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(Research Article)

Detecting the Variations in the Phase Angle through the Fatigue Life of Asphalt Concrete under Environmental Influence

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Abstract

The Asphalt concrete mixtures may exhibit changes in their mechanical behavior through the variation in environmental conditions and sustained loading time which enhances their fatigue life. In the present work, the role of the variations in the phase angle of the asphalt concrete on its fatigue life under three constant micro strain levels of (750, 400, and 250) microstrain to simulate the actual loading of the pavement in the field (heavy, moderate and low traffic volume) when experiences various environmental conditions of (5, 20, and 30) ℃have been assessed. Asphalt concrete mixtures were prepared using its optimum binder requirements, and then experienced laboratory roller compaction into a slab mold to a target density. Beam specimens were extruded from the prepared slab samples and tested using dynamic flexural stresses for fatigue life. It was noticed that longer fatigue life could be achieved at high testing temperature, and more sustained time is consumed to resist the deformation. The fatigue life from the phase angle point of view increases as the testing temperature rises. It was noted that the phase angle at failure declines by (2.5, and 62.5) %, (16.6, and 58.4) %, and (6.2, and 85.4) % when the testing environment decline from (30 to 20 and 5) ℃ respectively under (250, 400, and 750) constant microstrain levels respectively. The fatigue life increases by (2.3, and 3.1) folds, (7.1, and 11.5) folds, and (32.3, and 39) folds when the testing temperature rises from (5 to 20 and 30) ℃under (heavy, moderate, and low) traffic loading respectively. It can be revealed that the phase angle decline in general as the constant strain level increase for any specific testing environment and the fatigue life from the phase angle point of view increases as the testing temperature rises and decline as the constant strain level increase.

Keywords: Asphalt mixture, Phase angle, Strain level, fatigue life, flexural stress, test environment

1. Introduction

Ahmad et al., [1] investigated the impact of testing temperature on the variation in the phase angle of the asphalt concrete mixtures. The test was implemented at an environment temperature range of (30, 35, 40, 45 and 50) °C and various loading frequencies. It was revealed that the lower phase angle values can indicate lower viscosity of the asphalt binder due to increase in testing temperature. Demjan and Tomko, [2] reported that the phase angle is mainly dependent on the time lag in seconds between peak force loading frequency in Hz and maximum deformation of asphalt concrete. The Phase angle is defined as a visco-elastic parameter, and it is the delay between the strain and the corresponding amplitudes of applied stress as exhibited in Figure 1. It was revealed that the small phase angle can refer to brittle and very strong asphalt concrete mixture which may not deform under the applied stresses, while it is more likely to crack and fracture. However, asphalt concrete mixture with large phase angle, demonstrate flexible behavior of the mixture, which is less likely to fracture, and can exhibit permanent deformation and reduces the structural integrity of the mixture. Mandula and Olexa, [3] studied the relation between the phase angle of asphalt concrete mixture and the loading frequency.

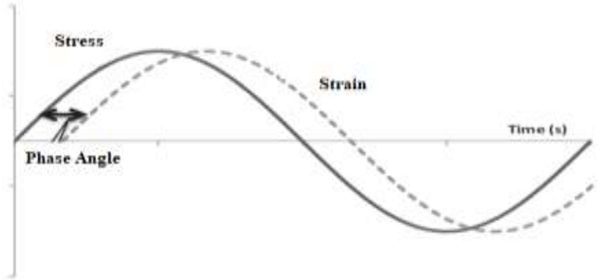

Figure 1. The delay between strain and stress amplitudes (phase angle), after Demjan and Tomko, 2014

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It was noticed that higher the testing temperature can exhibit higher phase angle values. This may explain the visco-elastic behavior of the asphalt concrete mixture when tested under variable environment. It was revealed that the average value of the phase angle at 0 °C temperature is 5 degrees while it is 30 degrees for the testing temperature of 27°C. Hussain et al., [4] addressed that the Phase angle of asphalt concrete mixture is an important property which may be considered in the selection of proper material for the mixture. It can also assist in quantifying the phase angle behavior for varying mixture characteristics to control premature failure of flexible pavements. It was revealed that he phase angle characteristics of asphalt concrete mixtures were modeled. The proposed model can be applied to various pavement mixtures used for base or wearing course by implementing the values of phase angle as an input and predict its value for the next loading frequency while keeping the testing environment as a constant. It was addressed that for the control of the rutting, minimization of the phase angle is required, while to resist the cracking of the pavement at cold environment, high phase angle is recommended. Mandula and Bokomlaško, [5] reported that the phase angle increases as the testing temperature rises. However, the decline of testing frequency of the load also may increase the phase angle. Zhang et al., [6] addressed that the phase angle may be calculated based on the master curve of the dynamic modulus test. It was stated that the resistance to permanent deformation at hot environmental temperature was improved; while the viscous flow in the low temperature was also enhanced. Alam and Hammoum, [7] modeled the material interaction within the microstructure and its relationship with individual material properties. It was revealed that the model can allow the calculation of the phase angle of asphalt concrete mixtures from the mechanical and physical properties of its constituents. Soleimani, [8] stated that the phase angle is a sound and direct measure for the asphalt concrete performance at low temperature. It was revealed that the Phase angle is a very good and sensitive parameter to detect the minor variations in the rheology of the asphalt binder. It can also provide a sensitive measure of the sol/gel nature of the asphalt material. A minor decline in phase angle will demonstrate a significant increase in stiffness at long loading times, and will reflect reversible hardening caused by a sol-gel transition. Ali et al., [9] investigated the factors that influence the phase angle for a wide range of asphalt concrete mixtures. It was revealed that a rise in the testing temperature of 17 °C may cause an increase the phase angle value by an average of 25 %. The phase angle at high temperature tends to decline as the temperature rises. However, phase angle exhibit an increase at lower temperature. Nobakht and Sakhaeifar, [10] assessed the impact of ageing process of asphalt concrete on the phase angle by conducting the complex modulus tests on asphalt mixtures after laboratory ageing. It was reported that predicting the phase angle by a model may accurately exhibit the master curves of the phase angle after different ageing periods. Sarsam, [11] revealed that the dynamic loading of the traffic can apply various compressive and shear stresses on asphalt concrete pavement which cause various strain with the same angular frequency but it is retarded in phase by an angle which is referred as phase angle. Full elastic behavior of the flexible pavement is expected when the phase angle is closer to 0°, while the stiffness of the mixture is also high exhibiting screen cracks due to fragility of the mixture. However, the viscous behavior of asphalt concrete is expected when the phase angle is closer to 90°, causing permanent deformation of the asphalt concrete mixture. Karami and Nikraz, [12] uses the phase angle and the flexural stiffness for evaluating the elastic and viscous behaviors of modified asphalt concrete with the aid of the dynamic flexural bending test under the controlled-strain mode of loading. Oshone et al, [13] evaluated the phase angles of asphalt concrete mixtures based on dynamic modulus data and evaluated the validity of such predictions. Wang and Zhang, [14] revealed that when testing asphalt concrete mixture, the phase angle and the stress were kept increasing with strain until reaching a critical peak point. The corresponding strains for peak phase angle and peak stress; however, the phase angle reached its peak slightly in slow trend than that of the stress. It was reported that the maximum stress is a yielding point, beyond which the phase angle started to drop, indicating that the fatigue damage reached a limit. The aim of the present work is to detect the variation of the phase angel of asphalt concrete and its role in enhancing the fatigue life under environmental influence. Asphalt concrete beam specimens will be prepared by laboratory roller and tested for fatigue life under dynamic flexural stresses using three levels of constant strain of (750, 400, and 250) microstrain to simulate the actual loading of the pavement in the field (heavy, moderate and low traffic volume) . The specimens will be tested at (5, 20, and 30) ℃ environment levels, and the variations in the fatigue life and phase angle will be monitored.

2. Materials and Methods

2.1 Asphalt cement: Asphalt cement binder with a penetration grade of 42, softening point of 49℃, and ductility of 150 Cm, was obtained from AL-Nasiriya oil Refinery, south of Baghdad, and employed in the present work. After accelerated ageing process of the binder by the thin film oven test, the softening point increases to 53℃, while the penetration and ductility declines to 33 Cm and 83 respectively. The test of mechanical properties of binder was conducted by following the ASTM, [15] procedures.

2.2 Fine and coarse aggregates: A mixture of crushed and natural fine aggregates and the crushed coarse aggregates were obtained from AL-Ukhaider quarry, north of Baghdad. Both aggregates type were cleaned by washing, and then air dried and sieved to different sizes. The bulk specific gravity of the fine and coarse aggregates is (2.558 and 2.542) respectively while the water absorption is (1.83 and 1.076) % for fine and coarse aggregates respectively.The test of physical properties of aggregates was conducted according to the ASTM, [15] procedures.

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

2.4 Selection of the combined aggregate gradation for preparation of asphalt concrete mixture: The dense gradation which is usually used for wearing course pavement layer was selected in the present study. It follows SCRB, [16] specification. The aggregates gradation exhibit 12.5 mm of nominal maximum size of aggregates. Figure 2 demonstrates the implemented aggregates gradation.

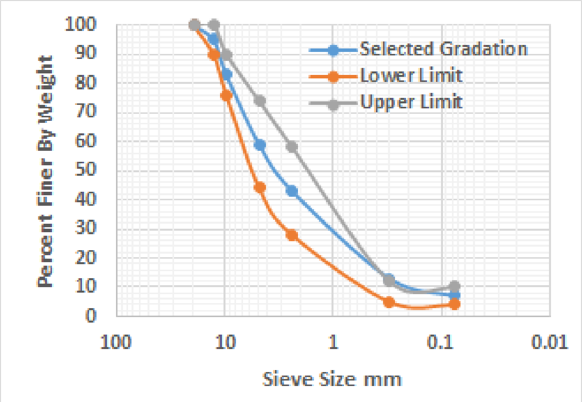

Figure 2. The selected combined aggregates gradation

2.5 Preparation of the asphalt concrete mixture, slab samples, and beam specimens: The asphalt cement binder was heated to 150ºC, and then it was mixed with the combined gradation of mineral filler, coarse and fine aggregates which was heated to 160ºC. The optimum asphalt binder content of 4.9 % was obtained based on Marshall Test. Details of the procedure of obtaining the optimum binder requirement can be referred to Sarsam and Alwan; [17]. 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 according to procedure described by EN12697-33, [18]. The details of conducting the compaction process can be referred to Sarsam, [19]. 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 twelve; The average value of testing duplicate beam specimens was considered for the analysis.

2.6 Testing for fatigue by implementing the dynamic flexural bending beam test: The four-point dynamic flexural beam bending test as demonstrated in Figure 3 was conducted according to AASHTO T321, [20] to detect the variation in the phase angle of asphalt concrete through the fatigue life under the influence of the testing environment of (5, 20, and 30) ℃ and constant strain levels. The beam specimens were stored in the testing chamber for three hours at the specific testing temperature before practicing the dynamic flexural stresses. Three target amplitudes of constant strain levels of (750, 400 and 250) microstrain has been implemented to simulate the actual loading of the pavement in the field (heavy, moderate and low traffic volume). Similar testing procedure using dynamic stresses, various constant strain levels, and various testing temperatures was adopted by Chen et al., [21].

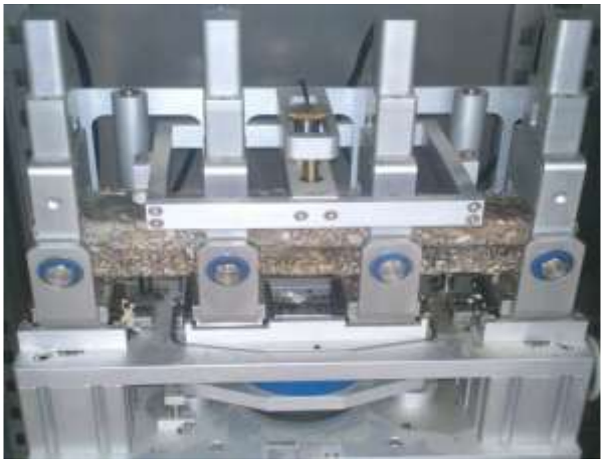

Figure 3. Four-point flexural bending test setup

3. Discussions on Test Results

3.1 Variation of phase angle under low traffic: Phase angle is the visco-elastic parameter of asphalt concrete, and it is the delay between the amplitudes of applied stress and the corresponding strain. The Phase Angle is an important property of asphalt concrete mixtures which may be implemented in the proper material selection to minimize premature failure of flexible pavements. Minimization of the phase angle is required to control the rutting at hot weather, however, to resist the cracking of the pavement at cold weather, high phase angle is recommended. Figure 4 demonstrate the variation in the phase angle through the fatigue process when the asphalt concrete is tested under low constant strain level of 250 micro strains which simulate the low traffic volume in the field. It can be observed that the phase angle increases through the fatigue life of asphalt concrete, the rate of increase is gentle at the early stages of loading, while it changes to sharp after an elapsed time of (10, 100, and 200) for specimens tested at (5, 20, and 30) seconds respectively. At failure, the phase angle is (30, 78, and 80) ˚ at (5, 20, and 30) ℃ environment respectively. The phase angle at failure decline by (2.5, and 62.5) % when the testing environment decline from (30 to 20 and 5) ℃ respectively. On the other hand, failure of the asphalt concrete specimens had occurred after (150, 5500, and 6000) seconds of practicing the dynamic flexural stresses when tested at (5, 20, and 30) ℃ environment respectively. Mandula and Bokomlaško, [5] reported similar behavior and stated that as the testing temperature rises, the phase angle increases.

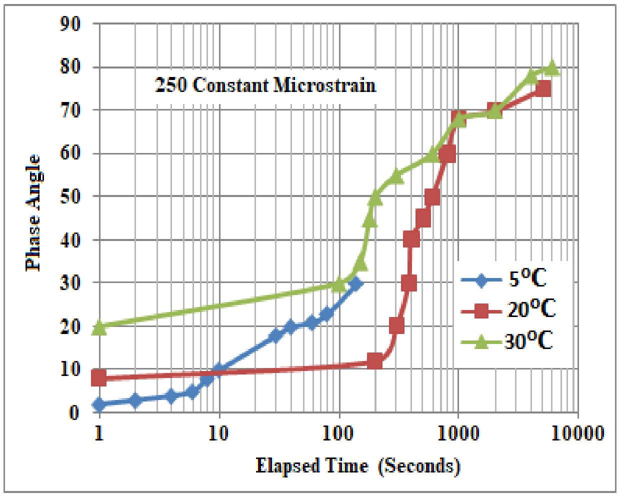

Figure 4. Variation of phase angle under 250 microstrain

3.2 Variation of phase angle under moderate traffic: Figure 5 exhibit the variation of phase angle through the fatigue process of asphalt concrete when the dynamic flexure stresses are applied using the moderate constant strain level of 400 microstrain which simulate the moderate traffic volume in the field.

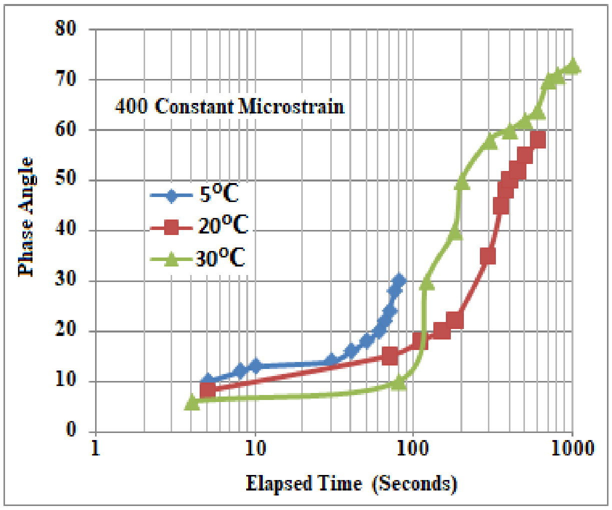

Figure 5. Variation of phase angle under 400 microstrain

A significant rise in the phase angle is detected throughout the elapsed time of stress application at moderate and high testing temperatures. However, the testing under cold environment of (5℃) exhibit gentle rise in the phase angle as the loading process proceeds, while the trend changes to sharp after 30 seconds of loading. Failure of the asphalt concrete specimens had occurred after (80, 600, and 1000) seconds of practicing the dynamic flexural stresses when tested at (5, 20, and 30) ℃ environment respectively. It can be stated that the asphalt concrete can sustain its quality as the testing temperature rises since the mode of failure changes from brittle with cracking to flexible with deformation as the testing environment changes from cold to hot. On the other hand, the phase angle at failure is (29, 60, and 73) ° at (5, 20, and 30) ℃ environment respectively. The phase angle at failure decline by (16.6, and 58.4) % when the testing environment decline from (30 to 20 and 5) ℃ respectively. This could be attributed to the increment of viscosity of the binder as the temperature falls down. Such behavior is in agreement with the work reported by Ahmad et al., [1].

3.3 Variation of phase angle under high traffic: Figure 6 demonstrate the variation of phase angle through the fatigue process of asphalt concrete when the dynamic flexure stresses are applied using the high constant strain level of 750 microstrain which simulate the heavy traffic volume in the field. A gentle trend of rise in the phase angle is detected throughout the elapsed time of stress application up to 50 seconds of the elapsed time of loading application.

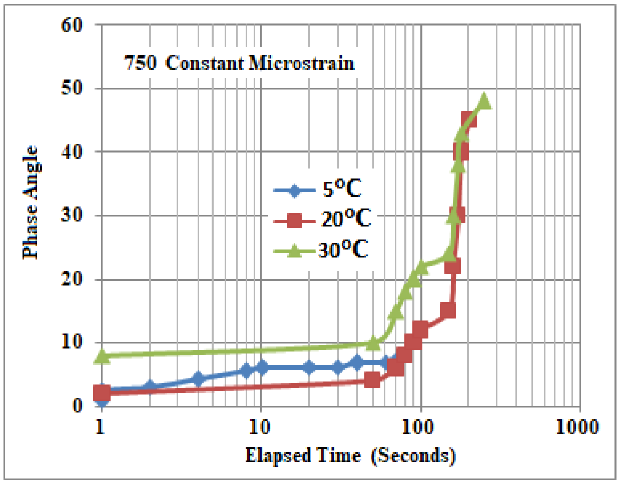

Figure 6. Variation of phase angle under 750 microstrain

However, as the dynamic flexural stresses application proceed, a significant sharp rise in the phase angle is noticed for the specimens tested at moderate and hot environments. Failure of the asphalt concrete specimens had occurred after (65, 200, and 250) seconds of practicing the dynamic flexural stresses when tested at (5, 20, and 30) ℃ environment respectively. It can be noted that the asphalt concrete can sustain its quality as the testing temperature rises under such high microstrain level since the mode of failure changes from brittle with cracking at cold environment to flexible with deformation as the moderate and hot testing environment. On the other hand, the phase angle at failure is (7, 45, and 48) ° at (5, 20, and 30) ℃ environment respectively. The phase angle at failure decline by (6.2, and 85.4) % when the testing environment decline from (30 to 20 and 5) ℃ respectively. This can be attributed to the increment of viscosity of the binder as the temperature falls down. Such behavior is in agreement with the work reported by Mandula and Bokomlaško, [5]. It can be revealed that the phase angle decline in general as the constant strain level increase for any specific testing environment. For the test at cold testing environment of 5℃, the phase angle at failure decline from (30 to 29 and 7) ˚ when the constant strain level rise from (250 to 400 and 750) microstrain respectively. This can be attributed to the stiff and brittle nature of the asphalt concrete structure under cold environment. However, when testing under 20 ℃ environment, the phase angle at failure decline from (75 to 60 and 45) ˚ when the constant strain level rise from (250 to 400 and 750) microstrain respectively. For the test at hot testing environment of 30℃, the phase angle at failure decline from (80 to 74 and 48) ˚ when the constant strain level rise from (250 to 400 and 750) microstrain respectively.

On the other hand, the fatigue life from the phase angle point of view increases as the testing temperature rises. Under heavy traffic loading (constant microstrain level of 750), the fatigue life increases by (2.3, and 3.1) folds when the testing temperature rises from (5 to 20 and 30) ℃ respectively. Under moderate traffic loading (constant microstrain level of 400), the fatigue life increases by (7.1, and 11.5) folds when the testing temperature rises from (5 to 20 and 30) ℃ respectively. However, under low traffic loading (constant microstrain level of 250), the fatigue life increases by (32.3, and 39) folds when the testing temperature rises from (5 to 20 and 30) ℃ respectively. Such behavior is in agreement with the work reported by Wang and Zhang, [14], Zhang et al., [6], Sarsam, [11].

4. Conclusions

On the bases of the limitations of the implemented testing program and materials, the following conclusions could be revealed.

- The phase angle at failure decline by (2.5, and 62.5) %, (16.6, and 58.4) %, and (6.2, and 85.4) % when the testing environment decline from (30 to 20 and 5) ℃ respectively under (250, 400, and 750) constant microstrain levels respectively.
- The phase angle decline in general as the constant strain level increase for any specific testing environment.
- The fatigue life from the phase angle point of view increases as the testing temperature rises and decline as the constant strain level increase.
- The fatigue life increases by (2.3, and 3.1) folds, (7.1, and 11.5) folds, and (32.3, and 39) folds when the testing temperature rises from (5 to 20 and 30) ℃ under (heavy, moderate, and low) traffic loading respectively.

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