



Assessment of deformation, modulus, crack healing and shear properties of recycled asphalt concrete

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Article History

Received: 02 March 2019

Accepted: 17 April 2019

Published: May 2019

Citation

Saad Issa Sarsam, Mostafa Shaker Mahdi. Assessment of deformation, modulus, crack healing and shear properties of recycled asphalt concrete. *Indian Journal of Engineering*, 2019, 16, 167-176

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General Note



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ABSTRACT

Recycling is considered as a cost-effective solution to enhance the pavement for additional service life. Implementation of recycling agent can provide the required flexibility and increase its micro crack healing potential. In this investigation, aged asphalt concrete was recycled with two types of additives, carbon black CB and styrene Butadiene rubber SBR. Two set of cylindrical specimens have been prepared, the first set has 102 mm diameter and 63.5 mm height and subjected to repeated punching shear (PS) stresses at 25°C and tested under stress level of 0.138 MPa. The second set has 102 mm diameter and 102 mm height and practices repeated compressive stresses (CS) at 40°C and tested under three stress levels of (0.069, 0.138, and 0.207) MPa. All the specimens were

tested in the pneumatic repeated load system PRLS with constant loading frequency of 60 cycles per minute. The loading sequence for each cycle is 0.1 second of load duration and 0.9 second of rest period. After 1000 load repetitions, the test was terminated. Specimens were withdrawn from the PRLS and stored in an oven for 120 minutes at 60°C to allow for microcrack healing by external heating. Specimens were returned to the PRLS chamber and subjected to another cycle of stresses repetition. The impact of crack healing was measured in terms of the change in Resilient Modulus M_r and permanent deformation before and after healing for each recycling agent. It was concluded that M_r under repeated (PS) increases by (137, 135 and 60)% for aged, CB treated and SBR treated mixtures respectively after healing. The permanent deformation under repeated CS decreases by (31, 43, and 45) %, (6, 49, and 10.6), (19, 24.5, and 13.2) % for aged, CB treated and SBR treated mixtures under stress levels of (0.069, 0.138, and 0.207) MPa respectively after healing.

Keywords: Resilient modulus, Recycling, healing, punching shear, deformation, asphalt concrete

1. INTRODUCTION

Aging of the asphalt pavement changes the serviceability performance of the roadway due to the initiation of various distress. The quality of asphalt concrete will change from flexible to stiff or semi-rigid, and the pavement will be susceptible to all types of distresses. Asphalt concrete mixture is considered to have nonlinear viscoelastic behavior, its fatigue life consists of two components, namely the resistance to fracture and crack, and the ability to heal the micro cracks. Both processes change with temperature and time. Such processes exhibit the sustainability potential of asphalt concrete pavement, [1]. The comparison of properties of mixture with recycling agents, which has been prepared in laboratory on the RAP material, and their performance has been compared with virgin mixes by Pradyumna and Jain, [2]. 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 compared to virgin mixes. The effect of rejuvenation on hot in place recycling HIR performance was investigated by Sabhafer and Hossain, [3] by assessing critical performance indicators such as cracking resistance, moisture susceptibility, and low temperature cracking. An experimental program was designed that included mechanical property measurements of the HIR mixture by conducting Texas overlay, thermal stress restrained specimen, and moisture susceptibility tests. Study results showed significant variability in the mechanical performance of HIR mixtures, which was attributed to the variability of binders. Sarsam and Husain, [4] investigated the influence of healing cycles and asphalt content on resilient modulus of asphalt concrete. It was concluded that permanent deformation decreases as the healing cycles increase. M_r under indirect tensile stress (ITS) increases by (33.4, 100), 100, and (25, 150) % after one and two healing cycles respectively as compared with control mix for mixes with 4.4, 4.9, and 5.4% asphalt content. Valdés et al, [5] presented an experimental study to characterize the mechanical behavior of bituminous mixtures containing high rates of reclaimed asphalt pavement (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 and cracking and fatigue behavior. Results show that high rates of recycled material can generally be incorporated into bituminous mixes by proper characterization and handling of RAP stockpiles. Greater part of the academic and industrial establishments has been focused on the development of techniques to reuse HMA with up to 40% RAP content, a few industry innovators have superior 100% reusing advances in the recent four decades to a degree where routine production of 100% reused mixes is in clear vision, [6]. As stated by Al-Qadi et al., [7], after more than 30 years since its first trial in Nevada and Texas, it appears that the use of RAP will not only be a beneficial alternative in the future but will also become a necessity to ensure economic competitiveness of flexible pavement construction. 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 rheology by enhancing the viscous response, [8]. Mhlongo et al, [9] examines the use 100% reclaimed asphalt pavement (RAP) for sustainable construction and rehabilitation of roads. The recovered aggregates fall within the envelope for continuously graded mix and the recovered binder is 5.3%. The new hot mix asphalt was design with virgin softer bitumen grade 50/70 to act as rejuvenator at 0, 0.3% and 0.6% to RAP. Test such as fatigue resistance and workability were conducted. Fatigue resistance of the recycled mixtures increases as the bitumen content increases. It was concluded that the performance of 100% RAP in terms of air voids, stability and ITS at 5.9% binder will be a good material for road construction and rehabilitation. 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, [10]. It was concluded that RAP mixture can hold the applied loading with minimal permanent deformation as compared to the recycled mixtures.

The aim of this investigation is the Assessment of the influence of two types of recycling agents on the deformation under repeated compressive stresses, resilient modulus and shear strength under repeated punching stress, and the role of microcrack healing in the enhancement of the recycled asphalt concrete.

2. MATERIALS AND METHODS

Materials implemented in this research were locally available, and economically valuable. They could be categorized into three groups, aged materials, asphalt cement, and recycling agents.

2.1. Aged Materials

The (aged) Reclaimed asphalt mixture was obtained by the rubblization of the asphalt concrete binder course from highway section at the Second Hindiyah Bridge which is at Karbala province. This highway was constructed in 2012 by the Ministry of Construction and Housing. The main problem of this road is the uneven thickness of asphalt concrete layers at different locations along the section, as well as the deformation of this road due to high traffic loads. The Reclaimed asphalt mixture obtained was guaranteed to be free from damaging substances and loam that may be stick on the top surface. The reclaimed mixture was heated to 130° C, combined and reduced to testing size as per AASHTO [11]; a typical sample was exposed to Ignition test based on AASHTO T 308 [11] procedure to obtain binder and filler content, gradation and properties of aggregate. Table 1 illustrates the properties of aged materials as obtained after Ignition test.

Table 1 Properties of Aged Materials obtained after Ignition Test

Material	Property		Value
Asphalt binder	Binder content %		3.84
Aged Mixture	Marshall Properties	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 (RAP) are demonstrated in Table 2.

Table 2 Properties of Coarse and Fine Aggregates and Mineral Filler Extracted from RAP

Material	Property	Value
Coarse aggregate	Bulk specific gravity	2.62
	Apparent specific gravity	2.76
	Water absorption %	1.021
	Percent of Fracture 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

Two samples have been obtained arbitrarily from RAP mixture and exposed to Ignition test to separate binder from aggregate, then aggregate was sieved to several sizes to determine gradation. The variances between samples were in a slight degree, and the average gradation of the two samples is shown in Table 3. It can be observed that the gradation of aggregate is within the Specification limits of Roads and Bridges SCRB [12] for binder course.

Table 3 Gradation of Aggregate Obtained from Aged Mixture (RAP)

Standard sieves (mm)	(% Passing by Weight of Extracted Aggregate + Filler)	
	% passing by weight	Specification limit, SCRB, [12]
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. Recycling Agents

Two types of recycling agent have been selected and prepared in the laboratory based on the available literature and previous investigations, [13, 14, and 15] and implemented in this work. They are (asphalt cement mixed with carbon black) and (asphalt cement mixed with Styrene Butadiene Rubber). Three percentages of carbon black and SBR, (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 as rejuvenator and mixed with the aged asphalt concrete. Finally, 1.5 % of carbon black and SBR has been selected to be mixed individually with 1% of asphalt cement and implemented as recycling agent. Such details can be found in [15]. Table 4 shows the properties of carbon black, while Table 5 present the properties of SBR as supplied by the manufacturer.

Table 4 Properties of Carbon Black as supplied by the manufacturer

Property	ASTM [16]	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

2.3. Asphalt Cement

Asphalt cement of penetration grade (40-50) obtained from Al-Dura refinery was implemented for the recycling process. Asphalt cement testing confirmed that its properties mostly conform to the specifications of State commission for Roads and Bridges SCRB [12]. Its physical properties are listed in Table 6.

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

Table 6 Physical properties of the prepared Rejuvenators

Physical properties	ASTM Designation, [16]	Asphalt cement	(SCRB, 2003), [12]
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. Blending of Asphalt Cement with Carbon Black and Styrene Butadiene Rubber SBR

Asphalt cement of penetration grade (40-50) from Al-Dura refinery was mixed with 1.5% of carbon black (by weight of added asphalt) which was obtained from local market in powder form. Carbon blacks have particle diameters in the range of (100 to 500) nanometers and surface areas of (15 to over 100) m²/g. Asphalt cement was heated to approximately 130°C, and the carbon black was added steadily to the asphalt cement with thrilling until homogenous blend was accomplished. The mixing and thrilling were sustained for thirty minutes by a mechanical blender. On the other hand, Asphalt cement of penetration grade (40-50) from Al-Dura refinery was mixed with 1.5% of SBR (by weight of added asphalt) which was obtained from local market in liquid form. Asphalt cement was heated to approximately 130°C, and the SBR was added steadily to the asphalt cement with thrilling until homogenous blend was accomplished, the mixing and thrilling were sustained for thirty minutes by a mechanical blender.

2.5. Experimental Program

The experimental program consists of preparation of recycled asphalt concrete specimens with various rejuvenator percentages using the Marshall method and selection of the optimum percentage of each rejuvenator type based on the Volumetric properties. Details of the properties of the recycling agents were published elsewhere, [15].

2.6. Preparation of Aged and recycled Mixtures and specimens

The laboratory size Aged mixture which was obtained from the reclaimed material from the site was heated to 150°C. The Marshall specimens were prepared for further testing to explore the performance after recycling. Recycled mixture consists of 100% RAP and rejuvenator (recycling agent) blended together 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 to the heated RAP. The rejuvenator was added as a percentage of asphalt content and mixed for two minutes till all mixture was visually covered with recycling agent as addressed by Sarsam and Saleem, [14]. The recycled mixture was prepared using two types of recycling agents, asphalt cement mixed with carbon black and asphalt cement mixed with SBR. Two types of specimens have been prepared, the first type is a standard Marshall specimen of 102 mm in diameter and 63.5 mm in height. Marshall mold, spatula, and compaction hammer were heated on a hot plate to a temperature of 130 °C. A piece of non-absorbent paper, cut to dimension, was inserted in the bottom of the mold. The asphalt mixture was placed in the preheated mold, and then it was spaded with a heated spatula 15 times round the perimeter and 10 times round the inner. Then another piece of non-absorbent paper added on the top of the mix. The temperature of mixture directly prior to compaction temperature was (150°C). The mold assemblage was fixed on the compaction pedestal and (75) blows on the top and the bottom of specimen were applied with identified Marshall Compaction hammer. The specimen in the mold was left to cool at room temperature for one day, then it was removed from the mold using automatic jack. The second type of specimens has 102 mm diameter and 102 mm height, specimens were constructed under static compaction to the same target density of the Marshall specimen using the same compaction temperature. The mixture was 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. The specimens in the mold were left to cool at room temperature for one day, then were removed from the mold using mechanical jack. Specimens of aged asphalt concrete before recycling were also prepared for comparison. Fig.1 exhibit part of the prepared specimens.

2.7. Repeated Double Punch Shear Test

This test is used to evaluate the shear resistance of the mixture. This test was implemented through many studies, [10, 17 - 19]. In this test, the Marshall specimen was used; it was conditioned at 25°C for two hours. The test was implemented by centrally loading of the cylindrical specimen, by means of two cylindrical steel punches seated on the top and bottom of the specimen, the specimen was fixed between the two punchers (2.54cm in diameter), perfectly allied one above the other, then subjected to repeated punching shear stress. 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. A heavier sine pulse of (0.1) sec load duration and (0.9)

sec rest period was 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 load repetitions, upon completion of test, the recording was terminated. Specimens were withdrawn from the PRLS and stored in an oven for 120 minutes at 60°C to allow the crack healing process by external heating. Specimens were returned to the PRLS chamber and subjected to another 1000 load repetitions, the deformation was monitored by digital camera throughout the test. The average of two specimens was calculated and considered for analysis as recommended by Sarsam and AL-Zubaidi, [18]. Fig. 2 shows the geometry of the specimen for the double punch test. Specimens were tested for punching shear strength before and after the healing process.

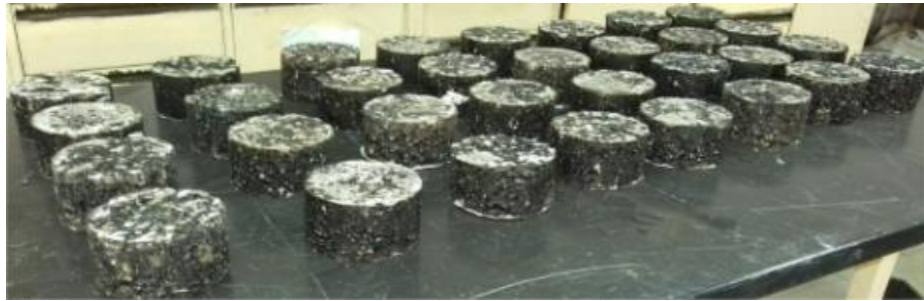


Figure 1 Part of the Prepared Specimens



Figure 2 Testing technique of the prepared specimens

2.8. Repeated Compressive Stress Test

The test was conducted according to ASTM, [16]. The Pneumatic repeated load system (PRLS) shown in Fig.2 was implemented. Repeated Compressive stress loading was applied on the specimen which was centered on the vertical plane. Such load assembly applies compressive stress on the specimen in the form of rectangular wave with constant loading frequency of (60) cycles per minutes. A heavier sine pulse of (0.1) sec load duration and (0.9) sec rest period was applied over the test duration. Before the test, Specimens were stored in the chamber of the testing machine at room temperature $40 \pm 1^\circ\text{C}$, dial gage of the deformation reading was set to zero before test start and the pressure actuator was adjusted to the specific stress level. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The test was continued for 1000 load repetitions, upon completion of test, the recording was terminated. Specimens were withdrawn from the PRLS and stored in an oven for 120 minutes at 60°C to allow the crack healing process by external heating. Specimens were returned to the PRLS chamber, conditioned for 60 minutes at $40 \pm 1^\circ\text{C}$ and subjected to another 1000 load repetitions, the deformation was monitored by digital camera throughout the test. The average of two specimens was calculated and considered for analysis as recommended by Sarsam and AL-Shujairy, [19]. Fig. 2 demonstrates the repeated compressive stress test assembly. Specimens were tested for compressive strength before and after the healing process.

3. RESULTS AND DISCUSSIONS

3.1. Assessment of Resilient Modulus (M_r) of Recycled Asphalt Concrete

The resilient modulus M_r was assessed using two testing techniques by implication of repeated (punching shear at 25°C and compressive stresses application at 40°C) using the pneumatic repeated load system PRLS. Variation of M_r could be observed among different testing techniques and testing temperatures for various asphalt concrete mixtures. The variation of M_r under testing techniques may be attributed to the size of the specimen and the loading sequence as well as the testing temperature. Fig. 3 exhibit the variation in resilient modulus among testing technique and mixture type. It can be noted that the (M_r) increased after the healing cycle regardless of the testing technique or recycling process. The resilient modulus increased by (137, 135 and 60)% after one healing cycle for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with (M_r) before (healing cycle) when punching shear is considered. On the other hand, and when repeated compressive stress is considered, It can be noted that the resilient modulus after the healing cycle increased by (20 ,18 and 5)% ,(16 ,12 and 23 %) and (10,13 and 5 %) under three level of compressive stresses (0.068,0.138, and 0.206) MPa at (40 °C) after one healing cycle for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with resilient modulus before (healing cycle). This could be attributed to the more stiffness added for the specimens after healing cycle. The stress level exhibit negative influence on resilient modulus while recycling demonstrates lower (M_r) as compared to the aged mixture regardless of the testing technique and testing temperature.

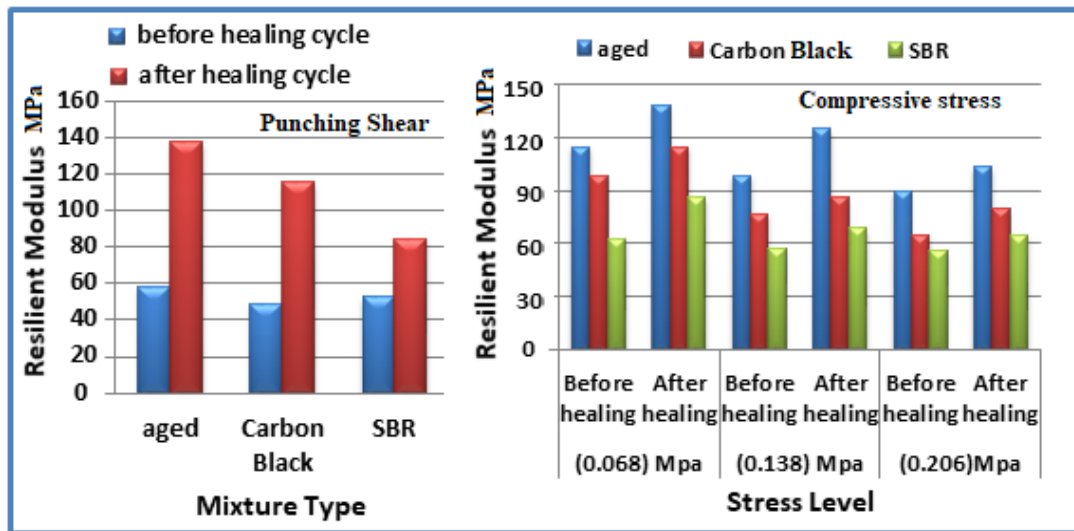


Figure 3 Impact of Recycling and Healing on Resilient Modulus under Repeated Loading

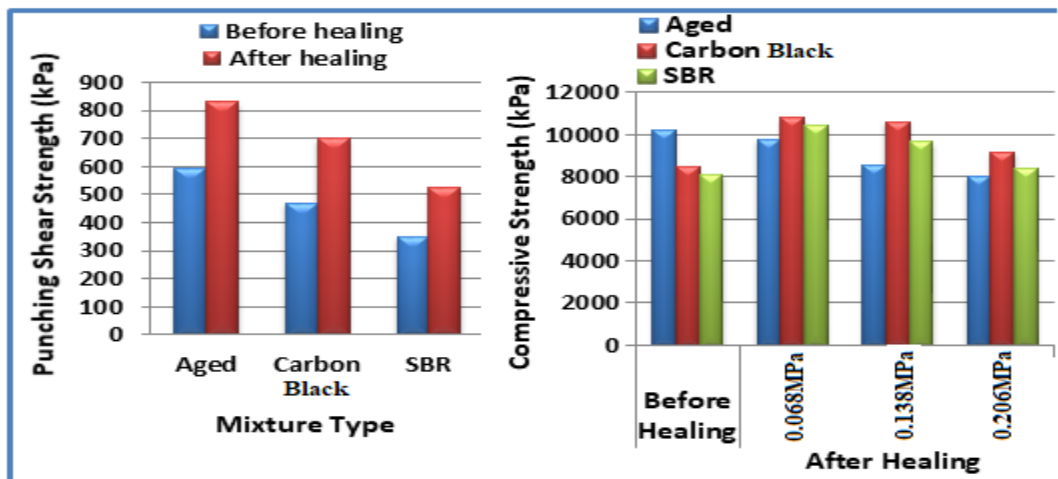


Figure 4 Influence of crack healing on strength properties of recycled mixtures

3.2. Effect of Crack healing on shear and compressive strength

Fig.4 demonstrates the influence of crack healing on strength properties of recycled mixtures after it was subjected to repeated loading. It can be identified that punching shear strength increases by (39 ,49 and 49) % for samples with the aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) rejuvenators respectively, when it was tested after the (micro crack healing cycle)and subjected to second round of repeated loading when compared to the controller specimens that tested before load repetitions. It can be noted that the aged mixture exhibits higher shear strength than recycled mixture. That maybe attributed to the additional flexibility gained by asphalt concrete after digestion with recycling agents.

For specimens exposed to repeated compressive strength at different level of stresses (0.068, 0.138, and 0.206) MPa, then exposed to crack healing cycle, after that the same samples experienced second round of load repetition, it can be detected that compressive strength decreases after healing cycle by (4 ,19 , and 21) % at level of stresses (0.068,0.138, and 0.206) MPa respectively for aged mixture when compared to the controller samples tested before healing cycle. This may be attributed to the increased stiffness of the specimens due to more loss of volatiles. However, the compressive strength increases after healing by (26, 25 and 7)% and (27,17 and 0.6) % at level of stresses (0.068,0.138,0.206) MPa for mixture recycled with (carbon black-asphalt) and (SBR-asphalt) rejuvenator respectively when compared to the controller samples tested before healing cycle. This may be attributed to the fact that stiffness increased for the specimens after healing for recycled mixture with (carbon black-asphalt) and (SBR-asphalt) rejuvenators.It can be noted that when increasing the level of stress, the compressive strength decreased for aged and recycled mixtures after healing.

3.3. Influence of Recycling and Crack Healing on Permanent deformation

Table 7 exhibits the impact of healing cycle technique under punching shear stress of (0.138) MPa at (25 °C) on Permanent deformation. It can be noted that the Permanent deformation after the healing decreased by (56.3, 40.7, and 70.2)% after one healing cycle for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with Permanent deformation before healing cycle. This maybe attributed to the stiffening of binder during the healing period. On the other hand, the permanent deformation was increased after recycling by (490 and 787) % and (700 and 300) % before and after healing after recycled with (carbon black-asphalt) and (SBR-asphalt) respectively as compared to aged mixture. This could be attributed to more viscosity added for the mixture after recycling.

Table 7 Permanent Deformation Parameters under Repeated Punching Shear Stress

Mixture type	Deformation Parameters before healing			Deformation Parameters after healing		
	Intercept microstrain	slope	Permanent microstrain @1000 cycles	Intercept microstrain	slope	Permanent microstrain @1000 cycles
Aged	135.35	0.296	1000	39.209	0.362	437.5
Carbon Black	169.14	0.815	5900	142.38	0.137	3500
SBR	346.75	0.423	5875	384.71	0.230	1750

It can be observed that the intercept increases after recycling before and after healing process. This indicates the added flexibility to the mixture after recycling. However, the intercept decreases, and the slope increases in general after crack healing. The intercept represents the permanent strain at N=1. (N is the number of load cycles), the higher the value of the intercept, the larger is the strain and the potential of permanent deformation. On the other hand, the second parameter is the slope which represents the rate of change in the permanent strain as a function of the change in loading cycles (N) in the log-log scale. High slope value of the mix indicates an increase in material deformation rate, hence, less resistance against rutting. It can be observed that recycling process has almost increases the slope due to reduced viscosity of the binder. Table 8 exhibit the permanent deformation of aged and recycled asphalt concrete under three levels of repeated compressive stresses. It can be observed that the deformation increases after recycling the aged asphalt concrete. This could be attributed to the added flexibility and reduced viscosity of the aged binder after digestion with the rejuvenators. On the other hand, carbon black-asphalt rejuvenator exhibits more flexibility and higher deformation regardless of the stress applied as compared with aged or SBR-asphalt recycled mixture. Table 9 exhibit the influence of recycling on the permanent deformation parameters. It can be observed that the intercept increases as the stress level application increase. It can be noted that recycling process has increases the intercept indicating more flexibility gained as compared to the

aged mixture. It can be noted that recycling process has almost increases the slope due to reduced viscosity of the binder. Such performance completely agrees with Sarsam and Jasim, [13] and Sarsam and AL-Shujairy, [19].

Table 8 Permanent Microstrain After 1000 Loading cycles of Compressive stress

Mixture Type	Stress Level (MPa)		
	0.068	0.138	0.206
Aged	8800	10300	14400
Recycled with Carbon black	14600	25400	25800
Recycled with SBR	9200	13100	15200

Table 9 Influence of Stress Level on Permanent Deformation Parameters

Stress level MPa	0.068		0.138		0.206	
Deformation parameter	Intercept	Slope	Intercept	Slope	Intercept	Slope
Mixture Type						
aged	277.31	0.4966	556.73	0.4227	648.9	0.4218
Carbon black	199.98	0.6152	466.95	0.5655	828.64	0.5036
SBR	402.29	0.4304	614.26	0.407	1669	0.3159

4. CONCLUSIONS

Based on the limitation of the testing program, the following conclusions can be drawn

1. The resilient modulus increased by (137, 135 and 60)% after healing cycle for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with (Mr) before healing under punching shear stress.
2. The resilient modulus after the healing cycle increased by (20 ,18 and 5)% ,(16 ,12 and 23)% and (10,13 and 5)% under three levels of compressive stresses (0.068, 0.138, and 0.206) MPa for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively when compared with (Mr) before healing.
3. The stress level exhibit negative influence on resilient modulus while recycling demonstrates lower (Mr) as compared to the aged mixture regardless of the testing technique and testing temperature.
4. Punching shear strength increases by (39 ,49 and 49) % while compressive strength decreases after healing cycle by (4 ,19, and 21) % and increases by (26, 25 and 7) % and (27, 17 and 0.6) % at level of stresses (0.068, 0.138, and 0.206) MPa respectively for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) rejuvenators respectively when it was tested after micro crack healing.
5. Permanent deformation after the healing decreased by (56.3, 40.7, and 70.2) % for aged and recycled mixture with (carbon black-asphalt) and (SBR-asphalt) respectively, while increased after recycling by (490 and 787) % and (700 and 300) % before and after healing after recycled with (carbon black-asphalt) and (SBR-asphalt) respectively as compared to aged mixture.
6. The deformation increases after recycling, carbon black-asphalt rejuvenator exhibits more flexibility and higher deformation regardless of the stress applied as compared with aged or SBR-asphalt recycled mixture.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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