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RESEARCH ARTICLE

Monitoring Micro Crack Healing Phenomena in Recycled Asphalt Concrete

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Abstract

Asphalt concrete usually practices cracking and distress during its service life. However, recycling process as well as crack healing phenomena can enhance the physical properties and extend the pavement service life. This investigation is concerned with monitoring the microcrack healing of recycled asphalt concrete through its influence on deformation measurement under three testing techniques, repeated (compressive, tensile and shear stresses). Reclaimed asphalt concrete mixture was recycled with [carbon black-asphalt] and [Styrene Butadiene Rubber (SBR)-asphalt] rejuvenators. Specimens have been tested with the aid of the pneumatic repeated load system (PRLS). The repeated loading of the three testing techniques was terminated after 1000 load repetitions, and the specimens could heal by external heating at 60°C for 120 minutes. Specimens were returned to the (PRLS) and subjected to another run of repeated stresses application after healing. It was concluded that the deformation increases after recycling process while it declines after microcrack healing regardless of the testing technique adopted. The deformation declines by (31.8, 5.8 and 19)%, (43, 49 and 24)% and (44, 10 and 13)% under three level of repeated compressive stresses of (0.068, 0.138, and 0.206) MPa at (40 °C) after healing cycle for reclaimed and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with permanent deformation before the healing cycle. The permanent deformation under repeated punching shear and indirect tensile stresses declines after microcrack healing by (32, 26 and 25.7) % and (73, 78.7 and 78.2) % for reclaimed, recycled with (carbon black-asphalt) and recycled with (SBR-asphalt) mixtures respectively.

Keywords: Asphalt concrete, deformation, recycling, repeated stress, tensile, shear, compression

1.Introduction

The asphalt concrete properties of mixtures with recycling agents which has been prepared in laboratory on the reclaimed asphalt pavement (RAP) material, and their performance has been compared with virgin mixes by Pradyumna and Jain,[1]. Various performance tests such as Retained Stability, Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR), and Resilient Modulus test has been carried out to compare the performance of RAP modified mixes and virgin mixes. It was concluded that the laboratory results indicate that the bituminous mixes with RAP and recycling agent provide better performance when compared to virgin mixes. Valdés et al,[2] presented an experimental study to characterize the mechanical behavior of bituminous mixtures containing high rates of (RAP). Two semi-dense mixtures containing 40% and 60% RAP, respectively were used for rehabilitation of a highway section. The mechanical properties were studied by determining the stiffness modulus, cracking and fatigue behavior. Results show that high rates of recycled material can be incorporated into bituminous mixes by proper characterization and handling of RAP stockpiles. The use of rejuvenators has the potential to restore rheology and chemical components of aged RAP bitumen, thus allowing a significant increase in the amount of RAP to be properly implemented in hot mix asphalt HMA. Results show that rejuvenators modify bitumen chemistry and consequently the rheology by enhancing the viscous response, Mazzoni et al.[3]. The dynamic behavior of the recycled asphalt concrete (with cutback and emulsion) in terms of the resilient

modulus (M_r), rutting resistance, and permanent microstrain have been investigated by Sarsam and Saleem,[4]. It was concluded that RAP mixture can hold the applied loading with minimal permanent deformation as compared to the recycled mixtures. A laboratory manufactured recycling agent consisted of 77% used oil with 22% reclaimed scrap tire rubber and 2% of detergent was implemented by Sarsam,[5], and the amount of recycling agent was in the range of (1-2) % by weight of mixture. It was found that using soft grade asphalt cement as a recycling agent revealed better performance than other types of recycling agents, Sarsam and AL-Janabi,[6]. A study by Noferinia et al, [7] focuses on the interaction between neat and RAP bitumen in asphalt mixes made with different RAP content. The effects of RAP on physical and rheological properties of the final bituminous blend were investigated. Findings from laboratory tests indicate that the aged binder influences physical and rheological properties of the final blend due to an interaction with the virgin binder. The effect of recycling agent on tensile and shear properties of aged asphalt concrete was investigated by Sarsam and AL-Zubaidi,[8]. It was found that using (soft asphalt cement blended with silica fume) as a recycling agent revealed better performance than the other type of recycling agent. Punching shear strength was higher than that of recycled mixed by 34% at optimum asphalt content. The effects on RAP with poor or unknown aggregate qualities to establish maximum allowable RAP contents to provide adequate friction have been explored by McDaniel et al.[9]. The effects of RAP on thermal cracking were then investigated at the potential allowable RAP contents. Laboratory testing showed that the addition of poor-quality

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RAP materials did impact the frictional properties and cracking resistance of the mixtures, but that lower amounts of RAP had little effect. The aim of this investigation is monitoring the deformation of recycled asphalt concrete under repeated compressive, tensile and shear stresses, and the role of microcrack healing in the enhancement of the recycled asphalt concrete resistance to deformation.

2. Materials and Methods

The Materials implemented in this investigation are locally available, and economically valuable. The materials are categorized into three groups namely, reclaimed (aged) materials, asphalt cement, and recycling agents.

2.1. Aged Material

The reclaimed (aged) asphalt mixture was obtained from the field by the rubblization of the asphalt concrete binder course layer from the highway section at Karbala province. This highway was constructed in 2012. The Reclaimed asphalt mixture obtained was free from damaging materials and loam that may be sticking on the top surface. Reclaimed material was heated to 130° C, combined and reduced to testing size as per AASHTO, [10]; a typical sample was obtained and exposed to Ignition test based on AASHTO T 308, [10] procedure to obtain binder and filler content, gradation and properties of aggregate. Table 1 exhibits the properties of reclaimed material as obtained after ignition test.

Table 1. Properties of Reclaimed Materials after Ignition Test

Material	Property	Value
Asphalt	Binder content %	3.84
Reclaimed Mixture	Stability	17.532 KN
	Flow	2.9 mm
	Bulk density	2.320 gm/cm ³
	Air voids	5.1 %
	Theoretical maximum density	2.448 gm/cm ³

On the other hand, the properties of the extracted coarse and fine aggregates and mineral filler from the reclaimed asphalt pavement binder layer are illustrated in Table 2.

Table 2. Properties of Coarse and Fine Aggregates and Mineral Filler Extracted from Reclaimed Asphalt Pavement RAP

Material	Property	Value
Coarse aggregate	Bulk specific gravity	2.62
	Apparent specific gravity	2.76
	Water absorption %	1.021
	Percent of Fractured Faces %	93
Fine aggregate	Bulk specific gravity	2.67
	Apparent specific gravity	2.81
	Water absorption %	1.82
Mineral filler	Percent passing sieve no.200	98
	Specific gravity	3.15

Samples were obtained from the RAP and practiced the Ignition test, then aggregates obtained after the ignition test were sieved to several sizes to determine the gradation. The average gradation data of the two samples is shown in Table 3, and it is within the Specification limits of Roads and Bridges SCRB,[11] for binder course.

Table 3. Gradation of Aggregates Obtained from Reclaimed Mixture (RAP)

Standard sieves (mm)	(% Finer by Weight of Extracted Aggregate + Filler)	Specification limit
25	100	100
19	96.5	90-100
12.5	86.5	70-90
9.5	72	56-80
4.75	44	35-65
2.36	31.5	23-49
0.3	12	5-19
0.075	5.85	3-9

2.2 Additives for Preparation of Rejuvenator Agents

Two types of hydrocarbon additives namely, carbon black and Styrene Butadiene Rubber (SBR) have been implemented in this investigation to prepare the rejuvenator agent. Three percentages of additives, (0.5, 1, and 1.5) % by weight of asphalt cement, and two percentages of asphalt cement, (1 and 2) % by weight of mixture have been blended and implemented as rejuvenator and mixed with the reclaimed asphalt concrete. Details of mixing, and the properties of rejuvenators are published at Sarsam and Mahdi, (2019). Table 4 exhibits the properties of carbon black, while Table 5 shows the properties of SBR as supplied by the manufacturers.

Table 4. Properties of Carbon Black as supplied by the manufacturer

Property	ASTM, [12]	Test result
Residue on Sieve No. 35	D-1514	10
Pour density gm/liter	D-1513	352.4
Ash content %	D-1506	0.75
PH	D-1512	7.5-9
Specific Surface Area (m ² /g)	D-6556	36
Oil absorption number	D-2414	122

Figure 1 below exhibit the additives implemented. The carbon black was in a powder form while the SBR was in a liquid form.

Figure 1. Additives Implemented in the work

Table 5. Properties of SBR as supplied by the manufacturer

Property	Value
Specific gravity (g/cm ³ at 25 °C)	1.01
Color	Milky white liquid
Chloride content	Nil
Butadiene (% by wt.)	40
Mean part size (micro- nicle)	0.17
Viscosity	Low

2.3. Asphalt Cement Binder

Asphalt cement binder of penetration grade (40-50) was obtained from Al-Dura refinery. It was implemented in the recycling process to prepare the rejuvenators. The physical properties of Asphalt cement are demonstrated in Table 6.

Table 6. Physical Properties of Asphalt Cement Binder

Physical properties	ASTM, [12] Designation	Asphalt cement	SCRB, [11]
Penetration	D5-06	43	40-50
Softening Point	D36-95	46	-
Ductility	D113-99	140	>100
Specific Gravity	D70	1.04	-
Flash Point	D92-05	269	>232
Retained Penetration of Residue	D5-06	57%	>55
Ductility of Residue	D113-99	73 cm	>25

2.4. Preparation of Rejuvenators by Blending the Asphalt Cement with Carbon Black and SBR

The Asphalt cement of penetration grade (40-50), was mixed with 1.5 % of carbon black (by weight of added asphalt) which was obtained in powder form. Asphalt cement was heated to 130° C, and the carbon black was added steadily to the asphalt cement with thrilling for thirty minutes with the aid of a mechanical blender until, homogenous blend was accomplished. On the other hand, Asphalt cement was mixed with 1.5 % of SBR (by weight of added asphalt) which was obtained in liquid form. Asphalt cement was heated to approximately 130° C, and the SBR was added steadily to the asphalt cement with thrilling for thirty minutes with the aid of a mechanical blender until homogenous blend was accomplished.

2.5. Preparation of Reclaimed and Recycled Mixtures Specimens

The reclaimed material was heated to 150° C, and the Marshall specimens were prepared for further testing to explore the performance after recycling. The recycled mixture consists of 100% of RAP and rejuvenator (recycling agent) blended at specified percentages depending on the mixing ratio. RAP was heated to 160°C and the recycling agent was heated to 120°C individually before it was added. The rejuvenator was added as a percentage of asphalt content and mixed for two minutes with the RAP until all mixture was visually covered with recycling agent as addressed by Sarsam,[5]. The recycled mixture was prepared using two types of recycling agents, (asphalt cement mixed with carbon black) and (asphalt cement mixed with SBR). The first type of specimens prepared were standard Marshall specimen of cylinder-shape with 102 mm diameter and 63.5 mm height according to ASTM, [12]. The temperature of mixture directly prior to compaction was (150°C). Specimens of reclaimed mixture before recycling were also prepared for comparison. Figure 2 Shows the furnace implemented for ignition test, while Figure 3 exhibit part of the prepared specimens. The second type of specimens prepared has 102 mm diameter and 102 mm height, such specimens have been constructed under static compaction to the same target density of the Marshall specimen using the same compaction temperature. The mixture was initially compacted at temperature of (150 °C) under an initial load of one MPa to set the mixture against the sides of the mold. After that, the required load of 20 MPa was applied for two minutes to achieve the target density. The specimens in the mold were left to cool at room temperature for 24 hours, then were removed from the mold using mechanical jack. Specimens of reclaimed asphalt concrete before recycling were also prepared for comparison. A total of 54 specimens with 102 mm in diameter and 102 mm in height were prepared for repeated compressive stress test. 27 specimens were tested before healing while 27 specimens were tested after healing.

For repeated punching stress test, a total number of 18 specimen with 102 mm in diameter and 63.5 mm in height were prepared, 9 specimens were tested before healing while the other nine specimens were tested after healing.

For repeated indirect tensile stress test, a total number of 18 specimen with 102 mm in diameter and 63.5 mm in height were prepared, 9 specimens were tested before healing while the other nine specimens were tested after healing. All the specimens were tested in triplicate and the average value was considered for analysis.

Figure 2. The ignition furnace

Figure 3. Part of the Prepared Specimens

2.6. Repeated (Tensile, Shear and Compressive) Stresses Test

Specimens have practiced the repeated indirect tensile stresses using the Pneumatic Repeated Load System PRLS apparatus. In this test, the specimen is conditioned at room temperature of 40 °C for two hours, and then the specimen is fixed on the vertical diametrical level between the two parallel loading bands (12.7 mm) in wide, then the repeated indirect tensile stresses are applied. The test was performed as per ASTM,[12] procedure. Such load assembly applies stress on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes with a stress level of 0.138 MPa. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period is applied over the test duration. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The test was continued for 1000 stress application repetitions, upon completion of test, the recording was terminated. The repeated double punch shear stresses test is used to evaluate the shear resistance of the mixture. This test was implemented through many studies, Sarsam and Saleem,[4]; Sarsam,[5]; Sarsam and AL-Janabi,[6] and Sarsam and AL-Zubaidi, [8]. In this test, specimens were conditioned at 40°C for two hours. The test was implemented by fixing the faces of the specimen between two punchers of (2.54cm in diameter). The test starts by centrally loading the cylindrical specimen, by means of two cylindrical steel punchers seated on the top and bottom of the specimen, the punchers are perfectly allied one above the other, then the repeated punching shear stresses are applied. Such load assembly applies shear stress on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes with a stress level of 0.138 MPa. Similar load repetition scheme to the repeated tensile stress was implemented. The repeated compressive stresses test was conducted according to ASTM, [12]. Repeated Compressive stress loading is applied on the specimen which is centered on the vertical plane. Such load assembly applies compressive stresses on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. Similar load repetition scheme to the repeated tensile and shear stress was implemented. Figure 4 demonstrates the repeated tensile, shear and compressive stress test assembly.

2.7. Microcrack Healing Technique

Microcrack Healing technique adopted in this work was the healing by the external heating. After practicing 1000 load repetitions, to allow for the initiation of microcracks, 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 microcrack healing as

recommended by Sarsam and Saleem,[4]; Sarsam and Mahdi, [13] and Sarsam and Saleem,[14]. Healing can take place in the asphalt concrete specimens due to the reduction in the viscosity of asphalt cement due to external heating. The expected melting and expansion of volume of the binder may fill part of the microcracks in the specimen. The specimens were cooled at room temperature for 24 hours, then conditioned by placing in the PRLS chamber at temperature (40°C) for 120 minutes, then the specimens were subjected to another 1000 load repetitions of tensile, shear or compressive stresses.

Figure 4. Testing technique of the prepared specimens in the PRLS

3. Results and Discussions

3.1. Influence of Recycling and Healing on Permanent Deformation Under Repeated Compressive Stresses

Figure 5 exhibit the permanent deformation accumulation of reclaimed and recycled asphalt concrete specimens under three levels of repeated compressive stresses of (0.068, 0.138, and 0.206) MPa. It can be observed that the permanent deformation increases after the recycling process of the reclaimed asphalt concrete. This may be attributed to the added flexibility and reduced viscosity of the reclaimed binder after its digestion with the rejuvenators. On the other hand, (SBR-asphalt) rejuvenator exhibits more flexibility and higher deformation regardless of the stress applied as compared with the reclaimed or (carbon black-asphalt) recycled mixture. This may be attributed to the added flexibility to the mixture by the addition of (SBR-asphalt) as well as to proper homogeneity of the obtained mixture. The first deformation parameter is the intercept which represents the permanent microstrain after the load cycle. The higher value of the intercept indicates larger strain and potential of permanent deformation. It can be noted that the intercept increases as the stress level application increase. However, it can be observed that recycling process increases the intercept which indicate more flexibility gained as compared to the reclaimed mixture.

Figure 5. Deformation of asphalt concrete specimens under repeated compressive stresses before healing

On the other hand, the second permanent deformation parameter is the slope, which represents the rate of change in the permanent microstrain as a function of the change in loading cycles. Higher slope value of the specimen indicates an increase in materials rate of deformation; hence, it focuses on its lesser resistance against rutting. It can be noted that recycling process has almost increases the slope due to reduced viscosity of the binder. Similar behavior was reported by Sarsam and AL-Janabi,[6]. Figure 6 exhibit the impact of healing cycle after (1000) load repetitions of compressive stresses (0.068, 0.138, and 0.206) MPa on permanent deformation.

Figure 6. Deformation of asphalt concrete specimens under repeated compressive stresses after healing

It can be noted that the microstrain after the healing cycle decline. The deformation declines by (31.8, 5.8 and 19)%, (43, 49 and 24) % and (44, 10 and 13) % under three level of compressive stresses (0.068, 0.138, and 0.206) MPa at (40 °C) after healing cycle for reclaimed and recycled mixture with (carbon black-asphalt and SBR-asphalt) respectively when compared with deformation before the healing cycle. This may be attributed to the stiffer mixture obtained after healing period due to the loss of more volatiles. The influence of (carbon black-asphalt) rejuvenator on microstrain is significantly higher and visible when compared with the reclaimed and (SBR-asphalt rejuvenator). Such behavior agrees with Sarsam and Jasim [15].

3.2. Influence of Recycling and Healing on Permanent Deformation Under Repeated Punching Shear Stresses

Figure 7 exhibit the impact of possible microcrack healing on the deformation behavior of recycled asphalt concrete under repeated punching shear stress. It can be noted that the deformation decreases after microcrack healing by (32, 26 and 25.7) % for reclaimed, recycled with (carbon black-asphalt) and recycled with (SBR-asphalt) mixtures respectively which may be attributed to the stiffer binder condition after healing. It can be observed that the intercept increases after recycling and before healing process. This indicates the added flexibility to the mixture after recycling. However, the intercept decreases, and the slope increases in general after microcrack healing. Such performance completely agrees with Sarsam and Jasim,[15]. It can be noted that the Permanent deformation after the recycling process increases by (490, and 910) % before healing, while

it decreases by (520 and 1046) % after healing for (carbon black-asphalt) and (SBR-asphalt) recycled mixtures respectively.

Figure 7. Deformation of asphalt concrete under repeated punching shear stresses

3.3. Influence of Recycling and Healing on Permanent Deformation Under Repeated Indirect Tensile Stresses

Figure 8 exhibit the variation in permanent deformation under repeated indirect tensile stresses due to microcrack healing. It can be noted that the deformation decreases by (73, 78.7 and 78.2) % for reclaimed, recycled with (carbon black-asphalt) and recycled with (SBR-asphalt) respectively after possible microcrack healing. This indicates the added flexibility to the mixture after recycling. This is further supported by the increased rate of deformation (slope).

Figure 8. Deformation of recycled asphalt concrete under repeated indirect tensile stresses

4. Conclusions

Based on the limitations of materials and testing program, the following conclusions can be drawn.

- The permanent deformation declines by (31.8, 5.8 and 19)%, (43 ,49 and 24)% and (44 ,10 and 13)% under three level of repeated compressive stresses of (0.068, 0.138, and 0.206) MPa at (40 °C) after the healing cycle for reclaimed and recycled mixtures with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with deformation before healing cycle.
- The permanent deformation under repeated punching shear stresses declines after microcrack healing by (32, 26 and 25.7) % for reclaimed, recycled with (carbon black-asphalt) and recycled with (SBR-asphalt) mixtures respectively.
- The deformation under repeated indirect tensile stresses declines by (73, 78.7 and 78.2) % for reclaimed, recycled with (carbon black-asphalt) and recycled with (SBR-asphalt) mixtures respectively after healing.
- After the microcrack healing process, specimens under repeated ITS exhibit more permanent deformation than those under repeated compressive or shear stresses.

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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