Civil Engineering Beyond Limits 3 (2022) 1703
Civil Engineering Beyond Limits
journal home: www.acapublishing.com/journals/1/cebel
Research Article

Influence of Micro-Crack Healing on Viscoelastic Properties of Moisture Damaged Asphalt Concrete

Saad Issa Sarsam *,[1]
[1]Professor, Sarsam and Associates Consult Bureau (SACB), Baghdad-IRAQ. Former head, Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq

Keywords

Moisture damage, Asphalt concrete, Healing, Viscoelastic, Deformation, Dissipated energy.

Abstract

One of major asphalt pavement distresses is the moisture damage which influences the degradation of the viscoelastic properties of the mixture. The present work assesses the impact of practicing micro-crack healing on the viscoelastic properties of moisture damaged asphalt concrete. Roller compacted slab samples of asphalt concrete were prepared at optimum binder content. Beam specimens were obtained from the slab samples and subjected to moisture damage. Part of the asphalt concrete beam specimens were then tested under dynamic flexural stresses, while another part of the asphalt concrete beams was subjected to micro-cracks healing process using external heating at 60° C for 120 minutes, then tested under the dynamic flexural stresses. The viscoelastic properties of asphalt concrete in terms of permanent deformation, flexural stiffness, phase angle, and cumulative dissipated energy were monitored and compared among both testing conditions. It was observed that a significant increase in the flexural stiffness could be observed after healing. The increase in the phase angle after healing is significant at the early stages of loading. Higher cumulative dissipated energy could be observed for mixture which had practiced micro-crack healing. It was concluded that healing process does not exhibit positive influence on permanent deformation of moisture damaged asphalt concrete. A significant increase of 41.6 % in the flexural stiffness could be observed after healing after the first load repetition as compared with the mixture before healing. The permanent deformation after healing is higher by 22 % at failure as compared with that of mixture before healing.

1. Introduction

Asphalt concrete is a viscoelastic material; it exhibits both elastic and viscous characteristics when practicing repeated loading and undergoing deformation. Asphalt concrete mixture can resist strain and shear flow linearly with time when stress is applied. It also exhibits time-dependent strain. Mandula and Olexa, (2017) [1] revealed that the elasticity of asphalt concrete mixture is the result of bond stretching along crystallographic planes in an ordered solid, while the viscosity is the result of the diffusion of molecules inside an amorphous material. When the asphalt concrete mixture is subjected to sinusoidal varying stress, the resulting strain will also be sinusoidal, having the same angular frequency but retarded by a phase angle. The cyclic indirect tensile tests were conducted on moisture damaged and dry specimens under various testing temperature, rest period, and ageing by Mehrara and Khodaii, (2015) [2]. It was observed that moisture conditioning the specimens does not significantly affect their damage recovery potential for a constant load to strength ratio. Ageing and rest period are the most influential factors on the damage recovery potential. It was concluded that ageing the specimens, considerably decreases their ability to recover. However, it also decreases the effects of moisture conditioning and temperature change on this ability. Sun et al., (2016) [3] assessed the healing properties of asphalt concrete which suffered moisture damage. It was revealed that the heating speed of asphalt concrete mixtures was enhanced at the presence of water. The test results indicated that heating could only partially heal the loss of strength of asphalt mixtures suffered moisture damage due to structural deformation of the samples. The presence of moisture on crack surfaces could prevent the thermal healing of cracks. It is recommended that the asphalt mixtures be healed in dry condition rather than at the presence of water. Li et al., (2020) [4] studied the effect of hydrodynamic impact on the healing and durability performance of asphalt concrete through moisture induced sensitivity test. The fracture-healing procedure was carried out to investigate the strength recovery ratios of the specimens. The change of air voids inside asphalt concrete and the crack healing ratio were observed. The results showed that the changing trends of fracture energy recovery ratio and strength recovery ratio were consistent with that of tensile strength. Mannan et al., (2017) [5] stated that healing is considered as an important property of asphalt binder since it helps to recover the fatigue damage during rest period. Moisture Induced Sensitivity Test was used to moisture-condition the binders and then tested to evaluate the healing and chemical properties respectively. The cohesion properties of the asphalt binder are also evaluated. Test results indicated that water is absorbed in the asphalt binder due to the moisture conditioning. However, the healing rate of asphalt binder decreases due to moisture conditioning. It was concluded that moisture conditioning process decreases the amount of healing by reducing the energy of separation of the binder. The overall healing of fatigue damage reduces due to moisture conditioning of the asphalt binder. Mannan, (2017) [6] revealed that the increase in the absorbed water groups due to moisture conditioning reduces the molecular mobility. Thus, moisture conditioning increases the activation energy and decreases the cohesion. This will decrease the instant healing and long-term healing respectively. For moisture conditioned binders, the long-term healing rate is inversely proportional to the percent water absorbed in the binder due to moisture conditioning. Thus, the moisture conditioning decreases healing in the asphalt binder. Karimi et al., (2021) [7] quantified the fracture properties of asphalt concrete mixtures with varying degrees of moisture damage. The results show that the area under the curve of the service time-fracture property provides a proper index to investigate the long-term fracture

*Corresponding Author: saadisasarsam@coeng.uobaghdad.edu.iq
Received 18 July 2022; Revised 04 October 2022; Accepted 17 October 2022 https://doi.org/10.36937/cebel.2022.1703

resistance of asphalt mixtures. The aim of the present investigation is to assess the impact of practicing micro crack healing on the viscoelastic properties of moisture damaged asphalt concrete. Beam specimens of moisture damaged asphalt concrete will practice dynamic flexural stresses, then, the beams will practice healing process. The change in the viscoelastic properties of the asphalt concrete in terms of deformation, phase angle, dissipated energy, and flexural stiffness due to healing will be evaluated.

2. Materials and Methods

The materials used in the present investigation are locally available and currently implemented for asphalt pavement construction. Testing process.

2.1. Asphalt Cement

Asphalt cement of 40-50 penetration grade which is equivalent to PG 64-16 performance grade specifications was obtained from Dura oil refinery and implemented in the present investigation; Table 1 illustrates its physical properties.

Table 1. Physical properties of asphalt cement

Property	Testing condition	ASTM, 2016 Designation	Test result
Penetration (0.1 mm)	25 °C, 100 gm, 5 seconds	D-5	41
Softening point (°C)	Ring and ball	D-36	49.4
Specific gravity	25 °C	D-70	1.04
Ductility (Cm)	25 °C, 5 Cm/Minute	D-113	100+
Flash point (°C)	Cleveland open cup	D-92	275
	After thin film oven test		
Penetration (0.1 mm)	25 °C, 100 gm, 5 seconds	D-5	27
Ductility (Cm)	25 °C, 5 Cm/Minute	D-113	40+
Mass loss (%)	163°C, 50 gm, 5 Hours	D-1754	0.3

2.2. Coarse and Fine Aggregates

The coarse and fine aggregates used are crushed quartz; it was obtained from Al-Nibaee quarry. Table 2 demonstrates the physical properties of fine aggregates, while Table 3 present the physical properties of coarse aggregates.

Table 2. Physical properties of fine aggregates

Property	ASTM, (2016) [8] Designation	Test value
Bulk specific gravity	C-128	2.604
apparent specific gravity	C-128	2.664
Water absorption (%)	C-128	1.42
Sand equivalent (%)	D-2419	51

Table 3. Physical properties of coarse aggregates

Property	ASTM, (2016) [8] Designation	Test value
Bulk specific gravity	C-127	2.584
apparent specific gravity	C-127	2.608
Water absorption (%)	C-127	0.57
Los Angeles abrasion (%)	C-131	13
Soundness in sodium sulfate solution (%)	C-88	2.67
Flat and elongated particles (%)	D-4791	1.6

2.3. Mineral filler

Ordinary Portland cement was obtained from Badoush cement factory and used as mineral filler. Table 4 presents its physical properties.

Table 4. Physical properties of mineral filler

Property	Test value
Passing sieve No. 200 (%)	96
Bulk specific gravity	3.150
Specific surface area (m^2/Kg)	312.5

2.4. Selection of Aggregates Combined Gradation

The selected aggregates gradation in the present investigation follows SCRB, (2003) [9] specification for dense graded wearing course pavement layer with 12.5 mm nominal maximum size of aggregates. Table 5 shows the selected combined aggregate gradation.

Table 5. Aggregates Gradation implemented for Wearing Course as per SCRB, (2003) [9]

Sieve size mm	Selected gradation	SCRB, (2003) [9] 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

2.5. 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 as per SCRB, (2003) [9]. The combined aggregates were then heated to 160 °C before mixing with asphalt cement. The asphalt cement was heated to 150 °C, 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 the binder. The optimum asphalt content of 4.3% 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 Alwan, (2014) [10]. The asphalt concrete mixtures were casted in a slab mold of (40 x 30 x 6) Cm and subjected to roller compaction to the target bulk density according to EN12697-33, (2007) [11]. The applied static load was 5 kN while the number of load passes was determined based on trial-and-error process. Details of the compaction process could be referred to Sarsam, (2005) [12]. The compaction temperature was maintained to 150 °C. Slab samples were left to cool overnight. Beam specimens of 50±2 mm high, 63±2 mm wide and 400 mm length were obtained from the compacted slab sample using the Diamond-saw. The total number of beam specimens obtained was eight, while the number of casted slabs was three.

2.6. Conditioning of Specimens for Moisture Damage

The beam specimens were subjected to moisture damage by conditioning the beams in water bath at 25° C for two hours, the air in the voids was evacuated using a compressor with a vacuum of 3.74 kPa applied for 10 minutes to obtain 80 % saturation. The beam specimens were then placed in deep freeze at (-18°C) for 16 hours. The frozen specimens were then moved to a water bath and stored for 24 hours at (60°C). Then they were dried and placed in the testing chamber for 120 minutes at 20° C before testing for fatigue life. The conditioning was conducted as per AASHTO,R-30(2002) [13].

2.7. Repeated Flexural Bending Beam Test

Figure 1 exhibit the dynamic flexural bending beam test setup. The four-point repeated flexural bending beam test according to AASHTO T321, (2010) [14] was implemented to identify the fatigue life and flexural stiffness of asphalt concrete beam specimens at intermediate pavement operating temperature of 20 °C and under constant microstrain level of 200. During the flexural fatigue test, the beam is subjected to repeated four-point loading. The load frequency is usually set 5 Hz, and the deflection caused by the loading is measured at the center of the beam. The test was terminated when the beam has reached a 50 percent reduction in stiffness. A repeated sinusoidal (tension-compression) load is applied to the two inner clamps on the beam specimen with the outer clamps providing a reaction load. This setup produces a constant bending moment over the center portion of the beam (between the two inside clamps). Beams were subjected to a repeated load at a constant strain level. One constant Micro strain level of 200 was tried to simulate heavy traffic mode of loading in the field.

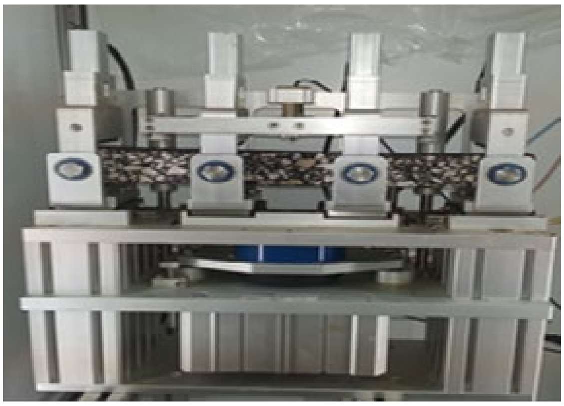

Figure 1. Four-point repeated flexural bending beam test

2.8. Crack Healing Technique

The micro crack healing technique implemented in this work was healing by the external heating as recommended by Sarsam, (2016) [15]. After the initiation of micro cracks due to flexural stresses repetitions for the beam specimens, the test was terminated. Specimens were withdrawn from the testing chamber, and stored in an oven for 120 minutes at 60 ° C to allow for micro crack healing. Specimens were subjected to another cycle of repeated flexure stress at 20 ° C for another course of load repetitions. The testing Temperate was (20°C), while the applied compressive stress was (138) kPa.

3. Results and Discussions

3.1. Influence of Micro Crack Healing on Flexural Stiffness of Moisture Damaged Mixture

Through the elastic behavior of asphalt concrete, the stiffness of the asphalt concrete mixture is higher, while the mixture shows screen cracks because of the fragility of the material. On the other hand, through the viscous behavior of asphalt concrete, permanent deformation is noticed of the asphalt concrete mixture on the top road surface. Stiffness of asphalt concrete describes the dynamic response of the mixture to sinusoidal loading as revealed by Shen and Carpenter, (2007) [16]. Moisture damage of asphalt concrete is a common type of pavement distress, the stiffness declines significantly due to the loss of adhesion between asphalt binder and aggregates, and the mixture exhibit cracking. Figure 2 demonstrates the influence of micro cracks healing on the flexural stiffness of moisture damaged asphalt concrete.

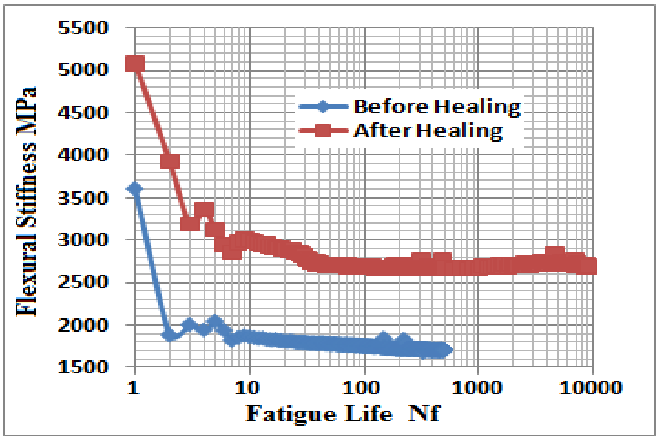

Figure 2. Influence of Micro Crack Healing on Flexural Stiffness

It can be detected that the healing process exhibits a positive influence on the flexural stiffness. A significant increase of 41.6 % in the flexural stiffness could be observed after healing after the first load repetition as compared with the mixture before healing. On the other hand, the fatigue life of the moisture damaged mixture increases many folds after practicing the healing process. This may be attributed to the increased adhesion after the healing.

3.2. Influence of Micro Crack Healing on Permanent Deformation of Moisture Damaged Mixture

Figure 3 demonstrates the influence of micro crack healing on permanent deformation of moisture damaged asphalt concrete. It can be noticed that micro crack healing process exhibit higher permanent deformation while the fatigue life increases. After 10 repetitions of flexural stresses, the permanent deformation changes its trend from sharp to steady. This may indicate the start of micro cracks. The permanent deformation after healing is higher by 22 % at failure as compared with that of mixture before healing. It can be stated that the micro crack healing process does not exhibit positive influence on permanent deformation of moisture damaged asphalt concrete. Such behavior agrees with the work reported by Mehrara and Khodaii, (2015) [2].

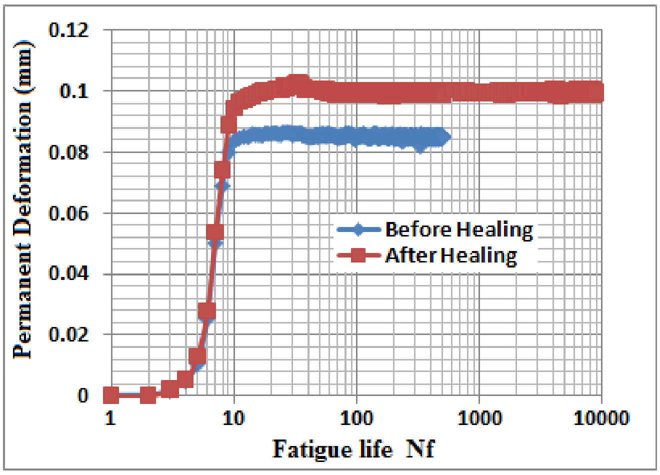

Figure 3. Influence of Micro Crack Healing on Permanent Deformation

3.3. Influence of Micro Crack Healing on Phase Angle of Moisture Damaged Mixture

Phase angle is one of the main indicators for viscoelastic behavior of asphalt concrete. When the phase angle is closer to 0 °, elastic behavior is expected in the material. However, when the phase angle is closer to 90° viscous behavior is exhibited. The phase angle is determined for calculations of the modulus and its elements and also for evaluating the dissipated energy. This viscoelastic parameter is load frequency and temperature dependent, however, there are also other inner factors which influence the phase angle value during repeated loading such as the inner degradation of the of asphalt concrete material. The phase angle is necessary for the calculation of the dynamic modulus, as without the phase angle, only the elastic modulus can be calculated, which refer to a static property of the material and does not describe the real asphalt mixture behavior which is subjected to repeated loading. Figure 4 exhibit the impact of micro cracks healing on phase angle of moisture damaged asphalt concrete, the influence of micro cracks healing is significant at the early stages of loading. The phase angle is 44° after healing which is higher than that of the mixture before healing by 69.2 %.

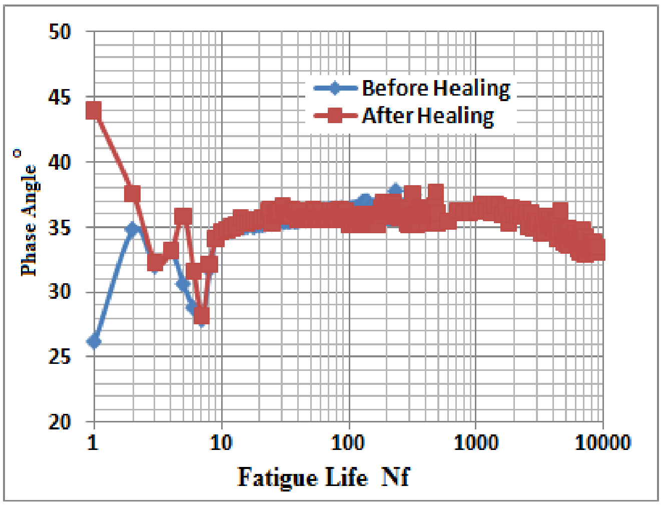

Figure 4. Impact of Micro Cracks Healing on Phase Angle

On the other hand, failure point of the phase angle is where it starts increasing, that is after eight repetitions of flexural stresses. The sudden change in the phase angle at this point may indicate inner structural changes. The possible cause of these changes was the creation of micro cracks. Based on these observations, it may be stated that the sudden behavior change to viscous state indicates the final stage of the fatigue life of the mixture. According to the test results, the phase angle value declines up to the possible failure point after one third of the test duration, the sharp increase in the phase angle started slightly before the final failure point. Similar findings were reported by Mandula and Olexa, (2017) [1].

3.4. Influence of Micro Crack Healing on Dissipated Energy of Moisture Damaged Mixture

Asphalt mixture dissipates energy through loading and relaxation. For an elastic material, the energy is stored in the system when the load is applied. Maggiore et al., (2014) [17] reported that all the energy is recovered when the load is removed; in this case the loading and the unloading curves coincide. However, viscoelastic materials are known by a hysteresis loop because the unloaded material traces a different path to that when it is loaded, usually referred as phase lag is recorded between the applied stress and the measured strain. In this case, the energy is dissipated in the form of damage, heat generation, or mechanical work. Dissipated energy is implemented to measure and evaluate the fatigue life of asphalt concrete mixtures. It is calculated by the software for each loading cycle. The change in the dissipated energy for different load cycles refers to the failure by initiation of micro cracks in the asphalt concrete mixture. The cumulative dissipated energy is the summary of dissipated energy in every cycle until failure of the mixture as revealed by Abojaradeh, (2013) [18]. As demonstrated in Figure 5, it can be detected that as the cumulative dissipation of the energy progress was observed, the dissipated energy during the test was mainly constant up to 100 repetitions of the flexural stresses, then, after this point, the cumulative dissipated energy started to increase sharply. Such behavior may indicate the initiation of micro cracks. Higher cumulative dissipated energy could be observed for mixture which had practiced micro crack healing as compared with the control mixture (before healing).

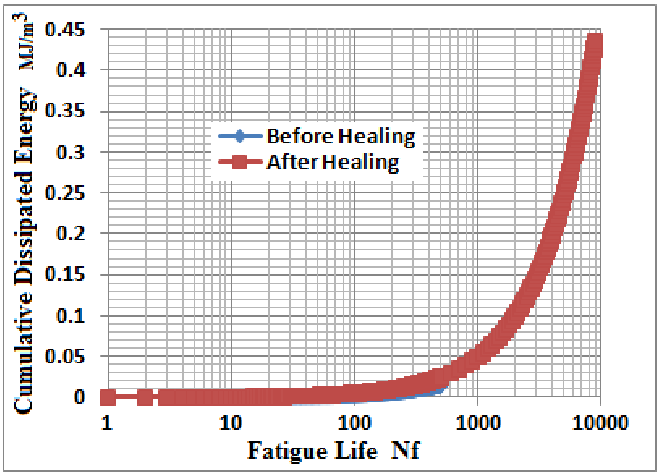

Figure 5. Impact of Micro Cracks Healing on Cumulative Dissipated Energy

4. Conclusion

The following concluding remarks may be addressed based on the limitation of materials and test program.

- The healing process exhibit a positive influence on the flexural stiffness. A significant increase of 41.6 % in the flexural stiffness could be observed after healing after the first load repetition as compared with the mixture before healing.
- The fatigue life of the moisture damaged mixture increases many folds after practicing the healing process.
- The permanent deformation after healing is higher by 22 % at failure as compared with that of mixture before healing. The micro crack healing process does not exhibit positive influence on permanent deformation of moisture damaged asphalt concrete.
- The influence of micro cracks healing on the phase angle is significant at the early stages of loading. The phase angle is 44° after healing which is higher than that of the mixture before healing by 69.2 %.
- Higher cumulative dissipated energy could be observed for mixture which had practiced micro crack healing as compared with the mixture before healing.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

[1.] Mandula J., Olexa T. Study of the Visco-Elastic Parameters of Asphalt Concrete. Elsevier, Procedia Engineering 190, (2017), P. 207 – 214. http://creativecommons.org/licenses/by-nc-nd/4.0/

[2.] Mehrara A., Khodaii A. Evaluation of moisture conditioning effect on damage recovery of asphalt mixtures during rest time application. Elsevier Construction and Building Materials 98. (2015). P. 294–304. http://dx.doi.org/10.1016/j.conbuildmat.2015.08.059

[3.] Sun Y., Wu S., Liu Q., Li B., Fang H. Ye Q. The healing properties of asphalt mixtures suffered moisture damage. Elsevier Construction and Building Materials. Volume 127, 30 November (2016), P. 418-424 https://doi.org/10.1016/j.conbuildmat.2016.10.048.

[4.] Li H., Yu J., Wu S., Liu Q. Wu Y., Xu H., Li Y. Effect of moisture conditioning on mechanical and healing properties of inductive asphalt concrete. Elsevier Construction and Building Materials. Volume 241, 30 April (2020), 118139. https://doi.org/10.1016/j.conbuildmat.2020.118139.

[5.] Mannan U., Ahmad M., Rafiqul A. Influence of Moisture Conditioning on Healing of Asphalt Binders. Elsevier Construction and Building Materials. Volume: 146 15 August (2017), P. 360-369.https://doi.org/10.1016/j.conbuildmat.2017.04.087

[6.] Mannan U. Characterization of asphalt healing and incorporation in a fatigue damage model. PhD. Dissertation, the University of New Mexico, Albuquerque, New Mexico. December, (2017). https://digitalrepository.unm.edu/ce_etds/192.

[7.] Karimi M., Dehaghi E., Behnood A. A fracture-based approach to characterize long-term performance of asphalt mixes under moisture and freeze-thaw conditions. 01 Jan (2021) -Engineering Fracture Mechanics. (Pergamon)-Vol. 241, p. 107418. Doi: 10.1016/J.ENGFRACMECH.2020.107418.

[8.] ASTM. American Society for Testing and Materials, ASTM: Road and Paving Material, Vehicle- Pavement System, Annual Book of ASTM Standards, Vol. 04.03. (2016). www.astm.org.

[9.] SCRB. State Commission of Roads and Bridges. Standard Specification for Roads & Bridges, Ministry of Housing & Construction, Iraq. (2003).

[10.] Sarsam S. I. and Alwan A. H. Assessing Fatigue Life of Super Pave Asphalt Concrete. American Journal of Civil and Structural Engineering AJCSE, (2014), 1(4):88-95.

[11.] EN 12697– 33, Bituminous Mixtures – Test Methods for Hot Mix Asphalt – part 33: Specimen prepared by Roller Compactor, (2007). European Committee for Standardization.

[12.] Sarsam S. I. Flexural and Cracking Behavior of Roller Compacted Asphalt Concrete, Journal of Engineering and Development, 9(4), (2005).

[13.] AASHTO R30. Standard Practice for Mixture Conditioning of Hot Mix Asphalt, AASHTO (2002), Washington, D.C.

[14.] AASHTO T-321. Method for Determining the Fatigue Life of Compacted Hot-Mix Asphalt (HMA) Subjected to Repeated Flexural Bending, AASHTO Provisional Standards. (2010). Washington, D.C.

[15.] Sarsam S. Monitoring dissipated energy through the fatigue process of asphalt concrete. Applied research journal, ARJ.Vol.2, Issue, 6.P.275-282, June (2016). http://arjournal.org.

[16.] Shen S., and Carpenter S. Dissipated energy concepts for HMA performance: Fatigue and healing, Technical report of research, University of Illinois at Urbana - Champaign, (2007), P.240.

[17.] Maggiore C., Airey G., Marsac P., A dissipated energy comparison to evaluate fatigue resistance using 2-point bending, Journal of Traffic and Transportation Engineering, Vol. 1, No. 1, (2014), P. 49–54.

[18.] M. Abojaradeh, Development of fatigue failure criterion for hot-mix asphalt based on dissipated energy and stiffness ratio. Jordan Journal of Civil Engineering, Volume 7, No. 1, (2013), P. 54-69.

How to Cite This Article

Sarsam, I.S., Influence of Micro-Crack Healing on Viscoelastic Properties of Moisture Damaged Asphalt Concrete, Civil Engineering Beyond Limits, 1(2022), 1703.
https://doi.org/10.36937/cebel.2022. 1703