Indian journal of
Engineering

Influence of constant strain levels on the viscoelastic properties of asphalt concrete

Saad Issa Sarsam*

To Cite:
Sarsam SI. Influence of constant strain levels on the viscoelastic properties of asphalt concrete. *Indian Journal of Engineering*, 2023, 20, e31ije1666
doi: https://doi.org/10.54905/disssi/v20i54/e31ije1666

Author Affiliation:
Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad, Iraq/Former Head, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
Email: saadisasarsam@coeng.uobaghdad.edu.iq

***Corresponding author**
Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad, Iraq/Former Head, Department of Civil Engineering, College of Engineering, University of Baghdad,
Iraq
Email: saadisasarsam@coeng.uobaghdad.edu.iq

Peer-Review History
Received: 29 May 2023
Reviewed & Revised: 02/June/2023 to 03/July/2023
Accepted: 06 July 2023
Published: 12 July 2023

Peer-Review Model
External peer-review was done through double-blind method.

Indian Journal of Engineering
pISSN 2319–7757; eISSN 2319–7765

ABSTRACT

The flexural stresses applied by vehicular movement exhibit a great influence on the viscoelastic properties of asphalt concrete pavement. However, the fatigue life of the flexible pavement is related to the ability of the pavement to sustain the accumulated strain in the pavement structure through the design life of the pavement and it is considered as a good measure of its fatigue life. In the present work, asphalt concrete mixtures were prepared in the laboratory at optimum binder content and compacted in a slab mold using the roller compaction. Beam specimens of 62 mm width, 56 mm depth, and 400 mm length; were obtained from the prepared asphalt concrete slab samples. The beam specimens were tested for fatigue under repeated flexural stresses at 20℃ environments following the constant strain mode of loading. Constant strain modes of three levels have been tried as target amplitude, (750, 400, and 250) microstrain and the implemented loading frequency was 5 Hz throughout the test. The viscoelastic properties of asphalt concrete specimens have been monitored, analysed, and compared. It was noticed that the phase angle of asphalt concrete rises at failure by (33.3 and 50) % when the constant strain level rises from 250 to 400 and 750 respectively. However, the cumulative dissipated energy of asphalt concrete specimens increases at failure by (10 and 24) folds when the constant strain level declines from 750 to 400 and 250 respectively. On the other hand, the fatigue life of asphalt concrete specimens was (6.1 and 141.8) folds higher than that of 750 constant strain level for specimens practicing 400 and 250 constant strain levels respectively. It was revealed that higher constant strain level can exhibit sharper trend of decline in its initial stiffness as compared with the other microstrain levels.

Keywords: Susceptible, viscoelastic, phase angle, dissipated energy, asphalt concrete, stiffness, flexure

1. INTRODUCTION

Asphalt concrete mixture problems were assessed by Mandula and Olexa, (2017). Such problems were caused by the inner properties of the mixture such as phase angle and the material response under dynamical loading. It was concluded that phase angle is considered as a basic dynamic loading feature and an indicator of visco-elastic material behavior; however, it describes the progress in the fatigue life of asphalt concrete mixtures (Sarsam, 2021; Sarsam, 2022a, Sarsam, 2022b). The test results indicated that the phase angle is stabilized after one third of the test duration, while strong increase in the phase angle starts just before reaching the failure point.

Ziari et al., (2020) assessed the impact of implementing various strain levels on the fatigue behavior of asphalt concrete mixtures using the four-point bending beam fatigue test. The test results revealed that the fatigue life of the binder was improved after the increase in the severity of ageing at low strain levels. However, the ageing process causes decline in the binders fatigue life under higher strain levels. It was concluded that from the statistical analysis point of view, the strain levels had a significant influence on the fatigue life of asphalt mixtures with proper level of significance.

Maggiore et al., (2013) conducted various strain-controlled tests for the same asphalt concrete mixture under the same loading condition, frequency of loading of 15 Hz, and the testing temperature of 20˚C. However, variations in the test results were noticed in the determination of phase angle, stiffness, fatigue life, and dissipated energy. It was concluded that dissipated energy is considered as a good parameter to explain the fatigue behavior of asphalt concrete mixtures while it is the key point to better verify the mechanical response of the same mixture from different kind of test.

Sarsam, (2016) studied the variations in the cumulative dissipated energy through the weakness process of asphalt concrete beam specimens. The specimens of asphalt concrete mixtures were assessed using the dynamic four-point flexure bending beam test in the controlled strain mode. The cumulative dissipated energy per each load cycle was detected through the accumulation of damage and the changes in the behaviour of the mixture. The impacts of binder content, strain level, and testing temperature on the cumulative dissipated energy of asphalt concrete were discussed and compared.

Dynamic bending beam tests was conducted by Ameri et al., (2016) on asphalt concrete mixtures prepared with these binders using different rates of loading (1000, 800, 600 and 400) micro-strain. The test results exhibited that the viscoelastic parameter of asphalt binder's integrity exhibits a strong correlation with the fatigue resistance of asphalt concrete mixtures. Asphalt concrete beam specimens were assessed by Varma et al., (2017) under three different micro strain amplitudes of 200, 400 and 600. The test data were used for calculation of the total dissipated energy. A linear viscoelastic model was implemented. However, the discontinuity in the evolution of phase angle which was determined from the stress–strain plot is considered for evaluation of the fatigue damage.

Ghuzlan and Carpenter, (2000) revealed that the constant strain mode of testing is preferred for more flexible mixtures like asphalt concrete, while the constant stress mode of testing is suitable for stiffer mixtures. The fatigue life of asphalt concrete mixture was investigated by Shafabakhsh et al., (2020) with the aid of fatigue test using the four-points bending beam test at constant strain levels of (900, 700, and 500) microstrain while the testing temperature was 20˚C. The implemented condition of reaching the failure was equivalent to a 50% reduction in the stiffness modulus of asphalt concrete throughout the load repetition. The load was applied at a frequency of 10 Hz without rest period.

An experimental assessment was conducted by Pasetto and Baldo, (2017) on the fatigue performance and stiffness of asphalt concrete. The dynamic flexural fatigue test was adopted in the strain and stress control modes of testing to assess the fatigue properties of the mixes. Based on the damage produced internally within the asphalt concretes, the dissipated energy approach was adopted for the fatigue life analysis. The aim of the present assessment is to study the impact of implementing constant strain levels on the viscoelastic properties of asphalt concrete. The changes in the phase angle, cumulative dissipated energy, fatigue life, and % initial stiffness will be monitored throughout the fatigue process with the aid of dynamic flexural bending beam test.

2. PROPERTIES OF MATERIALS AND METHODS OF TESTING

Asphalt Cement

The asphalt cement with a ductility of 150 cm, penetration grade of 42, and a softening point of 49℃ was obtained from AL-Nasiriya oil Refinery. After ageing process, the ductility decline to 83 cm, the penetration declines to 33 while the softening point increases to 53℃. The test of physical properties of binder was conducted according to the ASTM, (2015) procedures.

Fine and Coarse Aggregates

Crushed coarse aggregates mixed crushed and natural fine aggregates were obtained from AL-Ukhaider quarry. Such aggregates were washed, and then air dried and sieved to different sizes. The water absorption of the coarse and fine aggregates was (1.07 and 1.83) % respectively. The bulk specific gravity was (2.452 and 2.558) for coarse and fine aggregates respectively. The test of physical properties of aggregates was conducted according to the ASTM, (2015) procedures.

Mineral Filler

The limestone dust was implemented as the mineral filler. 94% of the filler passes sieve No. 200 (0.075mm). It was obtained from Karbala. The bulk specific gravity of the filler was 2.617.

Selection of the Aggregate Gradation for Preparation of Asphalt Concrete mixture

The combined aggregates gradation used in the present investigation is the dense graded wearing course pavement layer. It follows SCRB, (2003) specification. The combined aggregates gradation has 12.5 mm of nominal maximum size of aggregates. Figure 1 presents the selected combined gradation for wearing course.

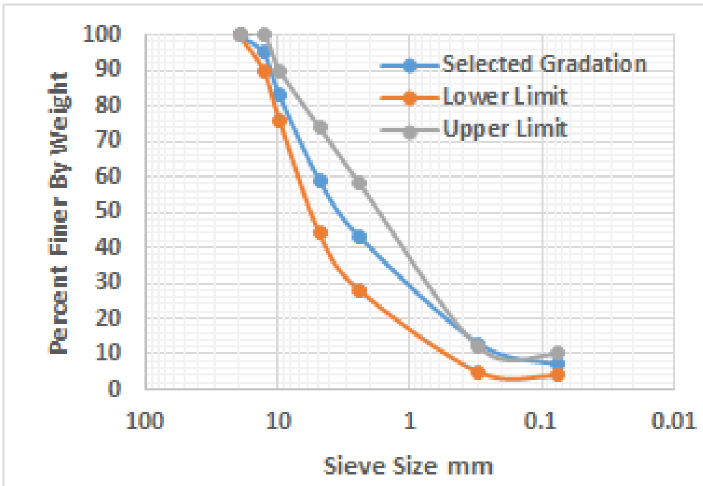

Figure 1 The Selected Combined Aggregates Gradation

Preparation of Asphalt Concrete Mixture and Specimens

The mineral filler was combined with fine and coarse aggregates and heated to 160℃ before mixing with the asphalt cement which was heated to 150ºC. The optimum asphalt binder content was 4.9%. Details of obtaining the optimum asphalt binder content may be referred to Sarsam and Alwan, (2014). The asphalt concrete mixtures were casted in a steel slab mold of (40 × 30) Cm while the depth of the mold was 6 Cm. The mixture was subjected to roller compaction until reaching the target bulk density according to EN 12697-33, (2007). The static load of 5 kN was applied.

The details of the compaction process may be referred to Sarsam, (2005). The compaction temperature was maintained to 150°C. Slab samples were left overnight to cool. Beam specimens of 40 Cm length, 5.6 Cm height, and 6.2 Cm width were extracted from the compacted slab sample using the diamond-saw. The total number of beam specimens obtained was fourteen, while the number of casted slabs was four. Beam specimens were tested in duplicate and the average value of test results was considered.

Testing for Fatigue by Implementing the Repeated Flexural Bending Beam Test

The dynamic flexural bending beam test according to AASHTO T321, (2014) was used to assess the impact of repeated flexural stresses on the viscoelastic properties and fatigue life of asphalt concrete specimens at moderate pavement temperature of 20°C and under three constant strain levels.

3. DISCUSSIONS ON TEST RESULTS

Influence of constant strain levels on the phase angle

The phase angle is the measured lag or delay between the applied load and the measured displacement when testing asphalt concrete beam specimen for fatigue life in the four points bending beam apparatus. The phase angle describes the viscoelastic behavior of the material tested. A larger value of phase angle measured is referred to a more viscoelastic material, resulting in a larger hysteresis loop. The phase angle is limited between (0-90) degrees. As in Figure 2, the phase angle increases as the loading proceeds regardless of the constant strain applied. The rate of increase is sharp at early stages of practicing dynamic flexural stresses. However, the rate exhibits gentle trend of increment after 10 seconds of loading.

On the other hand, it can be detected that as the applied constant strain increases, the phase angle also increases throughout the loading until failure. It can be detected that the fatigue life of asphalt concrete is significantly declines as the constant strain level increases. Failure of the asphalt concrete specimens could be detected after (10000, 600, and 80) seconds of starting the dynamic flexural stresses under constant strain levels of (250, 400, and 750) respectively.

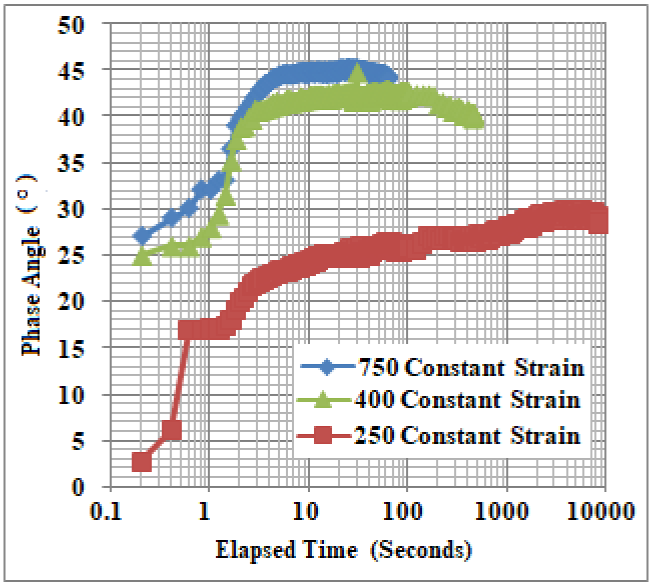

Figure 2 Influence of constant strain levels on the phase angle

The phase angle was (3, 25, and 27) ° at initial stage of loading under constant strain levels of (250, 400, and 750) respectively. However, it increases at failure after practicing the dynamic flexural stresses by (900, 60, 66) % under constant strain levels of (250, 400, and 750) respectively. The phase angle of asphalt concrete specimens at failure rises by (33.3, and 50) % when the constant strain level increases from 250 to 400 and 750 respectively. Such behaviour is in agreement with Rondón-Quintana et al., (2021).

Impact of constant strain levels on the cumulative dissipated energy

Asphalt concrete specimens that practice dynamic flexural stress loading usually follows a different path in the unloading part of the test by creating a loop or an area inside as revealed by Stegeman, (2020). This is the amount of dissipated energy, and it is a characteristic of a viscous elastic material like asphalt concrete mixture. The cumulative dissipated energy can indirectly explain that not all dissipated energy is causing damage. The energy dissipation approach in the analysis of fatigue resistance of asphalt concrete assumes that all the dissipated energy represents damage done to the material. The energy lost in the process of each loading and unloading cycle is accumulated, and then transformed into the surface energy of crack propagation to form a new surface. Such change may be considered as the amount of cumulative damage done to the asphalt concrete specimen.

Figure 3 exhibits the influence of constant strain levels on the cumulative dissipated energy of asphalt concrete. It can be detected that the dissipated energy increases as the dynamic loading proceeds. The rate of such increment is gentle at the start of loading application. After 100 seconds of dynamic loading, the trend of energy loss is significantly sharp. Higher constant strain level exhibit lower energy loss. At the start of practicing dynamic flexural stresses, the variation in the cumulative dissipated energy among constant strain levels is not significant.

However, at failure, the cumulative dissipated energy of asphalt concrete is (0.2, 0.4, and 5) MJ/m^3 under constant strain level of (750, 400, and 250) respectively. The cumulative dissipated energy of asphalt concrete increased by (3, 7, and 99) folds at failure as compared with that at the start of loading under constant strain level of (750, 400, and 250) respectively. However, the cumulative dissipated energy of asphalt concrete at failure rises by (10, and 24) folds when the constant strain level declines from 750 to 400 and 250 respectively. Similar findings were reported by Pasetto and Baldo, (2017).

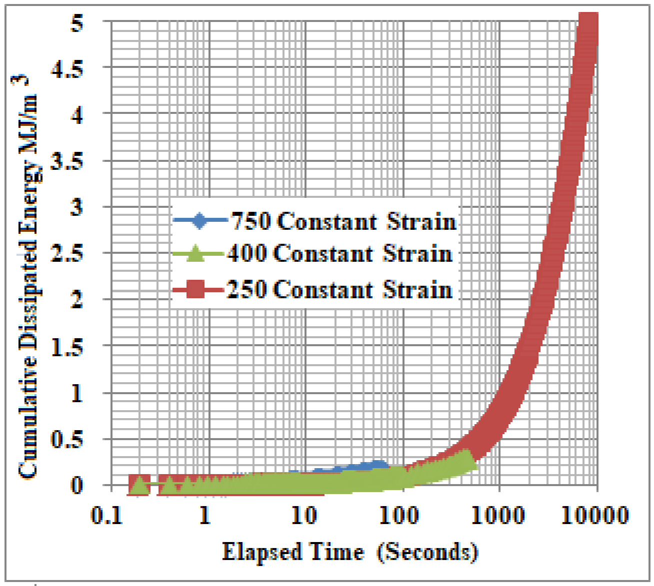

Figure 3 Influence of constant microstrain level on the cumulative dissipated energy

Influence of constant microstrain levels on the % initial stiffness

Figure 4 demonstrates the influence of constant microstrain levels on the % initial stiffness of asphalt concrete. It can be observed that the % initial stiffness declines sharply as the dynamic loading proceeds. However, sharper trend of decline in the initial stiffness could be observed at higher constant strain level as compared with the other strain levels. Such behavior may be related to the structural damage initiation and micro crack propagation in the mixture that sustain high level of strain.

At the point of failure, (when the flexural stiffness declines by 50% of its original value), the fatigue life of asphalt concrete shows significant improvement, while the constant strain levels decline. The fatigue life of asphalt concrete was (141.8 and 6.1) folds higher for specimens practicing 250 and 400 constant strain levels respectively as compared with the specimen practicing 750 constant strain level. Such behavior agrees with Poulikakos and Hofko, (2020) and Colpo et al., (2020).

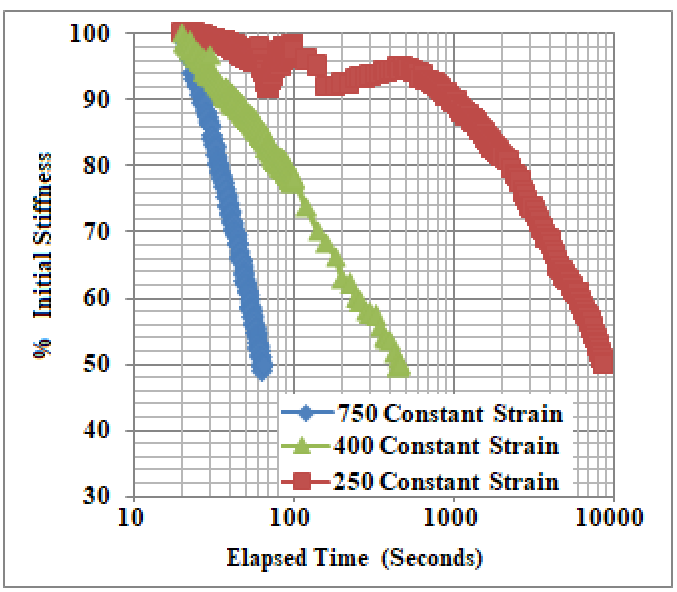

Figure 4 Influence of constant microstrain level on the % initial stiffness

4. CONCLUSIONS

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

1- The phase angle of asphalt concrete specimens at failure increases by (33.3, and 50) % as the constant strain level increases from 250 to 400 and 750 microstrain respectively.

2- The cumulative dissipated energy of asphalt concrete specimens at failure increased by (10, and 24) folds when the constant strain level declines from 750 to 400 and 250 microstrain respectively.

3- The fatigue life of asphalt concrete specimens was extended to (141.8 and 6.1) folds higher for specimens practicing 2050 and 400 constant strain levels respectively as compared with the specimen practicing 750 constant strain level.

4- Sharper trend of decline in the initial stiffness could be noticed at higher constant strain level as compared with the other microstrain levels.

Ethical issues

Not applicable.

Informed consent

Not applicable.

Funding

This study has not received any external funding.

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.

REFERENCES AND NOTES

1. AASHTO T321. Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending. American Association of State Highway and Transportation Officials, Washington, DC 2014.
2. Ameri M, Nowbakht S, Molayem M, Mirabimoghaddam M. A study on fatigue modeling of hot mix asphalt mixtures based on the viscoelastic continuum damage properties of asphalt binder. Constr Build Mater 2016; 106(1):243-252. doi: 10.1016/j.conbuildmat.2015.12.066
3. ASTM. Road and Paving Materials, Annual Book of ASTM Standards. American Society for Testing and Materials, West Conshohocken, USA 2015; 4(3).
4. Colpo G, Brito L, Doering D, Mocelin D, Hilgert A, Johnston M, Ceratti J. Fatigue behaviour study of a dense graded HMA using the four-point bending beam test aided by an in-situ instrumentation at BR-116/RS, Brazil. Transportes 2020; 28(2):14-28. doi: 10.14295/transportes.v28i2.1907
5. EN 12697 – 33. Bituminous Mixtures – Test Methods for Hot Mix Asphalt – Part 33: Specimen prepared by Roller Compactor. European Committee for Standardization 2007.
6. Ghuzlan KA, Carpenter SH. Energy-Derived, Damage-Based Failure Criterion for Fatigue Testing. Transportation Research Record, TRB, 1723. National Research Council, Washington, DC 2000; 141-149.
7. Maggiore C, Airey G, Di-Mino G, Marsac P, Di-Liberto M. Fatigue resistance: Is it possible having a unique response? 3rd 4PBB Conference, France 2013; 11. https://hal.archives-ouvertes.fr/hal-00851128
8. Mandula J, Olexa T. Study of the Visco-Elastic Parameters of Asphalt Concrete. Structural and Physical Aspects of Construction Engineering. Procedia Eng 2017; 190:207–214. doi: 10.1016/j.proeng.2017.05.328
9. Pasetto M, Baldo N. Dissipated energy analysis of four-point bending test on asphalt concretes made with steel slag and RAP. Int J Pavement Res Technol 2017; 10(5):446-453. doi: 10.1016/j.ijprt.2017.07.004
10. Poulikakos L, Hofko B. A critical assessment of stiffness modulus and fatigue performance of plant produced asphalt concrete samples using various test methods. Road Mater Pavement Des 2020; 22(9):1-13. doi: 10.1080/14680629.2020.1785927
11. Rondón-Quintana H, Reyes-Lizcano F, Zafra-Mejía C. Fatigue in asphalt mixtures – a summary to understand the complexity of its mathematical modeling. 1st International Conference on Physical Problems of Engineering (1st ICPPE). J Phys Conf Ser 2021; 2118(1):012009. doi: 10.1088/1742-6596/2118/1/012009
12. Sarsam S. Monitoring dissipated energy through the fatigue process of asphalt concrete. Appl Res J 2016; 2(6):275-282.
13. Sarsam SI, Alwan AH. Assessing Fatigue Life of Super pave Asphalt Concrete. Am J Civil Struct Eng 2014; 1(4):88-95.
14. Sarsam SI. Assessing the Sensitivity of Binder Content in Asphalt Concrete Mixture. Ind J Eng, 2022a; 19(51):310-316

15. Sarsam SI. Flexural and Cracking Behaviour of Roller Compacted Asphalt Concrete. J Eng Dev 2005; 9(4).
16. Sarsam SI. Influence of Ageing on Volumetric Properties of Rubber Modified Asphalt Concrete. Ind J Eng, 2021, 18(50), 267-276
17. Sarsam SI. Sensitivity of Physical Properties of Asphalt Concrete to the Change in Binder Content. Ind J Eng, 2022b; 19(52):395-402
18. SCRB. State Commission of Roads and Bridges. Standard Specification for Roads & Bridges, Ministry of Housing & Construction, Iraq 2003.
19. Shafabakhsh G, Akbari M, Bahrami H. Evaluating the Fatigue Resistance of the Innovative Modified-Reinforced Composite Asphalt Mixture. Hindawi Adv Civ Eng 2020; 20 20:10. doi: 10.1155/2020/8845647
20. Stegeman HR. Analysis of asphalt concrete fatigue through energy methods. MSc thesis, Delft University of Technology 2020.
21. Varma R, Padmarekha A, Ravindran P, Bahia H, Krishnan J. Evolution of energy dissipation during four-point bending of bituminous mixtures. Road Mater Pavement Des 2017; 18 (Sup 2):252-263. doi: 10.1080/14680629.2017.1304252
22. Ziari H, Amini A, Goli A. The effect of different aging conditions and strain levels on relationship between fatigue life of asphalt binders and mixtures. Constr Build Mater 2020; 244:118345. doi: 10.1016/j.conbuildmat.2020.118345