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Resilient Behavior of Asphalt Concrete through Microcracks Healing Process

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ABSTRACT

The worst situation that asphalt concrete pavement can practice throughout its service life is the repetitions of heavy wheel loading, and ageing process accompanied by harsh environment. However, the initiation of microcracks which indicate the start of pavement deterioration can be controled by enhancing the healing properties of asphalt binder. Supporting the healing property of asphalt binder by implementation of additives exhibit a resilient remeady for pavement distress. In the present investigation, the influence of polemeric additives (LDPE, and Crumb Rubber) on the resilient, and healing behavior of asphalt concrete mixtures was assessed. Slab samples were prepared and compacted by roller. Beam specimens were extruded from roller compacted slab samples and tested for fatigue under constant strain level using four point bending beam technique. The test was terminated when the stiffness reaches 50 % of its original values. Beam specimens were given a rest period of 120 minutes at 60°C of external heating to promote healing, then the specimens practiced another round of load repetitions. It was noticed that the permanent deformation of asphalt concrete and the resilient modulus declines after implementation of additives while the resilient deformation increase. The healing process decreases both types of deformations and increases the resilient modulus.

Keywords: Healing, Microcracks, Resilient, Deformation, Modulus, Asphalt concrete, Polymeric additives

1. INTRODUCTION

Healing of microcracks in asphalt concrete is considered as a resilient action to reserve the pavement quality as well as it is a sustainable solution to enhance the infrastructure. Definition of Healing of the microcracks in asphalt concrete pavement are defining the mechanism either from the materials perspective or from the perspective of the applied test conditions under which healing is observed. Varma et al., 2021 present an overview of various asphalt binder healing assessments with an emphasis on analysis, mechanical testing. The theories on the healing mechanism and their dependence on wide variety of factors including testing temperature, rest periods, moisture damage, and aging on the healing process were discussed and compared. Sarsam and

Jasim, 2018 investigated the influence of polymer additives on the permanent deformation and crack healing ability of asphalt concrete under repeated compressive stress. It was revealed that polymer additives have positive impact on micro crack healing process. The permanent deformation at optimum asphalt content decreases by a range of (14 - 67) % after one and two healing cycles respectively as compared with control mix. Jiang et al., 2019 revealed that Healing can be defined as the restoration process of the original asphalt binder properties to a damaged binder after the load is removed. Two major types of healing mechanism can be identified in literature, the first one is focused on the asphalt binder phase itself (cohesive healing), while the other on the asphalt binder- aggregate- mineral filler interphase, (adhesive healing). Cohesive fracture and healing are defined by Xie et al., 2017 based on the binding part in the mixture. However, in order not to consider the effects of any possible interactions with the aggregate, some researchers focused their studies on healing using asphalt binder alone. The adhesive healing between the interfaces of the aggregates and asphalt binder was explained by Sun et al., 2018. It occur due to the rebounding of the aggregates to the binder. Gong et al., 2015 focuses on the adhesion between the aggregate- asphalt binder interface to understand the healing and cracking in the material wherein the higher value of adhesive force indicates the ability to carry higher load. It was concluded that the healing at the aggregate- asphalt binder interface could be a major form of healing in the asphalt mixture. Sarsam and Jasim, 2017 & Sarsam and Al-Tuwayy, 2020 investigated the influence of polymer additives on the ability of crack healing of sustainable asphalt concrete pavement through its influence on deformation, and microstrain under repeated flexural strength. It was stated that the polymeric additives implication may cause reduction in the permanent deformation of asphalt concrete. The permanent microstrain declines in a range of (43 – 68) % before and after crack healing respectively. Lv et al., 2020 used the binder bond strength test to evaluate the adhesion and healing between the aggregates and binder. The healing was evaluated based on the recovery of the binder bond strength. Sarsam and Jasim, 2018 assessed the resilient behavior of modified asphalt concrete using polymer additives. Test results indicated that the process of micro crack healing and the implementation of polymer additives have positive influence on resilient modulus and deformation variables of asphalt concrete. Xiao, 2017 addressed that Polymer Material Healing technique is used to induce and enhance the self-healing ability of asphalt concrete. Asphalt binder material can be seen as a two-phase material, the liquid phase which is called colloid, and the solid phase which is called asphalting. Through the service life of the pavement, the liquid phase is gradually oxidize which cause the asphalt to become hard and fragile. To prevent this from happening, polymers are used in asphalt concrete pavement to assess the healing process. Sarsam and Mahdi, 2019 assessed the influence of crack healing in terms of the changing in the Resilient Modulus under indirect tensile stress and the permanent deformation under compressive stress before and after healing for asphalt concrete. It was concluded that the resilient modulus under repeated tensile stresses increases by a range of 25 % for polymer treated mixtures after healing. However, the permanent deformation under the repeated compressive stresses declines by a range of 20 % for polymer treated mixtures after healing. Xiang et al., 2020 stated that the fatigue-healing characteristics concept of asphalt concrete pavements can repair pavement microcracks and prolong fatigue life, this is not taken into consideration in the conservative traditional pavement designs since the design of asphalt pavements is mostly based on the fatigue performance of the mixture. A four-point bending fatigue-healing-fatigue test was implemented to investigate the fatigue-healing performance of asphalt concrete mixtures. The effects of healing time, healing temperature, loading strain, and degree of damage, on the fatigue-healing characteristics of asphalt mixtures were investigated. The testing results show that the fatigue-life healing index of asphalt concrete mixtures is inversely proportional to the degree of damage and the loading strain and proportional to the healing time. Sarsam and Husain, 2017 addressed the impact of healing cycles and asphalt content on resilient modulus of asphalt concrete. It was concluded that the permanent deformation declines as the healing cycles proceeds. The resilient modulus under repeated indirect tensile stress increases by 100 % after the healing cycle as compared with control mix for mixes prepared at optimum asphalt content. Varma et al., 2021 quantifies healing of asphalt concrete beam specimens. Experiments are conducted at a controlled displacement rate and at −15°C environment. After the crack propagation, samples are given a rest period of 2 h at 10°C to promote healing before retesting them. The amount of healing occurred after the rest period is evaluated using various healing indices based on the recovery of fracture toughness, stiffness, fracture energy, and peak load. It was observed that the amount of healing is different when comparing different healing indices. The stiffness-based healing index demonstrated the healing ability of asphalt binder. The aim of the present investigation is to assess the influence of polemeric additives (LDPE, and Crumb Rubber) on the resilient, and healing behavior of asphalt concrete mixtures. The variations in permanent and resilient deformation, the resilient modulus, and the fatigue life of asphalt concrete for control and polymer modified mixtures will be monitored before and after the healing process.

2. MATERIALS AND METHODS

Asphalt Cement

The asphalt cement with a penetration grade of (40-50) was obtained from Dura oil Refinery. The physical properties of the asphalt cement are presented in Table 1.

Table 1. The Physical Properties of Asphalt Cement

Property	Result	Unit	SCRB, 2003 Specification
Penetration as per (25ºC,100g,5 sec) ASTM D5-97	44	1/10mm	40-50
Softening Point as per (Ring & Ball).ASTM D5-36	48.9	ºC	50-60
Ductility (25ºC, 5cm/min). as per ASTM D113-07	>100	Cm	>100
Kinematic viscosity at 135ºC ASTM D-2170	365	C.st	-----
Flash point (Cleave land open cup). ASTM D-92	323	ºC	Min232
Specific gravity at 25 ºC as per ASTM D-70	1.04	------	(1.01-1.05)
After the Thin-Film Oven test as per ASTM D1754, 2016			
Retained penetration of original, % as per D946	60	%	>55%
Ductility at 25ºC,5 cm/min, as per ASTM D113-07	>100	Cm	>25
Loss in weight , ASTM D1754	0.34	%wt.	< 0.75

Coarse Aggregate

Crushed quartz coarse aggregate was obtained from Al-Nibaee quarry. The gradation of coarse aggregate ranges between (19.0 mm) and (4.75 mm). The physical properties of the coarse aggregate are presented in Tables 2.

Fine Aggregate

The fine aggregate was obtained from Al-Nibaee quarry. The size of fine aggregates ranges between 4.75mm and 0.075mm. The physical properties of the fine aggregate are demonstrated in Table 2.

Table 2. Physical Properties of Al-Nibaee Fine and Coarse Aggregates.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C127 and C128)	2.680	2.630
Apparent Specific Gravity (ASTM C127 and C128)	2.632	2.6802
Percent Water Absorption (ASTM C127 and C128)	0.423	0.542
Percent Wear (Los-Angeles Abrasion) (ASTM C131)	21.7	……

Mineral Filler

Ordinary Portland Cement obtained is implemented as mineral filler. The physical properties and chemical composition of mineral filler are shown in Table 3.

Table 3. Physical Properties and chemical Composition of Portland Cement.

Chemical Compound	% Content
Silica, Sio_2	21.50
Lime, Cao	62.52
Magnesia, MgO	3.75
Alumina, Al_2O_3	5.63
Loss on Ignition	1.32
Ferric Oxide, Fe_2O_3	3.34
Sulfuric Anhydride, SO_3	1.63
Total	99.69
Physical properties	
% Passing Sieve No.200 (0.075 mm)	98

Apparent Specific Gravity	3.10
Specific Surface Area (m²/kg)	315

Polymer Additives to Asphalt Cement

Two types of polymer additives were implemented in this work; Low density polyethylene (LDPE), and Scrap Tire crumb rubber. The polymer modified asphalt binders were prepared in the laboratory. Details of the production process of the modified binder and the properties of the additives were published in Sarsam and Jasim, 2018.

Selection of overall Aggregate Gradation

The overall gradations that was selected in this study follows SCRB R/9, 2003 specification for Hot-mix asphalt paving mixtures usually used for wearing course with aggregate nominal maximum size of (12.5 mm). Table 4. Show the gradation for wearing layer.

Table 4. Gradation of Aggregate for Wearing Course according to SCRB, 2003

Sieve size mm	19	12.5	9.5	4.75	2.36	0.3	0.075
Gradation	100	95	83	59	43	13	7
SCRB limits	100	90-100	76-90	44-74	28-58	5-12	4-10

Preparation of Asphalt Concrete beam Specimens

The overall aggregate mix was heated to 160°C, while the modified or control asphalt cement binders were heated to 150°C, then added to the aggregates and mixed thoroughly for three minutes using mechanical mixer until asphalt had sufficiently coated the surface of the aggregates and a homogeneous mixture is achieved. The beam mold of 76.2 mm width, 381.0 mm length, and 76.2 mm height was heated to 150°C. The internal surface of the mold was oiled slightly to prevent sticking. The asphalt concrete mixture was laid and spread uniformly into the heated mold with a spatula, then the mixture was subjected to a static compaction of 30 kN applied through steel plated of 80 mm thickness. The applied pressure was maintained for three minutes at 150°C to achieve the target Specimen's bulk density and thickness. The mold was left for 24 hours to cool, and then the beam specimen was extruded from the mold.

Testing of Beam Specimens for resilient properties

The beam specimens were subjected to repeated flexural bending in the Laboratory using pneumatic repeated Load system apparatus (PRLS). Four point bending beam test was used to estimate permanent and resilient deformation, fatigue life, and resilient modulus under repeated flexural stresses. The numbers of loading cycles that initiates micro crack failure of the beam is commonly considered as indicator of fatigue cracking potential. The specimen was left in the conditioned chamber for 120 minutes at the testing temperature of (20˚C) to allow for uniform distribution of temperature within the specimen. The position of applied loading was marked on the specimens. LVDT (Linearly Variable Differential Transformer) has been used to monitor the deformation of the beam under each load cycle. The repetitive flexural stresses were applied (0.1 second of load duration and 0.9 seconds of rest period) to the specimen and the flexural deformation at the central third of the specimen is measured under each load repetitions as recommended by ASTM, 2016, and Sarsam and Jasim, 2018. The test start to allow for the initiation of micro cracks, after 900 load repetitions, the test was terminated. Figure 1 exhibit part of the prepared specimens, the PRLS apparatus, and the failure mode of the beam specimen.

Crack Healing Technique

The micro crack healing technique implemented in this work was healing by the external heating. After the initiation of micro cracks after 900 of flexural stresses repetitions for the beam specimens, the test was stopped. Specimens were withdrawn from the testing chamber, and stored in an oven for 120 minutes at 60° C to allow for microcrack healing. Specimens were subjected to another cycle of repeated flexure stress at 20 ° C for another 900 repetitions. The testing Temperate was (20ºC), while the compressive stress was (138) kPa.

Figure 1. (A) part of the prepared specimens. (B) Failure mode. (C) PRLS Apparatus

3. RESULTS AND DISCUSSIONS

Impact of Polymer Additives and Crack Healing on Deformation of Asphalt Concrete

As demonstrated in Figure 2, the permanent deformation of asphalt concrete (in microstrain) decline after practicing the healing process. This may be attributed to the stiffening of asphalt cement binder during the healing period which increase its viscosity and lead to restrict the deformation. The permanent microstrain decline by (77.1, 43.9, and 26.4) % after healing process for control, LDPE treated mixture, and crumb rubber treated mixture respectively. However, when the polymer additives were incorporated into the asphalt concrete, the permanent deformation in microstrain decline significantly regardless of the healing process. It can be noticed that before healing, the permanent deformation declines by (71, and 83) % for LDPE treated mixture, and crumb rubber treated mixture respectively as compared with the control mixture. On the other hand, the permanent deformation after healing declines by (28.9, and 45.3) % for LDPE treated mixture, and crumb rubber treated mixture respectively as compared with the control mixture. Such behavior may be attributed to the increased adhesion between the aggregates and polymer modified binder which restrict the deformation under repeated loading. Such finding agree with the work reported by Lv et al., 2020.

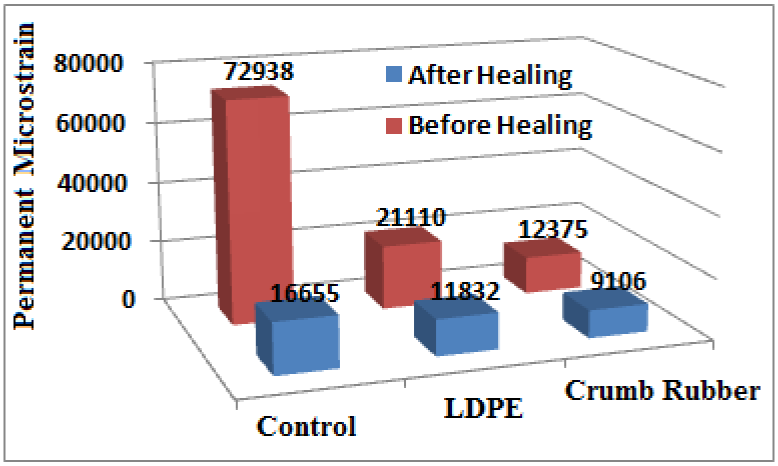

Figure 2. Influence of Healing on Permanent Strain

Figure 3 exhibit the influence of healing and polymer additives on the resilient deformation (in microstrain) of asphalt concrete. It can be observed that implementation of polymer additives into the asphalt concrete mixture exhibit a positive impact on the resilient deformation of the asphalt concrete mixtures. This could be attributed to the increased flexibility of the binder after incorporating the polymer. The resilient deformation in microstrain before healing process increases by (77.8, and 33.3) % after implementation of LDPE and crumb rubber additives respectively as compared with the control mixture. However, the resilient deformation in microstrain after healing process increases by (114.2, and 28.5) % after implementation of LDPE and crumb rubber additives respectively as compared with the control mixture. On the other hand, the healing process exhibit reduction in the resilient deformation by (22.1, 6.2, and 25) % for control, LDPE treated mixture, and crumb rubber treated mixture respectively. Such behavior could be attributed to the stiffening of the asphalt concrete mixture after the healing process. Similar behavior was reported by Varma et al., 2021.

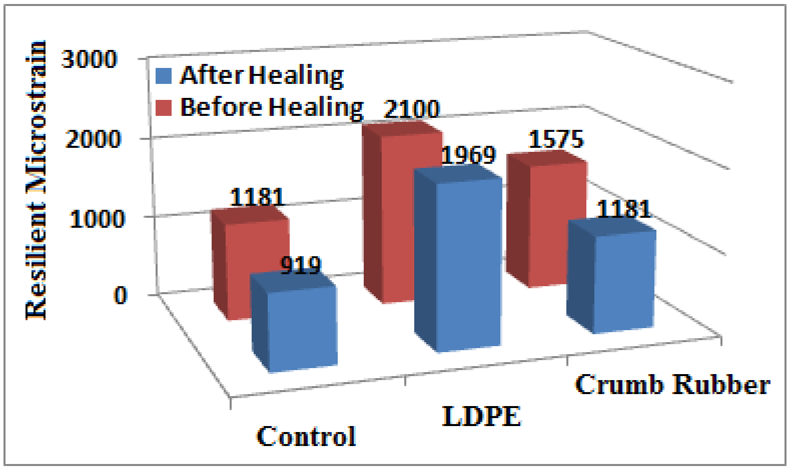

Figure 3. Influence of Healing on Resilient Strain

Impact of Polymer Additives and Crack Healing on Resilient Modulus of Asphalt Concrete

Figure 4 demonstrates the influence of implementation of polymer additives and practicing healing process on the resilient modulus of asphalt concrete. A reasonable resilient modulus is provided by the control mixtures regardless of the healing process. However, the resilient modulus declines after incorporating the polymer additives into the asphalt concrete mixture. On the other hand, the resilient modulus also decline after the healing process. This behavior may be attributed to the reduced flexibility after healing period. The resilient modulus decline after healing by (22.6, 7.1, and 25) % for control, LDPE treated mixture, and crumb rubber treated mixture respectively. However, the resilient modulus decline by (53.3, and 22.6) % after implementation of LDPE and crumb rubber additives respectively as compared with the control mixture before healing. On the other hand, the resilient modulus decline by (43.9, and 25) % after implementation of LDPE and crumb rubber additives respectively as compared with the control mixture after healing. Such behavior is in agreement with the work reported by Sun et al., 2018.

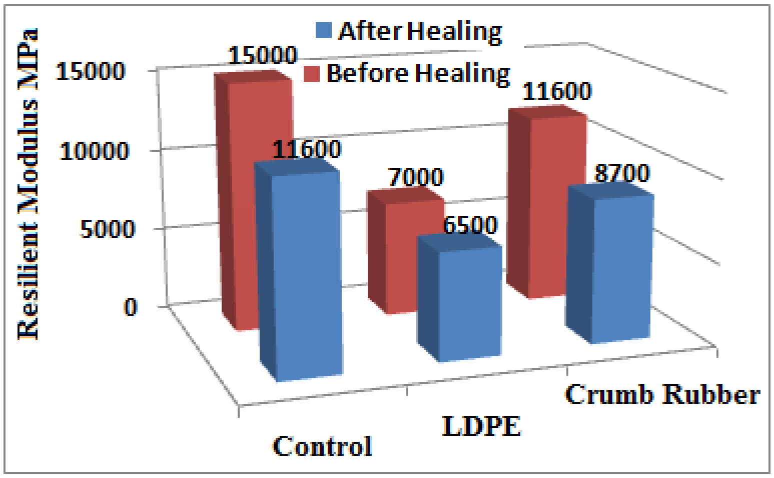

Figure 4. Influence of Healing on Resilient Modulus

Influence of Polymer Additives and Healing on Fatigue Life of Asphalt Concrete

Figure 5 demonstrate the relationship between the permanent deformation and fatigue life of control asphalt concrete mixtures. A significant variation in the rate of permanent deformation appears when testing the asphalt concrete specimens before and after the healing process. It can be noticed that the rate of deformation is gentle up to 100 repetitions of repeated flexural stresses while such rate changes to sharp after 100 repetitions. This may be attributed to the initiation of micro cracking after sustaining such load repetitions. On the other hand, the fatigue life of the control asphalt concrete increases after the healing process by 16.6 %. This may indicate more stable and stiff mixture obtained after the healing of microcracks process. Similar behavior was reported by Jiang et al., 2019.

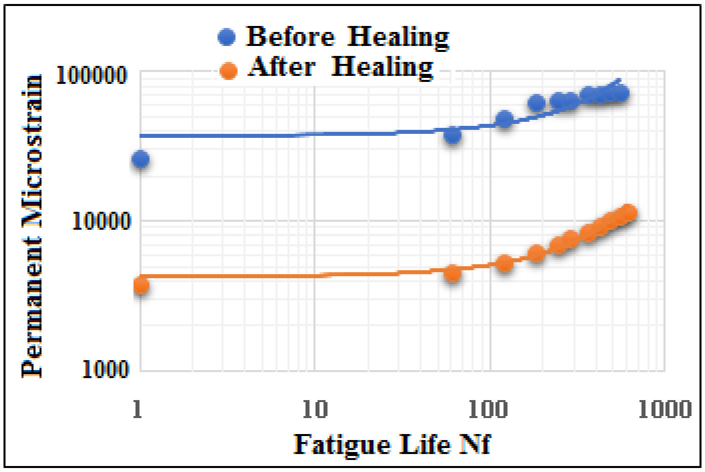

Figure 5. Deformation and Fatigue Life of Control Mixture

Figure 6 exhibit the variation in the deformation rate and fatigue life before and after healing process for asphalt concrete treated with LDPE polymer. It can be detected that there is no significant variation in the rate of permanent deformation among the healing process up to 100 repetitions of flexural stresses. However, the rate changes from steady to steep after 100 repetitions regardless of the healing process. This may indicate the initiation of microcracks. On the other hand, the fatigue life increases by 17 % after practicing microcrack healing process.

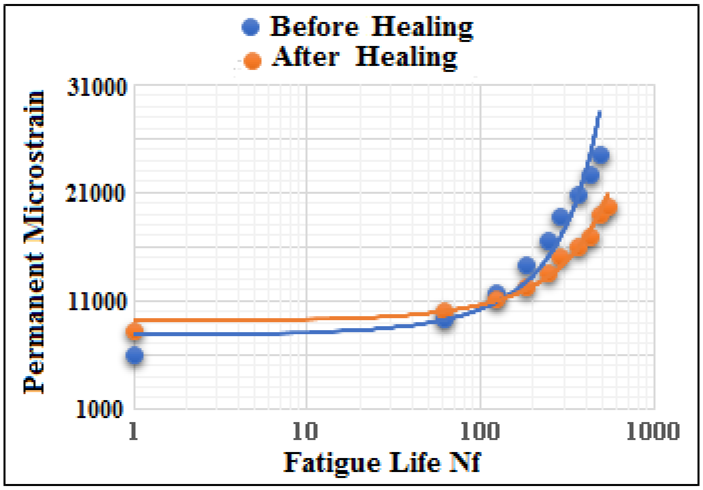

Figure 6. Deformation of LDPE Mixture

Figure 7 demonstrates the variation in the rate of permanent deformation of crumb rubber treated mixture before and after healing. It can be noticed that a significant variation in the deformation rate exists up to 100 repetitions of flexural stresses. The variation rate is steady up to 100 repetitions, then it shows gentle trend of increment. As the loading proceed, the variation is minimal. However, the variation in the fatigue life is not significant. This may be attributed to the fact that crumb rubber is obtained from scrap tires which exhibit low flexibility and high stiffness. Such behavior agree with the work reported by Sarsam and Jasim, 2018.

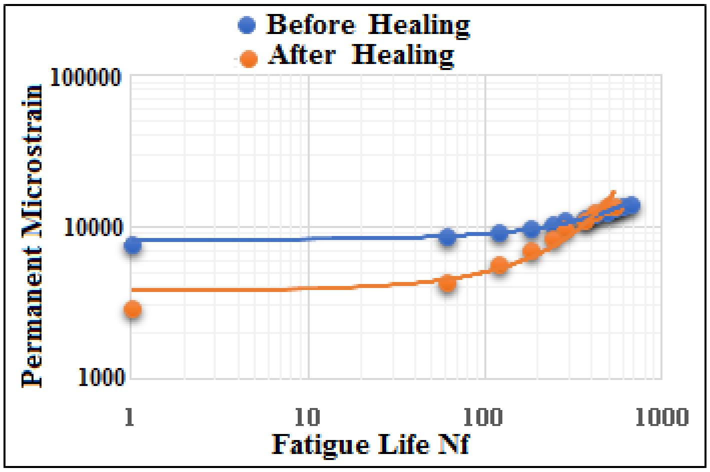

Figure 7. Deformation of Crumb Rubber Mixture

4. CONCLUSIONS

The following conclusions may be addressed based on the limitations of materials and testing program

1. The permanent microstrain decline by (77.1, 43.9, and 26.4) % after healing process for control, LDPE treated mixture, and crumb rubber treated mixture respectively.
2. The healing process exhibit reduction in the resilient deformation by (22.1, 6.2, and 25) % for control, LDPE treated mixture, and crumb rubber treated mixture respectively.
3. The resilient modulus decline after healing by (22.6, 7.1, and 25) % for control, LDPE treated mixture, and crumb rubber treated mixture respectively.
4. The permanent deformation of asphalt concrete and the resilient modulus declines after implementation of polymer additives while the resilient deformation increase.
5. The fatigue life of the control, and LDPE treated asphalt concrete increases after the healing process by (16.6, and 17) % while the crumb rubber treated mixture exhibit no significant variation in fatigue life after healing.

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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.

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