International Journal of Emerging Engineering Research and Technology
Volume 5, Issue 11, 2017, PP 55-62
ISSN 2349-4395 (Print) & ISSN 2349-4409 (Online)

Influence of Micro Crack Healing on the Deformation under Repeated Flexural Stress of Modified Asphalt Concrete

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ABSTRACT

Micro cracks in Asphalt concrete mixtures usually occurs due to loading and environment, however, they can heal by themselves in slow process under repeated loading at ambient temperature. The micro cracks healing can increase the lifetime of asphalt treated layer for several years, the aim of this work was to investigate the impact of polymer additives on the crack healing ability of sustainable asphalt concrete pavement through its influence on deformation, resilient strain under repeated flexural strength. Asphalt concrete beam specimens of 381mm length, 76.2mm height and 76.2 mm width have been prepared with optimum asphalt content requirement. Specimens were tested for permanent deformation under repeated flexural stress level of (138) kPa at 25°C environment. The loading cycle consists of load repetitions application for 0.1 second followed by 0.9 seconds of rest period. The testing technique was conducted for 660 repetition using the Pneumatic repeated load system (RPLS) to allow for the initiation of micro cracks. After the specified loading cycles, Specimens were withdrawn from the test chamber and stored in the oven for 120 minutes at 60 ° C to allow for micro crack healing, then were subjected to another loading cycle. Permanent deformation results vary depending on the type and proportions of additives. Polymer additives implementation causes reduction in the permanent deformation of asphalt concrete. The permanent strain decreases by (43, 53, and 60) % and (43, 7, and 68) % for SBS, LDPE and rubber modified asphalt concrete at optimum asphalt content before and after crack healing respectively.

Keywords: *Modified asphalt concrete, flexure stress, repeated load, deformation, resilient strain, crack healing*

INTRODUCTION

Asphalt concrete mixture needs to be flexible enough at low service temperature to prevent cracking and to be stiff enough at high service temperature to prevent rutting, [1]. Bitumen modified with polymer offers a combination of performance related benefits as the physical properties of the bitumen is improved without changing the chemical nature of it. Polymer modified bitumen increases the elasticity of the mix and also increases viscosity at higher temperature, [2]. The viscosity helps to limit the deflection while the elastic recovery reduces the residual deformation. [3] carried out a test for on the rutting resistance and it was found that the polymer modified pavement was able to withstand 4-10 times more loading cycles before ruts of various specified depths.

Laboratory investigations was carried out by [4] to determine the various engineering properties such as physical properties of asphalt cement and (polymer modified asphalt binder) PMAB with (styrene-butadiene-styrene triblock copolymer) SBS. The temperature susceptibility of PMAB-SBS is lower than asphalt cement. Moisture susceptibility of PMAC mixes is low when compared to AC mixes. The effect of adding several types of polymers on asphalt cement was evaluated by [5]. The mixing procedure should accommodate the physical homogeneity and chemical reaction so that the final modified asphalt cement can withstand the repeated loading stresses and provide the required durability for the design life of the pavement structure, [6]. [7] Used crumb to modify asphalt binder and the short-term aging effects on the properties of modified asphalts were evaluated. Penetration, softening points, ductility, viscosity, elastic recovery, low temperature creep, and rutting susceptibility were tested and analysed before and after thin film oven test. The results indicated that the softening point, viscosity, elastic recovery, creep stiffness, are all linearly increased with increasing age, while the penetration and ductility are linearly decreased with increasing age.

Experimental program involved modifying the asphalt using six types of polymers then evaluating the properties of the modified asphalt. It was found that the optimum percentage of PVC, plastic bags and novolac was 4%, and the optimum percentage of high density polyethylene HDPE was 5% by weight of asphalt. These percentages caused increase in kinematic viscosity, and caused reduction in penetration. [8] Had prepared the modified Asphalt cement for pavement construction in the laboratory by digesting each of the two penetration grade Asphalt cement (40-50 and 60-70) with Sulphur, fly ash, silica fumes. Three different percentages of each of the above mentioned additives have been tried using continuous stirring and heating at 150 ºC for 30 minutes. The prepared modified Asphalt specimens were subjected to physical properties determination; the penetration, softening point, ductility before and after laboratory aging. It was concluded that all percentage of additives has reduced the penetration value of asphalt cement. Softening point was increased with the addition of all percentage of additives. [9] Also showed the improvement in the resistance to plastic deformation with polymer modification. It is shown that the required number of load cycles to accumulate any value of plastic deformation increases as the polymer content is increased until 5% optimum polymer content is reached.

Experimental study was carried out by [10] on conventional bitumen and polymer modified binder. It has been shown that rutting resistance, indirect tensile strength and resilient modulus of the bituminous concrete mix with polymer modified bitumen is significantly improved. Polymers increase considerably the useful temperature range of the binders as stated by [11]. The effect of adding several types of polymers on asphalt cement and asphalt mixtures was evaluated by [12]. Experimental program involved two phases. The first phase was modifying the asphalt using six types of polymers then evaluating the properties of the modified asphalt. The second phase was evaluating the effect of binder modification on Marshall Mix design and indirect tensile strength of the asphalt concrete mixtures. It was found that the optimum percentage of polymers was in the range of 4-5% by weight of asphalt. These percentages caused increase in kinematic viscosity, stability, and indirect tensile strength. Using modified asphalt makes it possible to improve the fatigue and rutting resistance properties for some types of surfacing under particularly severe loading and environmental conditions of services, [13]. Inclusion of modifiers to asphalt could increase the viscosity of the binder, and reduce its thermal susceptibility of the binder, and increase the cohesion of the asphalt cement, [14]. A comparative evaluation of pavement fatigue life between modified and conventional asphalt concrete under the influence of changing the percentage of asphalt content by (0.5% ±) of the optimum was provided by [15], changing the testing temperature and under long-term aging and moisture damage impacts. The addition of crumb rubber could decrease the negative impact of aging process on overall properties of asphalt concrete as stated by [16]. Study of the implementation of sustainable solutions in the road industry, and to verify the possibility of using scrap tire rubber in asphalt concrete production have been conducted by [17].

The contribution of such crumb rubber (which is considered as waste material) in the aging process of asphalt concrete was investigated. For more than 25years, researchers have been reporting evidence of micro damage healing, initially on asphalt binders, and later on asphalt mixtures [18, 19, 20, 21and 22]. The impact of micro crack healing phenomena of asphalt concrete on the resilient characteristics under shear and tensile repeated stresses have been investigated by [23, 24 and 25]. In this investigation, Specimens of 100mm diameter and 75mm of height have been prepared at optimum asphalt content, and at 0.5% asphalt above and below the optimum. The aim of this work is to study the influence of three type of polymer additives on deformation and micro crack healing of asphalt concrete subjected to repeated flexure stress. The deformation of the specimens under repeated flexure stresses will be captured using LVDT. The impact of micro crack healing will be detected through the variation of the permanent deformation before and after healing.

MATERIALS AND METHODS

Asphalt Cement

The asphalt cement of (40-50) penetration grade was obtained from Daura Refinery and implemented in this investigation. The physical properties of the asphalt cement are presented in Table 1.

Coarse Aggregates

In this work, crushed coarse aggregate brought from Al-Nibaee quarry was used. It consists of hard, strong, and durable pieces. The gradation of coarse aggregate ranges between 3/4 in. (19.0 mm) and No.4 sieve (4.75 mm) according to SCRB R/9, [28] specification. The physical properties of the coarse aggregate are illustrated in Tables 2.

Table1. *Physical Properties of Asphalt Cement*

Property as per AASHTO, [26 and 27]	Result	SCRB, [28] Specification,
Penetration (25ºC,100g,5 sec)	44	40-50
Softening Point (Ring & Ball), ºC	48.9	50-60
Ductility (25ºC, 5cm/min), Cm	120	>100
Kinematic viscosity at 135ºC, CSt	365	_____
Flash point (Cleave land open cup), ºC	323	Min232
Specific gravity at 25 ºC	1.04	(1.01-1.05)
After thin film oven test		
Retained penetration of original,%	60	>55%
Ductility at 25ºC,5 cm/min, Cm.	75	>25
Loss in weight (163ºC,50g,5h), %	0.34	< 0.75

Fine Aggregate

Fine aggregate was brought from Al-Nibaee quarry. The gradation of fine aggregates ranges between passing 4.75mm (No.4) sieve and retains on 0.075mm (No.200) sieve. It consists of tough grains, free from clay, loam or other deleterious substance. The physical properties of the fine aggregate are shown in Table 2.

Table2. *Physical Properties of Coarse and fine Aggregates*

Property	Course Aggregate	Fine Aggregate
Bulk Specific Gravity	2.680	2.630
Water Absorption %	0.423	0.542
% Wear (Los-Angeles Abrasion)	20.7	-

Mineral Filler

Ordinary Portland cement was implemented as mineral filler in the asphalt concrete mixture. It was free from lumps or aggregations of fine particles. The Physical properties are listed in Table 3.

Table3. *Physical properties of Portland cement*

Test	Properties
% Passing Sieve No.200 (0.075mm)	98
Specific Gravity	3.1
Specific Surface Area (m^2/kg)	315

Polymer Additives to Asphalt Cement

Three types of polymer additives were implemented in this work; Low density polyethylene (LDPE), Styrene-butadiene-styrene (SBS) and Scrap Tire rubber (TR). The modified asphalt cement binders were produced in laboratory. Details of the production process and the properties were published elsewhere, [29]. Table 4 shows the properties of polymer additives, while "Figure. 1" exhibit the polymers implemented.

Table4. *Properties of polymer additives*

Polymer Type	Density Gm/Cm^3	Melting Temperature (°C)	Tensile Strength (MPA)	Tensile Elongation at Yield (%)
LDPE	0.92	110	20	600
SBS	0.85	180	16.5	660
Tire rubber	1.3	210	18	565

Mixing of Asphalt Cement with Polymer Modifiers

A cooking pressure vessel of 6 litres capacity was implemented throughout the preparation process of modified asphalt cement. Three percentages of each type of polymer additives have been implemented based on the literature survey conducted so that the variation in the physical and rheological properties among these additive percentages could be clearly detected. The mixture was subjected to four mixing periods (10, 20, 30 and 50) minutes and a temperature of 130 °C and the pressure applied by the vessel was maintained to 1bar (15 Psi).

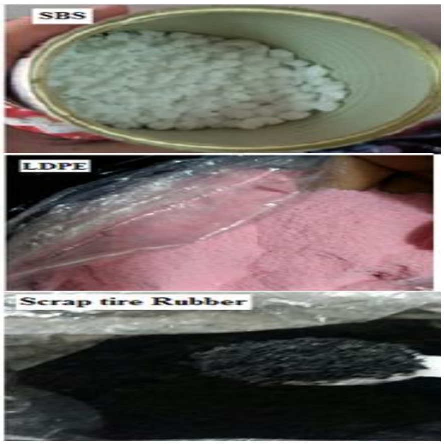

Figure1. *Polymer additives implemented*

Heating of the pressure vessel was applied through electric hot plate with a thermostat control. “Figure. 2” demonstrates the cooking pressure vessel implemented. After each mixing period, the pressure was released through the safety valve, and the vessel cover was removed as shown in “Figure. 3”. “Figure. 4” shows the swelling and formation of bubbles that could be observed after each mixing period indicating the chemical reaction occurred due to temperature and pressure.

Figure2. *Pressure vessel*

Figure3. *Temperature check*

Figure4. *Modified binder*

Selection of Asphalt Concrete Overall Gradation

The gradations that was selected in this study follow SCRB R/9, [28] specification for Hot-mix asphalt paving mixtures usually used for wearing course with aggregate nominal size of (12.5 mm). Table 5. Show the gradation for wearing layer.

Table5. *Selected Asphalt concrete gradation*

Sieve size (mm)	Selected gradation	SCRB [28] Specifications
19	100	100
12.5	95	90-100
9.5	83	76-90
4.75	59	44-74
2.36	43	28-58
0.3	13	5-12
0.075	7	4-10

Preparation of Modified Asphalt Concrete Specimen

The overall aggregate mix was heated to 160°C, while the pure or modified asphalt cement 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. The beam mold of 381.0 mm length, 76.2 mm width, and 76.2 mm height which consists of four portable sides made of 12.7 mm thickness standard C-channel steel section and 10 mm thick steel base plate was heated to 150°C. The internal surface of the mold was oiled slightly and a sheet of aluminum foil was placed on the base of mold to prevent sticking. The asphalt concrete mixture was transferred to heated mold, laid and spread uniformly with a heated spatula then subjected to 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 and then the beam specimen was extruded from the mold. “Figure. 5” shows the preparation of beam specimens while “Figure. 6” demonstrates part of the prepared beams. On the other hand, Table 6 exhibit details of the prepared beams. Similar procedure was followed by [1 and 8].

Repeated Flexural Bending Test

The beam specimens were subjected to repeated flexural bending in the Laboratory as shown in “Figure. 7” using pneumatic repeated Load system apparatus (PRLS) shown in “Figure 8”.

Figure5. *Preparations of Beam specimens*

Four point loading test with free rotation beam holding fixture at all loading and reaction point was used to estimate deformation and micro cracking potential in the flexural beam fatigue test.

Table6. *Details of the prepared beam specimens*

Asphalt cement type	Pure asphalt	LDPE modified	SBS modified	Rubber modified
Bulk Density gm/ cm^3	2.340	2.317	2.292	2.350
Optimum asphalt content %	4.8	5.3	5.6	5.3
Volume of voids %	3.9	5.5	5.41	4.0
Volume filled with asphalt %	73	68	70.4	75

The numbers of loading cycles that initiates micro crack failure of the beam is commonly considered as indicator of fatigue cracking potential.

Figure6. *Part of the prepared beam specimens*

The specimen was left in conditioned chamber for one hour at testing temperature (25˚C) to allow uniform distribution of temperature within the specimen and the position of applied loading was marked on the specimens. LVDT (Linearly Variable Differential Transformer) which convert the mechanical signal (displacement) to electrical signal has been used to monitor the deformation (total, permanent, and resilient) of the beam under each load cycle, and Positioned onto the specimen and set to zero.

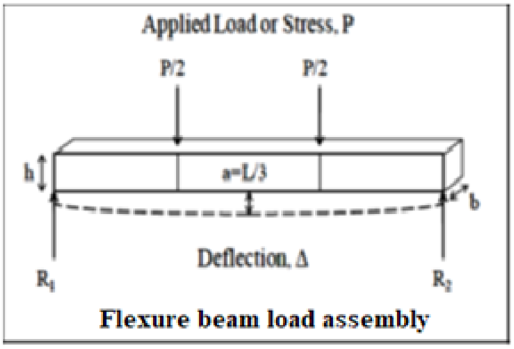

Figure7. *Four point loading for flexure stress*

The repetitive flexural stress was applied (0.1 sec. load duration and 0.9sec. 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 [8 and 13].

Figure8. *Pneumatic Repeated Load System Apparatus PRLS*

The test start to allow for the initiation of micro cracks, after 660 load repetitions, 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 possible micro crack healing. Specimens were subjected to another cycle of repeated flexure stress at 25 °C for another 660 loading cycles. Data have been analyzed, and the plot of strain-load repetitions was conducted.

RESULTS AND DISCUSSIONS

Impact of Asphalt Content and Crack Healing on Deformation Parameters

"Figure. 9" exhibit the influence of polymer additives on permanent micro strain before and after micro crack healing, it can be observed that the healing has limited the deformation to a great extent. LDPE and Rubber have controlled the permanent deformation for control mixture as well as for mixture after crack healing as compared to SBS modified asphalt concrete.

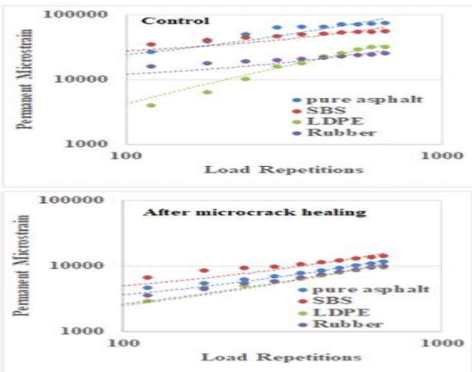

Figure9. *Influence of polymer additives on permanent micro strain*

"Figure. 10" shows the impact of healing cycle on the intercept of the strain-repetitions relationship, while "Figure. 11" exhibit the variation of slope with asphalt content. For pure and polymer modified asphalt cement mixture, the intercept and the slope increases with the increment of asphalt content. On the other hand the intercept decreases and the slope increases after micro crack healing as compared to control mixture. For pure asphalt mixture, the increment in the intercept was (8 and 33) % while the slope increases by (20 and 114) % when the asphalt content increase to (4.8 and 5.3) % respectively. After micro crack healing, the intercept decreases by (87, 53 and 69) % and the slope increases by (69, 81 and 63) % for (4.3, 4.8 and 5.3) % asphalt content respectively.

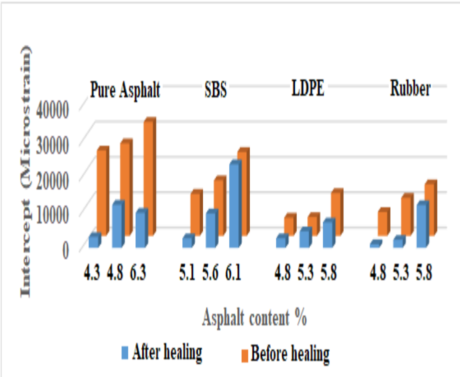

Figure10. *Variation of intercept with healing cycle and asphalt content*

For SBS modified mixture, the increment in the intercept was (32 and 99) % while the slope increases by (20 and 114) % when the asphalt content increase to (5.6 and 6.1) % respectively. After micro crack healing, the intercept decreases by (77, 38 and 0.5) % and the slope increases by (95, 93 and 77) % for (5.1, 5.6 and 6.1) % asphalt content respectively. For LDPE modified mixture, the increment in the intercept was (3 and 135) % while the slope increases by (18 and 92) % when the asphalt content increase to (5.3 and 5.8) % respectively. After micro crack healing, the intercept decreases by (47, 12 and 41) % and the slope increases by (68, 68 and 16) % for (4.8, 5.3 and 5.8) % asphalt content respectively.

For Rubber modified mixture, the increment in the intercept was (59 and 115) % while the slope increases by (23.5 and 29) % when the asphalt content increase to (5.3 and 5.8) % respectively. After micro crack healing, the intercept decreases by (84, 79 and 17) % and the slope increases by (173, 124 and 176) % for (4.8, 5.3 and 5.8) % asphalt content respectively. Similar findings was reported by [13].

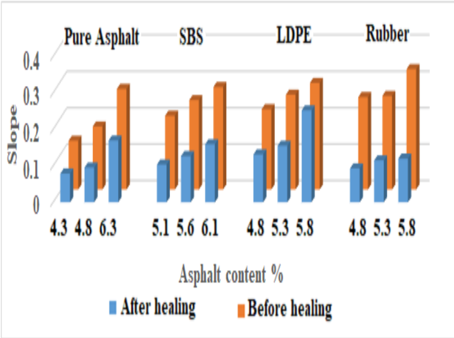

Figure11. *Variation of slope with asphalt content and crack healing*

Impact of Polymer Additive Type and Crack Healing on Deformation Parameters

In general, polymer additives causes reduction in the intercept value before and after micro crack healing, while it increases the slope value. For SBS modified asphalt concrete, the intercept decreases by (40 and 9) % and the slope increases by (33 and 42) % before and after healing respectively at optimum asphalt content. For LDPE modified asphalt concrete, the intercept decreases by (80 and 62) % and the slope increases by (63 and 50) % before and after healing respectively at optimum asphalt content. For Rubber modified asphalt concrete, the intercept decreases by (59 and 70) % and the slope increases by (20 and 84) % before and after healing respectively at optimum asphalt content.

Impact of Asphalt Content and Crack Healing on Permanent Strain under Flexural Stress

"Figure. 12" shows the effect of asphalt content and crack healing cycle on permanent strain after 660 load repetitions of flexural stress, it can be observed that the permanent strain increases as the asphalt content increase before and after healing cycle, the polymer additives exhibit reduction in the permanent strain. For pure asphalt mixture, the permanent strain increases by (36 and 68) % and (214 and 535) before and after healing when asphalt content changes to (4.8 and 5.3) % respectively. For SBS modified asphalt mixture, the permanent strain increases by (61 and 341) % and (131 and 172) before and after healing when asphalt content changes to (5.6 and 6.1) % respectively. For LDPE modified asphalt mixture, the permanent strain increases by (32 and 44) % and (21 and 174) before and after healing when asphalt content changes to (5.3 and 5.8) % respectively. For Rubber modified asphalt mixture, the permanent strain increases by (89 and 148) % and (40 and 148) before and after healing when asphalt content changes to (5.3 and 5.8) % respectively.

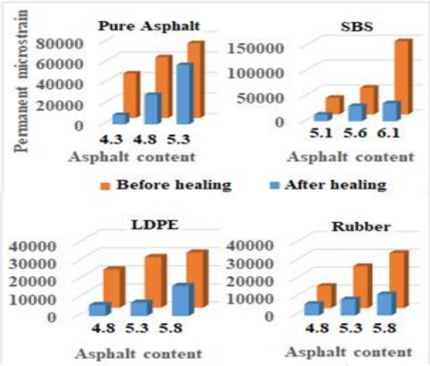

Figure12. *Impact of Asphalt Content and Crack healing on permanent strain*

Impact of Polymer Additive Type and Crack Healing on Permanent Strain

Polymer additives implementation causes reduction in the permanent deformation of asphalt concrete. For modified mixture, the permanent strain decreases by (43, 53, and 60) % for SBS, LDPE and rubber modified asphalt concrete at optimum asphalt content before healing, while the permanent strain decreases by (43, 7, and 68) % for SBS, LDPE and rubber modified asphalt concrete at optimum asphalt content after healing as demonstrated in “Figure. 12”.

CONCLUSIONS

Based on the testing program, the following conclusions may be drawn

1- Polymer additives implementation causes reduction in the permanent deformation of asphalt concrete. The permanent strain decreases by (43, 53, and 60) % and (43, 7, and 68) % for SBS, LDPE and rubber modified asphalt concrete at optimum asphalt content before and after crack healing respectively.

2- For SBS modified mixture after micro crack healing, the intercept decreases by (77, 38 and 0.5) % and the slope increases by (95, 93 and 77) % for (5.1, 5.6 and 6.1) % asphalt content respectively.

3- For LDPE modified mixture after micro crack healing, the intercept decreases by (47, 12 and 41) % and the slope increases by (68, 68 and 16) % for (4.8, 5.3 and 5.8) % asphalt content respectively.

4- For Rubber modified mixture after micro crack healing, the intercept decreases by (84, 79 and 17) % and the slope increases by (173, 124 and 176) % for (4.8, 5.3 and 5.8) % asphalt content respectively.

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Citation: *S. Saad Issa and J. Sara Ali, "Influence of Micro Crack Healing on the Deformation under Repeated Flexural Stress of Modified Asphalt Concrete", International Journal of Emerging Engineering Research and Technology, vol. 5, no. 11, pp. 55-62, 2017.*