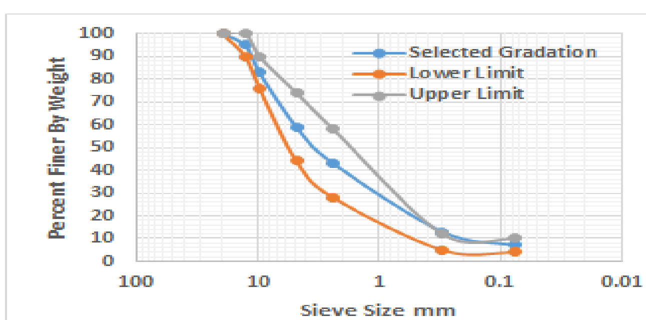

Figure 1. The implemented combined aggregates gradation

2.6 Preparation of fly ash-asphalt cement modified binder: The modified fly ash-asphalt cement binder was prepared by implementing the technique of wet process. In this process, the asphalt cement was heated in an oven to 150°C and then the fly ash was added in powder form using various percentages. The mixture was blended in a mixer at a blending speed of about 1300 rpm and the mixing temperatures of 160°C was maintained for 20 minutes to allow the possible chemical and physical bonding to occur of the components. The optimum percentage of fly ash was 4% by weight of binder. Details of the mixing procedure and selection of the optimum percentage could be found in Sarsam and Al-Lamy, [15].

2.7 Preparation of the asphalt concrete mixture, slab samples, and beam specimens: The asphalt cement or the modified asphalt cement was heated to 150ºC, and then it was mixed with the mineral filler and the combination of the fine and coarse aggregates which was heated to 160ºC. The optimum asphalt binder content of 4.9 % was obtained based on Marshall Test. Extra specimens with binder of ± 0.5 % lower and higher than that of the optimum were also prepared. Details of the procedure of obtaining the optimum binder requirement can be referred to Sarsam and Alwan; [16]. The prepared asphalt concrete mixtures were compacted in a rectangular slab mold of (40 × 30) Cm while the depth of the mold was 6 Cm. Laboratory roller compaction was conducted to the target bulk density for each binder requirement according to procedure described by EN12697-33, [17].The details of conducting the compaction process can be referred to Sarsam, [18]. The temperature of the compaction was maintained at 150°C throughout the rolling compaction process. The asphalt concrete slab samples were left to cool overnight. Beam specimens of 5.6 Cm height, 40 Cm length, and 6.2 Cm width, were obtained from the prepared slab sample with the aid of diamond-saw. The total number of the prepared slab samples of asphalt concrete was three, while the number of the tested asphalt concrete beam specimens was eighteen; The average value of testing duplicate beam specimens was considered for the analysis.

2.8 Long-term ageing process: Part of the asphalt concrete beam specimens were subjected to oxidation ageing (long-term ageing) process. The beam specimens were stored at 85°C in an oven for (120 hours) as recommended by AASHTO R-30, [19] procedure. The beam specimens of asphalt concrete were removed from the ageing oven and kept in the testing chamber of the dynamic testing apparatus for 120 minutes at 20°C testing temperature before starting the dynamic test.

2.9 Testing for fatigue by implementing the dynamic flexural bending beam test: The four-point dynamic flexural beam bending test was conducted according to AASHTO T321, [20] to assess the impact of fly ash, binder content, and ageing process on the fatigue life of asphalt concrete. The test was conducted at intermediate pavement operating temperature of 20°C while using three target amplitudes of constant microstrain levels of (750, 400 and 250) microstrain as demonstrated in Figure 2.

Figure 2. The four-point dynamic flexural bending beam test setup

3. Results and Discussions

3.1 Influence of asphalt binder content on the fatigue life: Figure 3 shows the impact of asphalt binder content on the fatigue life of the control asphalt concrete mixture. It can be detected that the highest fatigue life could be detected when the optimum binder content of 4.9 % was implemented regardless of the adopted constant strain level. The fatigue life declines by (92.5, and 95.3) %, (86.0, 96.5) %, and (56.1, 88.7) % for mixtures prepared with (4.9, 5.4, and 4.4) % binder content respectively when the implemented constant strain level increases from (250 to 400 and 750) microstrain. However, asphalt concrete mixtures prepared with optimum binder content of 4.9 % when compared with mixtures prepared with (5.4, and 4.4) % binder content exhibit higher fatigue life of (119, 891) %, (16.8, 67.7) %, (198, 311) % under constant strain level of (250, 400, and 750) microstrain respectively. It can be revealed that mixtures prepared with optimum binder content exhibit the longest fatigue life regardless of the constant strain level as compared with mixtures prepared with higher or lower binder content. Similar behavior was reported by Sarsam, [21].

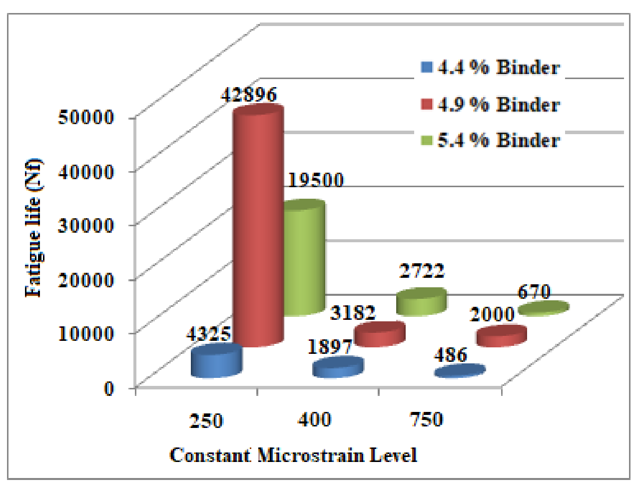

Figure 3. Influence of binder content on fatigue life

3.2 Influence of ageing on fatigue life: Figure 4 demonstrates the influence of long term ageing process on the fatigue life of control asphalt concrete mixture which was prepared with 5.4 % binder content when tested under 750 microstrain. It can be observed that the fatigue life of the control asphalt concrete mixture decline by 17.1 % after practicing the long term ageing process.

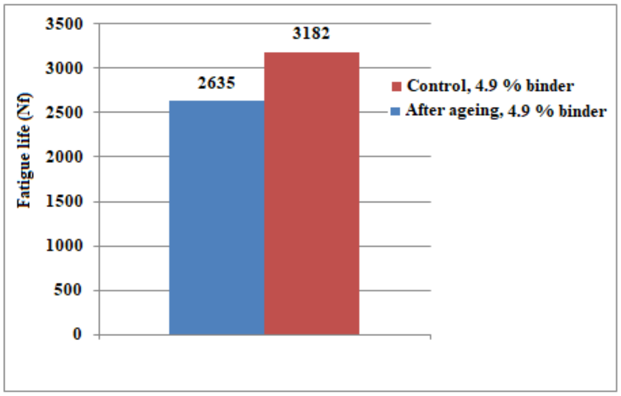

Figure 4. Impact of ageing on fatigue life at 750 microstrain

This could be attributed to the stiffening of asphalt concrete mixture due to the evaporation of volatiles from the asphalt cement binder. Such behavior is in agreement with the work addressed by Zhu et al., [22].

3.3 Influence of coal fly ash on fatigue life: Figure 5 exhibit the positive influence of implementation of coal fly ash on the fatigue life of asphalt concrete. It can be detected that implication of coal fly ash exhibit higher fatigue life of asphalt concrete at optimum binder content of 4.9 % regardless of the constant strain level implemented. The fly ash modified mixture exhibit higher fatigue life by (94.6, 220.6, and 72.8) % when the constant strain level is (250, 400, and 750) microstrain respectively. However, higher binder content of 5.4 % in the fly ash treated mixture still exhibit further increase in the fatigue life of asphalt concrete by (33.5, 29.2, 6.5) % as compared with mixture prepared with optimum binder requirement respectively when the constant strain level is (250, 400, and 750) microstrain. This may be attributed to the high specific surface area provided by the coal fly ash additive which requires more binder to coat the filler particles, blocking more voids, and increase the adhesion of the particles to resist the applied stresses. Such behavior of the influence of filler is in agreement with the work reported by Tenza-Abril et al., [23].

3.4 Influence of coal fly ash on ageing: Figure 6 demonstrates the impact of implication of coal fly ash additive for modification of asphalt cement on the behavior of asphalt concrete mixture prepared using the optimum binder requirement of 4.9 % through the long term ageing process. It can be observed that further decline in the fatigue life of asphalt concrete could be detected for the mixtures modified with coal fly ash after ageing process as compared with the mixture before ageing process. The fatigue life declines by (63.9, 63.1, and 57.5) % after ageing process for modified mixtures prepared with optimum binder content when the mixtures practiced constant strain level of (250, 400, and 750) microstrain respectively. it can be revealed that the coal fly ash exhibit negative influence on the fatigue life of asphalt concrete after the long term ageing process. This may be attributed to the decline of adhesion between the modified binder and the aggregates particles. Such behavior agrees well with the work reported by Sarsam, [24].

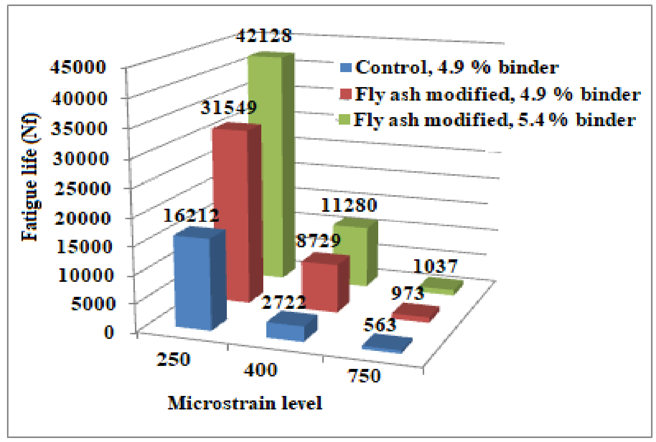

Figure 5. Influence of fly ash on fatigue life

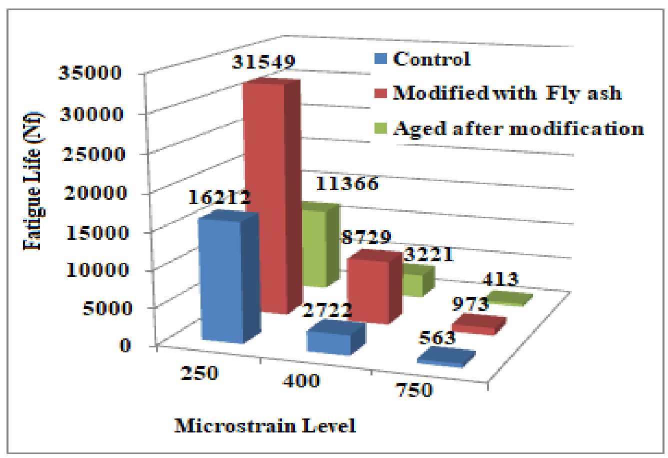

Figure 6. Influence of fly ash modification and ageing on fatigue life

4. Conclusions

On the bases of the limited testing and materials property, the following remarks could be addressed.

- The fatigue life of asphalt concrete declines by (92.5, and 95.3) %, (86.0, 96.5) %, and (56.1, 88.7) % for mixtures prepared with (4.9, 5.4, and 4.4) % binder content respectively when the implemented constant strain level increases from (250 to 400 and 750) microstrain.

- The fatigue life of the control asphalt concrete mixture decline by 17.1 % after practicing the long term ageing process.
- The fly ash modified mixture prepared with optimum binder content exhibit higher fatigue life by (94.6, 220.6, and 72.8) % when the constant strain level is (250, 400, and 750) microstrain respectively.
- Higher binder content of 5.4 % in the fly ash treated mixture exhibit further increase in the fatigue life of asphalt concrete by (33.5, 29.2, 6.5) % as compared with mixture prepared with optimum binder requirement respectively when the constant strain level is (250, 400, and 750) microstrain.
- The fatigue life of modified asphalt concrete prepared with optimum binder content declines by (63.9, 63.1, and 57.5) % after ageing process when the mixtures practiced constant strain level of (250, 400, and 750) microstrain respectively.
- The coal fly ash exhibit negative influence on the fatigue life of asphalt concrete after the long term ageing process.

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