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Assessment of the Crack Healing for Recycled Asphalt Concrete

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Abstract

Recycling of asphalt concrete for pavement construction is considered as a sustainable issue. The load repetition practiced by the pavement causes an initiation of micro cracks, while the self-healing phenomena of cracking can extend the service life of the pavement. In this investigation, aged asphalt concrete was obtained from the field and digested with carbon black and Styrene Butadiene Rubber (SBR) as recycling agents. Specimens of 102 mm diameter and 63.5 mm height of aged and recycled mixtures were prepared and compacted using Marshal method at 150°C. Specimens were subjected to repeated indirect tensile stresses ITS for 1000 load repetition through a heavier sine pulse of (0.1 sec. load duration and 0.9 sec. rest period) and constant stress level of 0.138 MPa with loading frequency of (60) cycles per minutes. Specimens were allowed to heal by external heating for 120 minutes under 60°C, then subjected to another 1000 ITS load repetition cycle. Dial gages and video capture have been used to monitor the deformation of the specimen under each load cycle. Then, the recorded data was analyzed for finding resilient modulus (Mr) and permanent strain. It was concluded that permanent deformation declines by (4, 4.7 and 20)% for aged and recycled mixtures with carbon black and SBR respectively after healing. The (Mr) at 25°C increases by (25, 30, and 20.5)% and (7.7, 5.8 and 5)% for (unconditioned and conditioned) aged and recycled mixtures with carbon black and SBR respectively after healing as compared with the similar mixture before healing.

Keywords

Crack Healing, Recycling, Asphalt Concrete, Tensile, Repeated Load, Resilient Modulus, Deformation

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1. Introduction

Recycling of aged asphalt concrete pavement could reserve the flexibility of the mixture and extend the life of the pavement for many years. The pavement will sustain the load repetitions and experience microcracking. Recycling agents can support the self-healing of micro cracks. Sarsam and Saleem, [1] studied the indirect tensile strength ITS for aged and recycled pavement with two types of recycling agents and concluded that the Indirect tensile strength at 25°C, 40°C and 60°C revealed low value for recycled mixtures when compared to aged mixture. The percent reduction in (ITS) value at 25°C was (11.1 and 21.5)% and at 40°C was (12.3 and 19.6)% and at 60°C was (20.2 and 10.9)% for recycled mixtures with cutback and emulsion respectively. Pradyumna and Jain [2] describes 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. Various performance tests such as Retained Stability, Indirect Tensile Strength (ITS) and Tensile Strength Ratio (TSR), 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 recycled asphalt pavement (RAP) and recycling agent provide better performance compared to virgin mixes. studied the influence of different RAP preparation procedures, prior to the production of a recycled asphalt mixture, on the success of the manufacturing process was investigated by

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Oliveira et al, [3]. A 50% recycling ratio was used in order to test if a high level of RAP incorporation could be achieved by an adequate control of the production process. It was concluded that when an adequate size reduction and separation procedure is used, mixtures with better quality can be obtained since the mix design specifications can be achieved more easily and the binder of the final mixture is less aged by the high temperatures. The dynamic behavior of the recycled asphalt concrete (with cutback and emulsion) in terms of the resilient modulus (Mr), rutting resistance, and permanent microstrain have been investigated has been studied 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. The resilient modulus is lower by (24 and 39)% for mixes recycled with cutback and emulsion respectively as compared to that of RAP. The rate of strain (slope) increases by 11% and 4% when cutback and emulsion were implemented as a recycling agent respectively as compared to that for RAP mixture. Abu El-Maaty and Elmohr, [5] investigated the use of a homogeneity reclaimed asphalt pavement in the pavement industry and evaluated the effects of partial and total replacements of aggregates by RAP on the mechanical and durability performance of dense-graded HMA mixtures. The performance of RAP mixtures was evaluated through a series of laboratory tests including Marshall test, indirect tensile strength test, granule adhesion test and material test systems. A series of binder mixes containing varying percentages of RAP were designed and subjected to different moisture conditioning periods (1, 3 and 7 days) to investigate the moisture damage effect on RAP mixtures. The laboratory results indicated that when properly designed, the asphalt mixes with RAP especially at 50 to 100% replacement ratio provided better performance compared to those of new conventional HMA mixtures where they improved the mechanical properties, durability performance and also stripping resistance. El-Hmrawey et al, [6] studied the physical properties of RAP and their influence on the durability performance of a binder asphalt pavement mix. A series of binder mixes containing varying percentages of RAP were designed and subjected to different moisture conditioning periods to investigate the moisture damage effect on RAP mixtures. A mix made from only virgin material was selected as the control mix. The effect of RAP on the durability of binder course mix was evaluated through a series of laboratory tests including Marshall test, indirect tensile strength test and the water sensitivity tests where many moisture damage indicators were obtained such as retained Marshall stability, Marshall quotient, durability index, tensile strength ratio, resilient modulus ratio and energy loss ratio. The results indicated that the additional of RAP especially at 50% content was beneficial in improving the durability performance and reducing the moisture susceptibility of the hot mix asphalt mixtures. The asphalt concrete usually had self-healing competence during appropriate breaks or heating. The self-healing competence is associated with viscosity of asphalt cement, which decreases with increasing temperature, healing time and when the crack is small, [7] and [8]. For increased recycling of waste asphalt concrete, Jang et al, [9] evaluated the stability and durability performance of cold-recycled asphalt that used cementless binders and polymers. For cementless binders, the study used powder added with 80% ground granulated blast furnace slag (BFS) and fly ash, with the optimal mixture ratio derived from prior experiments. It was concluded that as the addition of polymers increased, Marshall stability increased but the flow values decreased. Abrasion resistance and dynamic stability (DS) were superior for specimens that used cementless binders and polymers than for those that used OPC. Mazzoni et al, [10] stated that 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 HMA. Sarsam, [11] stated that the 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. Sabhafer, and Hossain, [12] investigated the effects of rejuvenation on hot in place recycling performance 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 mixture by conducting thermal stress restrained specimen, and moisture susceptibility tests. Study results showed significant variability in the mechanical performance of mixtures, which was attributed to the variability of binders. Sarsam, [13] studied recycling of asphalt concrete and concluded that aging increases Hveem cohesion, but it has negative effects on Marshall, tensile, and flexural properties. Recycling has a positive effect on Asphalt concrete overall properties and have changed the mode of deflection from cracking to bending. The variation in gradation has also significant effects on both aged and recycled conditions of Asphalt concrete. The aim of this work is to study the crack healing process in recycled asphalt concrete mixture after implementation of carbon black and SBR as recycling agents. Specimens will be subjected to moisture damage and will be tested under repeated indirect tensile stress.

2. Materials and Methods

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

2.1. Aged Asphalt Concrete Mixture

The aged asphalt concrete mixture was obtained by the rubblization of the asphalt concrete binder course layer from highway section at Karbala province. This highway was constructed in 2012 and suffers the deformation due to high traffic loads. The aged asphalt mixture obtained was free from dust and loam that may be stick on the top surface. The aged mixture was heated to 130° C, combined and reduced to testing size as per American association of state highway and transportation officials AASHTO [14]; a representative sample was exposed to Ignition test based on AASHTO T 308 [14] procedure to obtain binder and filler content, gradation and properties of aggregate. Table 1 illustrates the properties of aged mixture.

Table 1. Properties of Aged Mixture Obtained after Ignition Test.

Material	Property		Value
Asphalt binder	Binder content%		3.84
		Stability	17.532 KN
		flow	2.9 mm
Aged Mixture	Marshall Properties	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 aged asphalt concrete mixture are demonstrated in Table 2.

Table 2. Properties of Coarse and Fine Aggregates and Mineral Filler Extracted from Aged Asphalt Concrete.

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

The gradation of the aged asphalt concrete mixture after ignition test is shown in Figure 1. It can be observed that the gradation of aggregate is within the Specification limits of Roads and Bridges SCRB [15] for binder course layer.

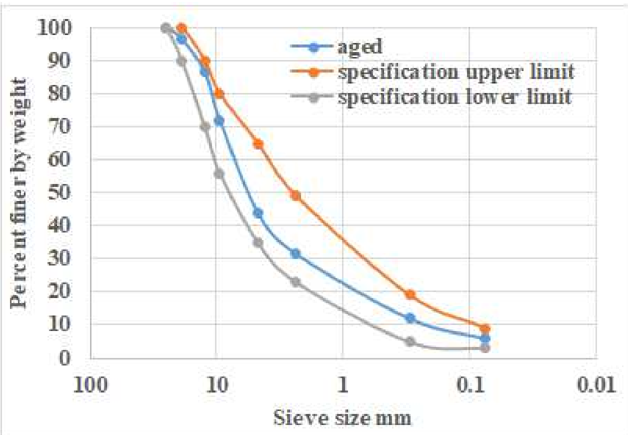

Figure 1. Gradation of aged asphalt concrete mixture.

2.2. Additives

Two types of additives namely carbon black and Styrene Butadiene Rubber (SBR) have been implemented in this work to prepare the recycling 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 aged asphalt concrete. Table 3 shows the properties of carbon black, while Table 4 present the properties of SBR as supplied by the manufacturer.

2.3. Recycling Agents

Two types of recycling agent have been selected and prepared in the laboratory based on the available literature and previous investigations, [4, 7] and [16-20] and implemented in this work. They are asphalt cement mixed with carbon black and asphalt cement mixed with Styrene Butadiene Rubber (SBR).

Table 3. Properties of Carbon Black.

Property	ASTM [21]	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
Particle diameters (nanometers)		120

Table 4. Properties of SBR.

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

2.4. 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 conform to the specifications of State commission for Roads and Bridges SCRB [15]. Its physical properties are listed in Table 5.

2.5. 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. Asphalt cement was heated to approximately 130°C, and the carbon black was added steadily to the asphalt cement and mixed until homogenous blend was accomplished. The mixing was 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. Table 5 exhibit the influence of rejuvenator on the physical properties of asphalt cement.

Table 5. Physical properties of Asphalt cement and the prepared Rejuvenators.

Physical Property	Test Conditions	ASTM [21] Designation	Binder type			SCRB [15]
			Asphalt cement	Asphalt +1.5% carbon black	Asphalt +1.5% SBR	
Penetration	25°C, 100gm, 5sec	D5-06	43	38	36	40-50
Softening Point	-	D36-95	46	50	52	-
Ductility	25°C, 5cm/min	D113-99	140	132	143	>100
Specific Gravity	25°C	D70	1.04			
Flash Point	Cleveland open cup	D92-05	269	281	315	>232
After Thin Film Oven Test D1754-97						
Retained Penetration of Residue	25°C, 100gm, 5sec	D5-06	57%	51	45	>55
Ductility of Residue	25°C, 5cm/min	D113-99	73 cm	62	53	>25
Loss on Weight	163°C, 50g, 5hours	-	0.32	0.27	0.22	-

2.6. Preparation of Recycled Asphalt Concrete Mixtures and Marshal Specimens

The Aged mixture which was obtained from the reclaimed material from the site, it was heated to 150°C. The Marshal specimens were prepared to explore the performance after recycling. Recycled mixture consists of 100% aged asphalt concrete and rejuvenator (recycling agent) blended together at specified percentages depending on the mixing ratio. Aged asphalt concrete was heated to 160°C while the recycling agent was heated to 120°C before it was added to the aged mixture. The rejuvenator was added as a percentage of asphalt content and mixed for two minutes until all mixture was visually covered with recycling agent as addressed by Sarsam, [16]. The recycled mixture was prepared using two types of recycling agents, asphalt cement mixed with carbon black and asphalt cement mixed with SBR. A standard Marshal specimen of 102 mm in diameter and 63.5 mm in height was prepared. 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 Marshal 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. Specimens of aged asphalt concrete before recycling were also prepared for comparison.

2.7. Repeated Indirect Tensile Stress Test

Specimens were subjected to the repeated indirect tensile stresses according to the procedure of ASTM [21]. In this test, Marshall Specimens were used; the specimen was stored at room temperature of 25 °C for one day; then the specimen was fixed on the vertical diametrical level between the two parallel loading bands (12.7 mm) in wide. The specimen was fixed in the pneumatic repeated Load system apparatus (PRLS) shown in Figure 2. Asphalt concrete specimens were subjected to repeated indirect tensile stress for 1000 load repetitions at 25°C to allow the initiation of micro cracks. Such timing and test conditions were suggested by Sarsam and Saleem, [4] and Sarsam and Mahdi, [16]. Such load assembly applies indirect tensile 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, dial gage of the deformation reading was set to zero and the pressure actuator was adjusted to the specific stress level equal to 0.138 MPa. A digital video camera was fixed on the top surface of the (PRLS) to capture dial gage reading. The average deformation of duplicate specimens was calculated and considered for analysis.

2.8. Moisture Damage

This test was performed to assess the resistance to moisture damage of the mixtures; the test was conducted according to ASTM D4867 [21]. A group of six specimens were arranged, three specimens were tested for indirect tensile strength by storage in a water bath at 25 °C for half an hour; the average value of ITS for these specimens was calculated (ITS for un-conditioned specimens). The additional three specimens were conditioned through placing in volumetric container (4000-ml) heavyweight- wall glass full of water at room temperature of 25°C, a vacuum of 3.74 kPa (28mm Hg) was applied for 10 min. to attain (55 to 80%) degree level of saturation. The specimens were retained in deep freeze at (-18°C) for (16 hours). Then the freezed specimens were placed into a water bath for (24 hours) at (60°C), After that they were retained in a water bath on 25°C for one hour. Finally, they were tested for indirect tensile strength. The average value of ITS was calculated (ITS for conditioned specimens).

2.9. Crack Healing Technique

Crack Healing technique adopted in this work was healing by the external heating. After 1000 load repetitions, to allow for the initiation of micro cracks, 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 crack healing as recommended by Sarsam and Saleem, [1], Sarsam and Saleem, [4], Sarsam and Mahdi, [16]. Healing occurred in the asphalt concrete mixture specimens due to the reduction in the viscosity of asphalt cement due to external heating. The specimens were cooled at room temperature for 24 hours, it was conditioned by placing in the PRLS chamber at temperature (25°C) for 120 minutes, then the specimens were subjected to another1000 load repetitions of indirect tensile stresses. After first and second cycles of load repetitions in PRLS device, and before and after healing process, part of the specimens were tested in versa tester to find the indirect tensile strength.

Figure 2. Repeated indirect tensile stress test in progress in the PRLS.

3. Results and Discussions

3.1. Healing Indicators

The healing of asphalt concrete is usually evaluated by the recovery of the material's mechanical properties, such as increment in tensile strength and resilient modulus, reduction in permanent deformation and rate of deformation which have been considered as healing indicators by Sarsam and Mahdi, [16], Sarsam and Saleem, [4]. The commonly used healing index is the ratio of the material strength or properties after healing to the original strength or properties. In this case, a higher ratio indicates a better healing performance. In this investigation, the healing index obtained from the recovery of strength, resilient modulus and reduction of deformation were used to measure the healing ability of asphalt concrete. Table 6 exhibit the influence of moisture damage on micro crack healing indicators of the aged and recycled asphalt concrete.

Table 6. Micro crack healing indicators in deformation of asphalt concrete.

Mixture type	Healing index (%)					
	Before moisture damage			After moisture damage		
	Permanent microstrain @1000 repetitions	Intercept	Slope	Permanent microstrain @1000 repetitions	Intercept	Slope
Aged	0.96	0.27	1.37	0.92	0.13	2.01
Recycled with carbon black	0.95	0.21	1.87	0.97	0.87	1.05
Recycled with SBR	0.80	0.21	1.57	0.96	0.10	2.69

3.2. Effect of Crack Healing on Permanent Deformation Under Repeated ITS

Specimens were subjected to repeated ITS and tested in the (PRLS). The test was stopped after (1000) load repetitions at level of stress (0.138 Mpa) to initiate microcracks for (unconditioned and conditioned) specimens. Specimens were stored into an oven for two hours at 60°C for crack healing process by external heating, after that the specimens were subjected to another cycle of repetitions of indirect tensile stresses of (0.138 Mpa). Figure 3 illustrates the influence of healing cycle on permanent deformation for recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) and for aged mixture. The figure demonstration exhibit that permanent strain declines after healing cycle for reclaimed and recycled mixture, the percent declines were (4, 4.7, and 20)% for unconditioned aged and recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) respectively. After practing moisture damage, the conditioned specimens exhibit declain in permanent deformation due to micro crack healing by (7.3, 2.5, and 3.7)% for aged and recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) respectively. This could be attributed to the fact that micro crack healing increase the stiffness of mixtures that lead to decrease permenant deformation. On the other hand, the moisture damage exhibit negative impact on permanent deformation. It increases microstrain by (172, 204, and 82.8)% and (162, 212, and 120)% for (aged and recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) respectively before and after micro crack healing. Similar findings were reported by Shunyashree et al, [18].

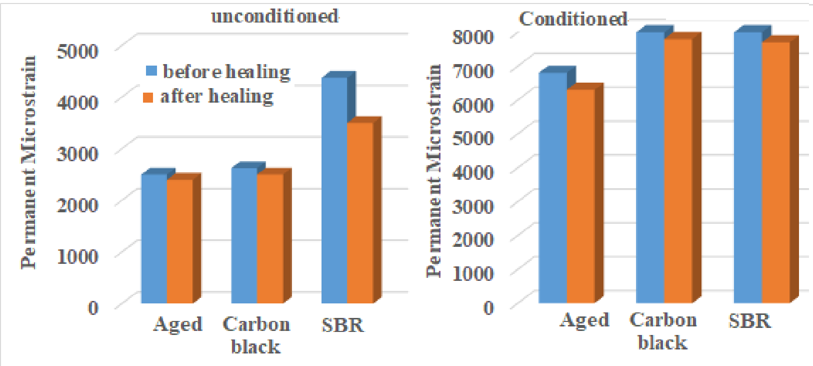

Figure 3. Impact of moisture damage on Permanent Microstrain before and after Healing Cycle.

3.3. Effect of Crack Healing on Resilient Modulus Under ITS

Table 7 demonstrates the healing indicators of resilient modulus of asphalt concrete after 1000 load repetitions, it can be observed that the healing before moisture damage was more pronounced when compared to that after moisture damage. This could be attributed to the possible stripping occurred after conditioning the specimens. Figure 4 illustrations the effect of the crack healing technique on (Mr) under ITS for aged and recycled mixture (unconditioned and conditioned) when subjected to repeated level of stress of (0.138 Mpa). The Mr increases after crack healing cycle for aged and recycled mixture. The proportion of increase was (25, 30.2, 20.5) % and (7.7, 5.8 and 5)% for (unconditioned and conditioned) aged and recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) respectively. This could be attributed as a result of the healing of the cracks in addition to the evaporation of more volatiles and thus increases the Resilient Modulus. Similar behavior was reported by Sarsam and Saleem, [4].

Table7. Healing indicator of Resilient Modulus under (ITS).

Mixture type	Healing index of Resilient Modulus	
	Before moisture damage	After moisture damage
Aged	1.25	1.08
Recycled with carbon black	1.29	1.06
Recycled with SBR	1.20	1.04

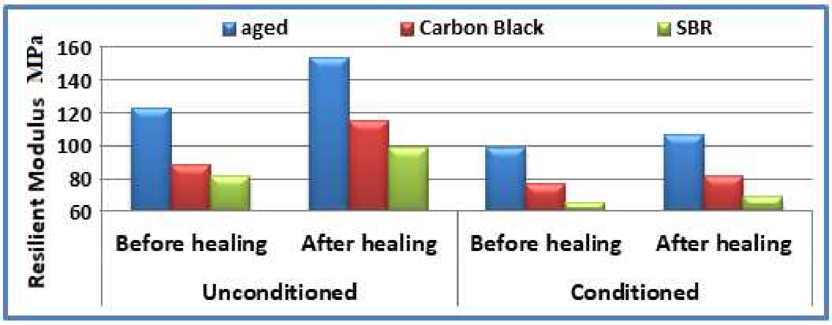

Figure 4. Resilient Modulus (Mr) before and after Healing Cycle Under (ITS).

3.4. Effect of Crack Healing on Indirect Tensile Strength

Specimens were subjected to indirect tensile strength determination before and after moisture damage and crack healing. Table 8 shows the healing indicator of ITS. It can be noticed that the influence of crack healing was more pronounced before the moisture damage process. Figure 5 exhibit the variation of ITS among moisture damage and crack healing. The variation of tensile strength was pronounced for un-conditioned and conditioned recycled mixture with (carbon black-asphalt and SBR-asphalt) rejuvenators and Reclaimed mixture respectively after it was exposed to repeated loading and healing cycle. It can be detected that Indirect tensile strength increases by (13.8, 18.6 and 22.5)% and (32.5, 28.6 and 27.3) for samples (un-conditioned and conditioned) with the Reclaimed 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 samples tested before (load repetitions). This may be attributed to the more stiffness added for the specimen after healing cycle and Healing cycle works to increase the aging of the specimens. On the other hand, stripping of asphalt film from the aggregates decreases the cohesion between aggregate particles which decreases the tensile strength. Such findings agree well with Sarsam and AL-Shujairy, [7].

Table 8. Healing indicator of (ITS).

Mixture type	Healing index of ITS	
	Before moisture damage	After moisture damage
Aged	1.13	1.37
Recycled with carbon black	1.13	1.25
Recycled with SBR	1.18	1.09

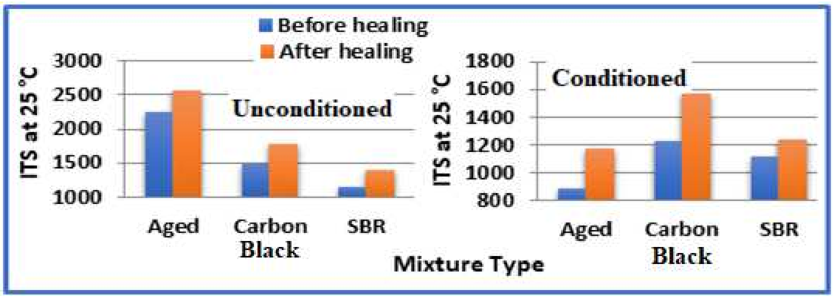

Figure 5. Indirect tensile strength of asphalt concrete.

4. Conclusions

The following conclusions could be drawn based on the testing program

1. The permanent deformation after (1000) load repetitions of (ITS) declines by (4, 4.7, and 20)% for aged and recycled mixtures with carbon black-asphalt and SBR-asphalt respectively after (one cycle of healing) when compared with the similar mixture before healing.
2. The moisture damage exhibit negative impact on permanent deformation. It increases microstrain by (172, 204, and 82.8)% and (162, 212, and 120)% for aged and recycled mixture with (carbon black-asphalt and SBR-asphalt rejuvenators) respectively before and after micro crack healing.
3. Mr after (1000) load repetitions of indirect tensile stress ITS at 25°C increases by (25, 30.2, and 20.5)% and (7.7,

5.8 and 5)% for (unconditioned and conditioned) aged and recycled mixtures with carbon black-asphalt and SBR-asphalt respectively after (one cycle of healing) when compared with the similar mixture before healing.

4. After healing cycle the indirect tensile strength (ITS) increases by (13.8, 18.6 and 22.5)% and (32.5, 28.6 and 27.3)% for samples (un-conditioned and conditioned) with the aged and recycled mixture with (carbon black-asphalt and SBR-asphalt) rejuvenators respectively.

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