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ARTICLE

Modeling the Impact of Testing Mode on the Viscoelastic Behavior of Asphalt Concrete

Saad Issa Sarsam

Sarsam and Associates Consult Bureau (SACB), Baghdad, 10081, Iraq

ABSTRACT

The variations in the viscoelastic characteristics of asphalt concrete due to testing mode are assessed and modeled in the present investigation. Asphalt concrete mixture was prepared at its optimum asphalt binder requirement and compacted in slab mold with the aid of roller compaction. Beam specimens of 6.2 cm width, 5.6 cm depth, and 40 cm length, were obtained from the slab samples with the aid of a diamond saw, and tested using controlled stress and strain techniques under dynamic flexural stresses. The viscoelastic properties such as the phase angle, cumulative dissipated energy, permanent deformation, flexural stiffness, and micro strain were monitored and modeled among the two testing techniques. It was noticed that higher micro strain and permanent deformation are detected when testing the asphalt concrete specimens under constant strain mode. However, higher phase angle, flexural stiffness, and energy dissipation could be observed under the constant stress mode of the test.

Keywords: Stress; Asphalt concrete; Constant strain; Phase angle; Cumulative dissipated energy; Flexural stiffness; Deformation

1. Introduction

The testing mode of the asphalt concrete mixture may possess a significant influence on the test results. Sarsam [1] addressed that lower dissipated energy is considered as an essential requirement in the case of constant strain while higher dissipated energy is considered as an essential requirement in the case of constant stress to create the required permanent deformation. It was concluded that the choice to implement a testing mode of asphalt concrete mixture is required in the evaluation process of the viscoe-

*CORRESPONDING AUTHOR:
Saad Issa Sarsam, Sarsam and Associates Consult Bureau (SACB), Baghdad, 10081, Iraq; Email: saadisasarsam@coeng.uobaghdad.edu.iq

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lastic properties of asphalt concrete. However, the variation in such properties is considered significant among the modes of testing. The testing under stress control mode presents the behaviour of asphalt concrete in fatigue which is commonly adopted for evaluation of the resistance to fatigue of thick pavements and stiff materials. On the other hand, the testing under strain control mode is implemented in the case of the conventional asphalt concrete mixtures and flexible pavement as addressed by Artamendi and Khalid [2]. Sudarsanan and Kim [3] provided an overview of the cracking caused by fatigue and discussed the common mechanistic models for the prediction of the fatigue life of asphalt concrete mixtures on the bases of different fatigue test results. The numerical models found and used in numerical simulation software have been implemented for the prediction of the fatigue life of asphalt pavement structures. The fatigue testing was implemented with the aid of both constant strain and constant stress load applications. It was observed that in the constant strain mode of testing, the strain is maintained constant, while the stress is allowed to be variable. However, in the constant stress mode of testing, the load is maintained constant while the strain is allowed to be variable. Based on the experts finding, the thick asphalt pavements with an exceeded thickness of 12.5 cm, generally were shown to perform more closely to a constant stress mode in the field. However, thin asphalt pavements with a thickness lesser than 12.5 cm generally can perform more closely to a constant strain mode in the field. The constant strain mode of testing is considered to be suitable for more flexible mixtures, while the constant stress mode of testing is recommended for stiffer materials as reported by Ghuzlan, and Carpenter [4]. Isailović et al. [5] revealed that during the cyclic fatigue testing of asphalt concrete under stress control mode, the strain amplitude exhibits a continuous change which can be detected after each loading cycle either under compressive or tensile stress conditions. The change in the strain may vary in association with the change in the mechanical properties based on the specific viscoelastic behavior of the asphalt concrete and the type of loading. The approach based on dissipated energy was implemented and it was calculated. It was revealed that the test is analyzed based on a similar number of load repetitions at failure, while the changes in mechanical properties are identified. An experimental study was conducted by Pasetto and Baldo [6] on the fatigue performance and stiffness of asphalt concrete. Flexural fatigue tests were performed in strain and stress-controlled modes of testing to verify the fatigue properties of the asphalt concrete mixes.

The cumulative dissipated energy approach, which is based on the internal damage produced within the asphalt concrete structure, was implemented for the fatigue analysis. Rajbongshi [7] stated that the possible modes of loading the asphalt concrete specimens are bounded by two test methods, namely, constant stress testing and constant strain testing, which can be implemented in the laboratory for evaluating the fatigue behavior of asphalt concrete pavement. It was revealed that the constant stress mode of loading is usually applicable to asphalt concrete pavement layers with 20 cm thickness and over. However, the constant strain mode of loading is considered more suitable for thin asphalt concrete pavement layers of 5 cm thickness or lower. A technique for improving the accuracy of a dissipated energy measurement was proposed by Shiozawa et al. [8] based on the phase information. The dissipated energy was calculated as double of the frequency component of the measured temperature change. It was revealed that the double of the frequency component includes the influence of the harmonic vibration and the energy dissipation of the fatigue testing machine. It was stated that the proposed method can provide a significant improvement in the accuracy of estimating the fatigue-limit and the possibility of the detection of future possible crack initiation points based on the dissipated energy. A transfer function for consideration of the fatigue life transition from the constant strain mode of test to the constant stress mode of testing was developed by Yu and Zou [9]. The transfer function was combined with the laboratory models of fatigue prediction which was developed using the constant microstrain level of 618 and four points bending fatigue beam testing to create a new asphalt pavement fatigue cracking prediction model. Laboratory fatigue tests on asphalt concrete and full-scale field studies were conducted by Hosseini et al. [10] and indicated that the effective stiffness modulus of asphalt concrete mixtures declined significantly under repeated stress application without the presence of visible cracks. It was addressed that this can indicate that the damage is accumulating in the material structure, which in turn, causes a reduction in the effective volume which is capable to bear the applied stresses by cracking while the effective stiffness modulus is declined. The fatigue behavior of asphalt concrete mixtures was assessed by Shen et al. [11] using the dissipated energy concept. It was stated that the dissipated energy of an asphalt concrete mixture may be significantly related to its fatigue life. A significant relationship exists between the number of loading cycles to failure and the total dissipated energy while a such relationship is not affected by testing temperature, mode of loading and frequency, but it is highly dependent on material type. Adhikari and You [12] stated that the simplest fatigue prediction models are based on either controlled stress mode of loading or controlled strain mode. The major role of these fatigue life prediction models is furnishing a significant relation between asphalt pavement response in strain, load repetitions to failure, and mixture properties. The major parameters of such models are mainly dependent on a repeated stress sequence while the coefficients are determined from empirical data regression. The fatigue life of asphalt concrete specimens using the four-point bending beam fatigue test was assessed by Shafabakhsh et al. [13] at constant strain conditions. The implemented strain levels were 500, 700, and 900 microstrains while the testing temperature of 20 °C was maintained. The adopted condition to reach the failure limit was assigned to be equivalent to a 50% decline in the stiffness of the asphalt concrete throughout the load repetition, while the load was applied in the form of semi sinusoidal at a frequency of 10 Hz without a rest period. The implemented loading waveform was sinusoidal and semi sinusoidal in a controlled strain mode and sinusoidal in a controlled stress testing mode.

The aim of the present assessment is to model the impact of testing mode (constant stress and constant strain) on the viscoelastic properties of asphalt concrete such as phase angle, permanent deformation, flexural stiffness, cumulative dissipated energy, and micro strain with the aid of dynamic flexural stresses.

2. Properties of materials and methods of testing

The implemented materials in this assessment study are currently used for asphalt pavement construction in Iraq.

2.1 Asphalt cement

Asphalt cement binder is obtained from AL-Nasiriya oil Refinery with a penetration of 42. The softening and flash points are 49 ºC and 256 ºC respectively. The important physical properties of asphalt cement could be referred to as Sarsam [1].

2.2 Fine and coarse aggregates

Crushed coarse aggregates were obtained from AL-Ukhaydir quarry. A combination of natural and crushed sand was used as fine aggregates. **Figure 1** exhibits the important physical properties of the aggregates.

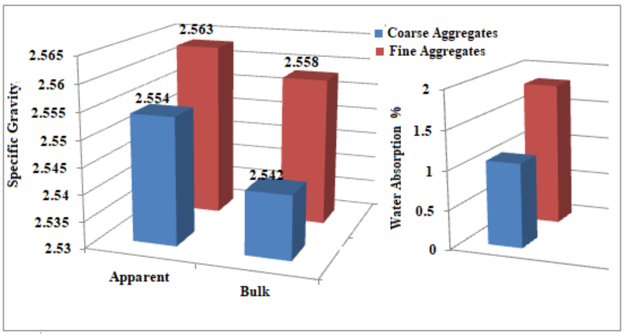

Figure 1. Physical properties of aggregates.

2.3 The mineral filler

The mineral filler implemented in this assessment was the lime stone dust which was obtained from the lime plant at Karbala. The bulk specific gravity of the lime stone dust is 2.617 while the percent finer by weight (passing sieve No. 200) is 94%.

2.4 Selection of combined aggregates gradation

The combined aggregate gradation adopted in the present assessment was according to SCRB [15] requirements for wearing course layers of asphalt concrete. The combined gradation has a 12.5 mm nominal maximum size of aggregate. **Figure 2** shows the gradation of the combined aggregate.

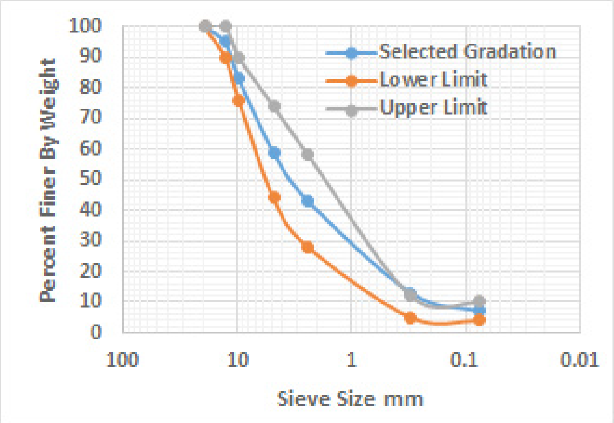

Figure 2. The selected combined aggregates gradation [15].

2.5 Preparation of the asphalt concrete mixture

The obtained aggregates were washed, dried to constant weight, and separated into different sizes by the sieving process. The Aggregates were recombined with the mineral filler to meet the wearing course gradation according to the requirements of SCRB [15]. The aggregates mixture was heated to 160 ºC and the asphalt cement binder was heated to 150 ºC. The predetermined amount of heated binder was mixed with the heated aggregates thoroughly for two minutes until a suitable coating of aggregate particles with the binder was achieved.

2.6 Preparation of the asphalt concrete slab samples and the beam specimens

The asphalt concrete mixture was compacted in the slab mold using the roller compactor shown in **Figure 3** according to the procedure recommended by EN12697-33 [16], to achieve the target bulk density. The binder content was 4.9%. The slab mold has a dimension of (40 cm × 30 cm) and the thickness of the sample in the mold was 6 cm. A static load of 5 kN was applied. The compaction temperature was maintained at 150 ºC. The compacted slab was left in the mold to cool overnight, and then removed from the mold. Beam specimens of asphalt concrete were extracted from the slab samples using a diamond saw.

The extracted beam specimens have dimensions of 6.2 cm width, 5.6 cm depth, and 40 cm length according to ASTM [14]. Two slab samples have been prepared while 6 beam specimens were extracted from each slab sample. The prepared beams were subjected to dynamic flexural stresses using the four-point bending beam test apparatus shown in **Figure 4**. The repeated flexural stresses were applied on the beam according to the procedure recommended by AASHTO T-321 [17]. The beam specimens were divided into two parts, the first part was tested under a constant micro strain level of 250, and a frequency level of 5 Hz, while the testing environment was 20 °C. On the other hand, the second part practiced the test under a constant stress level of 100 kPa, and a frequency level of 5 Hz, while the testing temperature was maintained at 20 °C. The test results of the viscoelastic properties were monitored. The beam specimens were tested at successive haversine cycles in the constant strain or stress modes.

Figure 3. The asphalt concrete roller compactor.

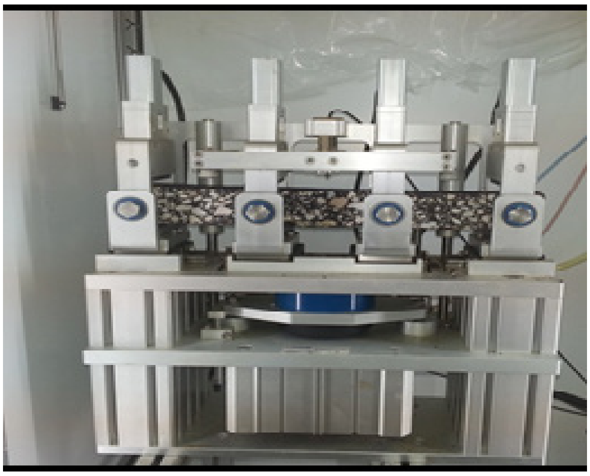

Figure 4. Dynamic flexural bending test.

3. Test results and discussions

3.1 Impact of mode of testing on the flexural stiffness

Figure 5 demonstrates the variation of flexural strength of asphalt concrete among variations in the testing technique of constant stress and constant strain. The polynomial mathematical relationship starts increasing in a straight line up to a flexural stiffness of 5000 MPa, and then the relationship changes to non-linear and reaches the failure at 7500 MPa while it declines after further loading. Higher flexural stiffness could be detected under the constant stress testing technique as compared with that under constant strain testing mode. This may be attributed to the accumulation of damage to the structure of asphalt concrete mixture under repeated constant strain which can initiate micro cracks. It can be addressed that the asphalt concrete exhibit longer fatigue life under constant stress mode as compared with the case under constant strain mode of testing. Shafabakhsh et al. [13] reported similar behavior.

3.2 Impact of mode of testing on the phase angle

Figure 6 exhibits the variation in the phase angle among the testing techniques implemented. The phase angle is considered as a good indicator of viscoelastic behavior. The observation of Phase angle is considered to be important for understanding the structural soundness and material behavior. The scatter of the phase angle around the polynomial model indicates the minimal influence of testing mode on the phase angle up to a phase angle of 10°. However, the trend of the relationship changes to non-linear at higher values of phase angle. A higher phase angle could be observed under constant stress testing mode as compared with that at constant strain mode. Such behavior agrees with the work reported by Rajbongshi [7].

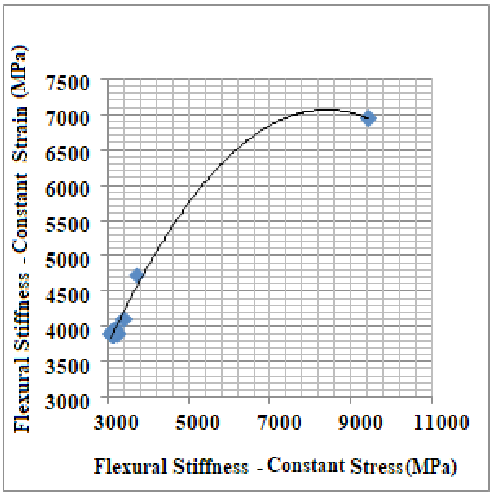

Figure 5. Variation in flexural stiffness.

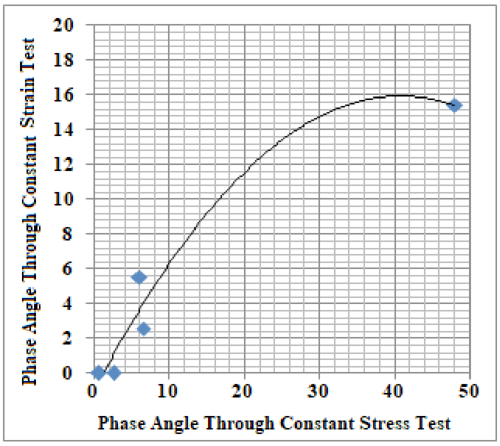

Figure 6. Variation in phase angle.

3.3 Impact of mode of testing on permanent deformation

As demonstrated in **Figure 7**, a gentle increment in the permanent deformation at the initial stages of loading could be observed. However, the rate of deformation increases sharply as the loading proceeds. Higher permanent deformation is seen under constant strain mode as compared with that at constant stress mode. This may be related to the accumulation of deformation under the constant strain mode of testing.

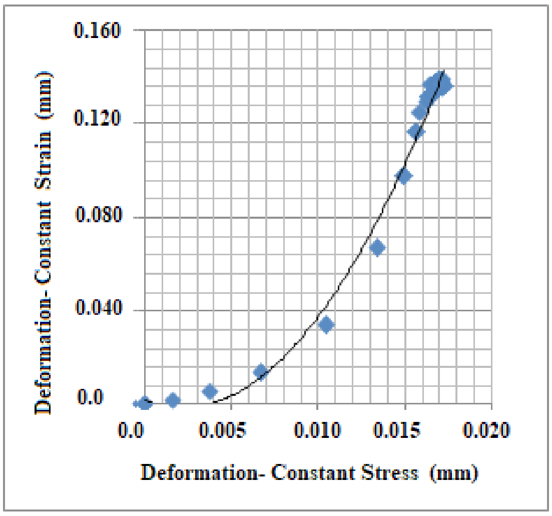

Figure 7. Variation in permanent deformation.

3.4 Impact of mode of testing on micro strain

Figure 8 exhibits the polynomial shape of the mathematical model. A similar trend of increment in the micro strain could be noted as that of the deformation behavior. A higher micro strain level is detected when testing the specimens at constant strain mode as compared with that under constant stress mode.

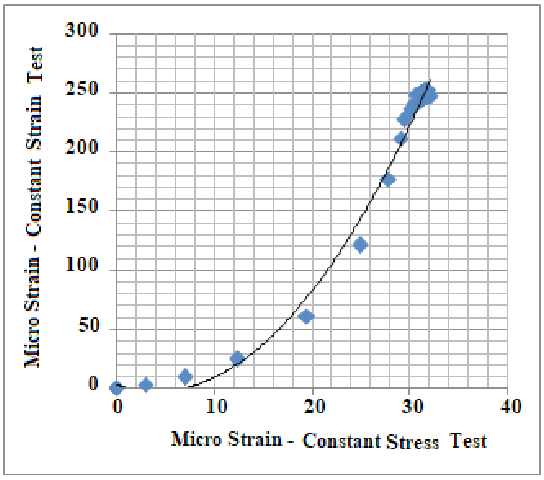

Figure 8. Variation in micro strain.

3.5 Impact of mode of testing on the cumulative dissipated energy

Figure 9 demonstrates that more energy is dissipated when testing the asphalt concrete specimens under constant stress mode as compared with that at constant strain mode of test. Dissipated energy is considered as a proper engineering parameter, which represents the internal damage that can develop within the asphalt concrete mixture during repeated flexural stress loading.

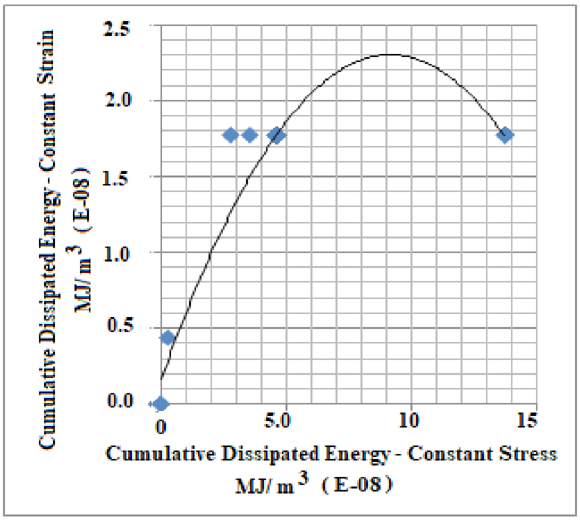

Figure 9. Variation in cumulative dissipated energy.

The evolution of dissipated energy over the test can be represented by the polynomial equation curve, which can present three different phases as revealed by Wu et al. [18]. The first phase is characterized by a sharp decline in the cumulative dissipated energy at the early stages of loading. Whereas it substantially exhibits gentle reduction with the load cycles in the second phase. Therefore a considerable rate of the input energy is dissipated to cause internal damage. The transition from the second phase to the third one (approaching failure), which is denoted by a low rate of increment in dissipated energy with the number of loading cycles, allows us to verify the failure due to fatigue of the asphalt concrete by exhibiting a decline in the energy dissipation. A similar finding was reported by Isailović et al. [5] and Maggiore et al. [19].

In order to exhibit a proper flexural stiffness under a constant stress mode of testing than that of a constant strain mode of testing, higher dissipated energy is required. However, lower dissipated energy is suitable in the case of the constant strain mode of testing to exhibit the same permanent deformation as that for the constant stress mode. **Table 1** presents the mathematical polynomial models obtained which represent the variation in the viscoelastic behavior of asphalt concrete when practicing different modes of loading. A high coefficient of determination indicates a strong impact of the testing mode on the viscoelastic behavior of asphalt concrete. The (Y) represents the viscoelastic properties of asphalt concrete after practicing the constant strain mode of flexural load repetitions. On the other hand, the (x) represents the viscoelastic properties of asphalt concrete after practicing the constant stress mode of flexural load repetitions.

Table 1. Modeling of the viscoelastic behavior.

Viscoelastic Property	**Mathematical Model**	**Coefficient of Determination R2**
Flexural Stiffness (MPa)	$Y = 1.39x - 1057$	0.989
Cumulative Dissipated Energy (kJ/m^3)	$Y = -0.00003x^2 + 0.465x + 0.000000002$	0.948
Phase Angle (˚)	$Y = 0.01x^2 + 0.835x - 1.069$	0.958
Deformation (mm)	$Y = 632.4x^2 - 2.794x + 0.002$	0.989
Micro Strain	$Y = 0.334x^2 - 2.741x + 3.822$	0.989
Y= Property at constant strain mode X= Property at constant stress mode		

4. Conclusions

Based on the implemented materials limitations and the executed testing program, the following conclusions may be drawn.

Higher flexural stiffness could be detected under the constant stress testing technique as compared with that under the constant strain testing mode. The asphalt concrete exhibit longer fatigue life under constant stress mode as compared with the case under constant strain mode of testing. A higher phase angle could be observed under constant stress testing mode as compared with that at constant strain mode. Higher permanent deformation and micro strain are seen under constant strain mode as compared with that at constant stress mode. More energy is dissipated when testing the asphalt concrete specimens under constant stress mode as compared with that at constant strain mode of test.

Conflict of Interest

There is no conflict of interest.

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