Prospects of Using Liquid Asphalt as Rejuvenation Agent for Asphalt Pavement Recycling

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Abstract:

The trend nowadays is to reduce the consumption of energy and reserve natural resources. Using Reclaimed Asphalt Pavement (RAP) is considered as an economical and environmental friendly process. This work assesses the prospects of using liquid asphalt (cutback and emulsion) as rejuvenation agent for pavement recycling. Asphalt concrete mixture obtained from site as rubblized binder course was tested for its existing physical properties, then rejuvenated with medium curing cutback or cationic emulsion. Specimens have been prepared from the rejuvenated mixture and tested for Marshall Properties, temperature susceptibility, and moisture damage. Test results were compared with those of aged mixture. It was concluded that the temperature susceptibility decreases by (9 and 24) % for cutback and emulsion treated mixtures as compared to added mix. Marshall Stability decreases by (11 and 15.5) % while the tensile strength ratio increases by (23 and 28) % for cutback and emulsion treated mixtures as compared to added mix. The bulk density increases by (1.8 and 1.1) % while the total volume of voids decreases by (6.5 and 5.3) % for cutback and emulsion treated mixtures as compared to added mix. The indirect tensile strength at 25 ℃ is lower than that of aged mixture by (11 and 21.5) % for cutback and emulsion treated mixtures respectively.

Keywords:

Rejuvenation Agent, Reclaimed Asphalt Pavement, Recycling, Cutback, Emulsion

1. Introduction

In recent years, attitudes towards the environment have changed considerably and conservation of resources has become an extremely important issue, for this reason and because of the increased demand and limited aggregate and binder supply, Hot Mix Asphalt (HMA) producers have begun using reclaimed asphalt pavement (RAP) as a valuable component in HMA, [1,2]. As a result, there has been renewed interest in increasing the amount of RAP used in HMA, [3,4]. Experience and previous recycling processes made by many agencies, have indicated that the recycling of asphalt pavements is a very beneficial approach from technical, economic and environmental perspectives, [5,6,7]. Certain aspects should be considered in the choice of recycling agent, in addition to having the chemical composition required to restore the necessary components of the aged binder, a material must have a high flash point to insure safety in handling and shipping, be easy to disperse, have a low volatile loss during hot mixing, resist hardening, and be uniform from batch to batch to insure compatibility, [8, 9]. [6] Used a laboratory manufactured recycling agent consisted of 77% used oil with 22% reclaimed scrap tire rubber and 2% of detergent, and the amount of recycling agent was in the range of (1-2%) by weight of mixture. Used oil is also adopted in this study as a recycling agent, and the optimum percentage is experimentally found. Used oil was also adopted as a recycling agent by [10], who addressed that, using rejuvenator improves the performance of the totally recycled HMA mixtures (i.e., longer life cycle), and reduces the mixing temperature (i.e., lower energy consumption), also it is necessary to have an adequate workability, and the used engine oil is considered a good economic and environmental alternative, [11,12]. Another study for this concern is carried by [5]. Two type of recycling agents were used, soft grade asphalt and a chemical rejuvenating agent which is cationic emulsion composed of selected maltene and asphaltenes fractions derived from petroleum crude. It was concluded that the addition of soft grade bitumen alone did not produce any softening effect, and softening took place with the addition of recycling agent. [13] Used (Sulphur with asphalt) blend to rejuvenate the recycled mixtures. He prepared recycled mixtures with 100% RAP content. The Sulphur was used as a powder and various percentages of Sulphur/asphalt have been investigated in this study (0/100, 10/90, 20/80, 30/70, 40/60, 50/50). It was concluded that recycled mixes with Sulphur exhibit significantly better engineering properties than conventional mixtures, and a percentage of 20/80 Sulphur/asphalt showed the best comparative performance. [14] Evaluated the performance of asphalt concrete recycled mixtures using Marshall test, it was concluded that Significant improvement in Marshall stability was noticed for recycled mixtures properties comparing to aged mixture, the percent of improvement was (185%, 198%, 97%, 135%) for recycling agents (Soft Ac, Ac + Sulphur, Oil, Oil + Rubber) successively. [15] Studied indirect Tensile strength test on recycled mixture with different recycling agents (used oil, oil + crumb rubber, soft grade asphalt cement, and asphalt cement + Sulphur powder), Marshall specimens were used in this test, the specimens were conditioned in water bath for three different temperatures at 25 ℃, 40 ℃, and 60 ℃. the results show that ITS at 25 oC for recycled mixture with (Soft Asphalt) and mixing ratios of virgin/old materials (50/50) and (40/60) was higher than corresponding virgin mixture value.

2. Materials and Methods

The materials implemented in this investigation consist of reclaimed asphalt concrete (aged material), and Rejuvenation agents, which is medium curing cutback and cationic emulsion (liquid asphalt).

2.1. Aged Materials (Reclaimed Asphalt Pavement)

The reclaimed asphalt mixture was obtained by the rubblization of binder course layer of asphalt concrete of the highway in the province of Babylon. This highway was heavily deteriorated with various cracks and ruts existed on the surface. Reclaimed asphalt mixture obtained was assured to be free from deleterious substances and loam that gathered on the top surface. The reclaimed mixture was heated, combined and reduced to testing size as per AASHTO, [16]; a representative sample was subjected to Ignition test according to AASHTO T 308, [16] procedure to obtain binder and filler content, gradation and properties of aggregate.

Table 1. *Properties of Aged Materials after Ignition Test.*

<table>
<tr><th>Material</th><th colspan="2">Property</th><th>Value</th></tr>
<tr><td>Asphalt binder</td><td colspan="2">Binder content %</td><td>5.46</td></tr>
<tr><td rowspan="4">Coarse aggregate</td><td colspan="2">Bulk specific gravity</td><td>2.59</td></tr>
<tr><td colspan="2">Apparent specific gravity</td><td>2.63</td></tr>
<tr><td colspan="2">Water absorption %</td><td>1.071</td></tr>
<tr><td colspan="2">Wear% (Los Angeles abrasion)</td><td>23%</td></tr>
<tr><td rowspan="3">Fine aggregate</td><td colspan="2">Bulk specific gravity</td><td>2.601</td></tr>
<tr><td colspan="2">Apparent specific gravity</td><td>2.823</td></tr>
<tr><td colspan="2">Water absorption %</td><td>1.94</td></tr>
<tr><td rowspan="2">Mineral filler</td><td colspan="2">Percent passing sieve no.200</td><td>98%</td></tr>
<tr><td colspan="2">Specific gravity</td><td>2.85</td></tr>
<tr><td rowspan="5">Aged Mixture</td><td rowspan="5">Marshall Properties</td><td>Stability kN</td><td>17.4</td></tr>
<tr><td>Flow mm</td><td>3.05</td></tr>
<tr><td>Air voids %</td><td>5.21%</td></tr>
<tr><td>Bulk density gm/cm^3</td><td>2.329</td></tr>
<tr><td>Maximum theoretical density Gmm gm/cm^3</td><td>2.465</td></tr>
</table>

Gradation for the old (reclaimed) aggregate obtained from aged mixture was determined; six samples have been selected randomly from the rubblization process of material stack. These samples were subjected to Ignition test to isolate binder from aggregate and then aggregate was sieved and separated to various sizes to calculate gradation for each sample. The differences between samples were in a minor extent, and the average gradation of the six samples obtained to be the old aggregate gradation is shown in Table 2 which illustrates that the gradation of old (reclaimed) aggregate for binder layer has slimly deviation with Specification limits of Roads and Bridge SCRB, [17].

Table 2. *Gradation of Old (reclaimed) Aggregate Obtained from Aged Mixture.*

Sieve size (mm)	**%Finer by weight**	**SCRB Specification, Binder course, [17]**
25.4	---	100
19	99	90-100
12.5	91	70-90
9.5	81	56-80
4.75	61	35-65
2.36	45	23-49
0.3	16	5-17
0.075	6.6	3-9

2.2. Recycling Agents

Two types of recycling agent (liquid asphalt) based on available literature, [6, 11, 12, 14, 15, 18], have been implemented in this work. They are medium curing cutback liquid asphalt, and cationic emulsion liquid asphalt.

2.3. Liquid Asphalt (Medium Curing Cutback)

Medium curing cutback liquid asphalt (MC-30) obtained from Al-Dura refinery was adopted for recycling in this work, the properties are listed in Table 3.

Table 3. Properties of medium curing cutback liquid asphalt.

Property	Test Conditions	ASTM Designation, [19]	Value
Kinematic viscosity	60 ℃	D2170	42
Flash point	-	3143	52
Distillate, volume percent of total distillate	225 ℃ 260 ℃ 315 ℃	D402	23 47 89
Residue from distillation	360 ℃	D402	63
percent volume by difference Tests on residue from distillation:			
Viscosity	60 ℃	D2171	67
Ductility	25 ℃	D113	132
Solubility in trichloroethylene	-	D2042	0.2
Water	-	D95	0.13

2.4. Liquid Asphalt (Cationic Emulsion)

Cationic emulsion liquid asphalt obtained from ministry of industry and minerals was adopted for recycling in this work, the properties are listed in Table 4.

Table 4. Properties of Cationic emulsion liquid asphalt.

Property	Test Conditions	ASTM Designation, [19]	Value
Viscosity	50 ℃	D7496	235
Storage stability	24-h	D6930	0.7
Coating ability and water resistance:			
Coating, dry aggregate Coating, after spraying Coating, wet aggregate Coating, after spraying	-	D244	good fair fair fair
Particle Charge	-	D7402	positive
Sieve Test	-	D6933	0.063
Distillation: Oil distillate, by volume of emulsion, % Residue, %	-	D6997	7 93
Tests on Residue from Distillation			
Penetration, 25 ℃	25 ℃,100g,5 S	D5	57
Ductility	25 ℃, 5 cm/min	D113	59
Solubility in trichloroethylene, or N-Propyl B	-	D2042	113

2.5. Preparation of Recycled Mixture

Recycled mixture consists of reclaimed mixture (RAP) 100% and recycling agent mixed together at specified percentages according to the mixing ratio. First, RAP was heated to approximately 160oC and liquid asphalt was added to the heated RAP at the desired amount; 0.5% by weight of mixture was added and mixed for two minutes until all mixture was visually coated with recycling agent as addressed by [6]. The recycled mixture was prepared using two types of liquid asphalt: cutback and emulsion.

2.6. Preparation of Accelerated Short Term Aged Recycled Mixture

Recycled mixture was heated to 130 ℃ to become loose and then diffuses in shallow trays with 3cm thickness and subjected to one cycle of accelerated aging practical by laying inside an oven at 135 ℃ for 4 hours as per Superpave procedure, [16,18]. The mix was stirred every 30 minutes during the short term aging practical to prevent the outside of the mixture from aging more than the inner side because of increased air exposure. After the accelerated aging practical was completed, Marshall Specimens, were constructed from the short term aged asphalt concrete after heating the material to 150 ℃.

2.7. Preparation of Asphalt Concrete Specimens

Asphalt concrete were prepared from the reclaimed material obtained from field and after accelerated short term aging of recycled mixture was used in preparation of asphalt concrete specimens.

2.8. Preparation of Marshall Specimens

It is a cylindrical 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 150oC. A piece of non-absorbent paper, cut to size, was placed in the bottom of the mold before the mixture was introduced. The asphalt mixture was placed in the preheated mold, and then it was spaded drastically with a heated spatula 15 times around the perimeter and 10 times around the interior. Another piece of non-absorbent paper cut to size was placed on the top of the mix. The temperature of mixture immediately prior to compaction temperature was (150 ℃). The mold assembly was placed on the compaction pedestal and 75 blows on the top and the bottom of specimen were applied with rimmed compaction hammer of 4.535 kg sliding weight, and a free fall in 457.2 mm. The specimen in mold was left to cool at room temperature for 24 hours and then it was removed from the mold using mechanical jack. Marshall Specimens were subjected to the following tests: Marshall Test (9 specimens), indirect tensile test at 25 ℃, 40 ℃, and 60 ℃ (27 specimens), indirect tensile ratio (9 specimens). Figure 1 shows the reclaimed material, while Figure 2 exhibit part of the prepared specimens.

Figure 1. *Reclaimed material.*

Figure 2. *Part of the prepared specimens.*

2.9. Resistance to Plastic Flow (Marshall Test)

This method covers the measurement of the resistance to plastic flow of cylindrical specimen of asphalt paving mixture loaded on the lateral surface by mean of the

Marshall apparatus according to ASTM D 1559, [19]. Three specimens for each combination were tested and the average results were reported.

2.10. Indirect Tensile Strength (ITS) Test and Temperature Susceptibility

The indirect tensile strength followed the procedure of ASTM D6931, [19]. Marshall Size Specimens were used in this test, and percent of air voids for specimens was the same as that for Marshall Test. The specimen was conditioned by placing in water bath at four different temperatures (20, 25, 40, and 60 ^{o} C) for 30 minutes and then the specimen were centered on the vertical diametrical plane between the two parallel loading strips (12.7 mm) in wide. Vertical compressive load at rate of 2 in/min (50.8 mm/min) by Versa tester machine was applied until the dial gage reading reached the maximum load resistance; the reason of conducting this test is to evaluate the tensile strength and temperature susceptibility for the mixtures. (ITS) was calculated using equation (1).

$$\text{ITS}=\frac{2000*P}{\pi*T*D} \qquad (1)$$

Where:

ITS = Indirect Tensile Strength, kPa

P = Maximum load resistance at failure, N

D = Diameter of specimen, mm

T = Thickness of specimen immediately before test, mm

The Temperature Susceptibility was calculated using equation (2).

$$\text{TS}=\frac{(\text{ITS})\text{t1}-(\text{ITS})\text{t2}}{\text{t2}-\text{t1}} \qquad (2)$$

Where:

TS = Temperature susceptibility (kPa / °C)

(ITS) t1= Indirect tensile strength at t1 =25 ℃

(ITS) t2 = Indirect tensile strength at t2 =40 ℃

The tensile strength ratio test was performed to evaluate the moisture damage resistance of mixtures, and the procedure followed (ASTM D4867), [19]. A set of six specimens were prepared, three specimens were tested for indirect tensile strength by storing in a water bath at 25oC for 30 minutes, and an average value of ITS for these specimens was computed as SI (ITS for unconditioned specimens). The other three specimens were conditioned by placing in volumetric flask 4000-ml heavy- wall glass filled with water at room temperature 25˚C and then a vacuum of 28mm Hg (3.74 kPa) was applied for 5 to 10 min. to obtain 55 to 80 % degree level of saturation. The specimens were then placed in deep freeze at -18˚C for 16 hours. The frozen specimens then were moved to a water bath for 24 hours at 60oC. Then they were placed in a water bath at 25oC for 1 hour, and they were tested for indirect tensile strength. The average value was computed as SII (ITS) for moisture-conditioned specimens). The indirect tensile strength ratio could be calculated from equation (3).

$$\text{TSR}=\frac{SII}{SI} *100 \qquad (3)$$

Where:

TSR = Indirect tensile strength ratio, %

SI= Average (ITS) for unconditioned specimens, kPa

SII = Average (ITS) for moisture-conditioned specimens, kPa

3. Results and Discussion

3.1. Impact of Recycling Agent on Air Voids and Bulk Density

Recycling agents used in recycled mixtures showed an adequate percent air voids (between 3-5%) and the aged mixture tested had the highest percent air voids with 5.21%. Figure 3-a presents the percent air voids for the aged and recycled mixture. It can be observed that the total volume of voids decreases by (6.5 and 5.3) % for cutback and emulsion treated mixtures as compared to added mix, this may be attributed to the lower viscosity provided by the addition of rejuvenation agent which support a better compaction of the specimen. This was further supported by the variation of bulk density. Improvement in bulk density of recycled mixtures was noticed, bulk density of aged mixture was 2.329 gm/cm3, and this low density could be attributed to difficulties in compaction due to the high viscosity of aged binder, while recycled mixtures exhibit higher bulk density as compared to aged mixture. Figure 3-b show the bulk density for aged and recycled mixture. The percent of improvement in bulk density for recycled mixtures with (cutback and emulsion) was (1.85 and 1.16) % respectively as compared with aged mixture. This agrees with the findings of [14, 18, 20].

3.2. Impact of Recycling Agent on Marshall Stability and Flow

Based on Figure 4-a, it was found that recycling decreases Marshall stability, as the stability value was high for aged mixture (17.4 kN), it decreased for recycled mixtures with (cutback)and (emulsion) liquid asphalt by (10.91 and 15.5) % respectively as compared with aged mixture. This may be attributed to the fact that aged mixture contains hardened asphalt, which will lead to increased stability due to higher asphalt viscosity, while recycled mixtures lack such high cohesion bonding effect because of their reduced viscosity (increased workability) and increased binder content (after adding the rejuvenator). This agrees well with the findings of [18, 21, 22, 23].

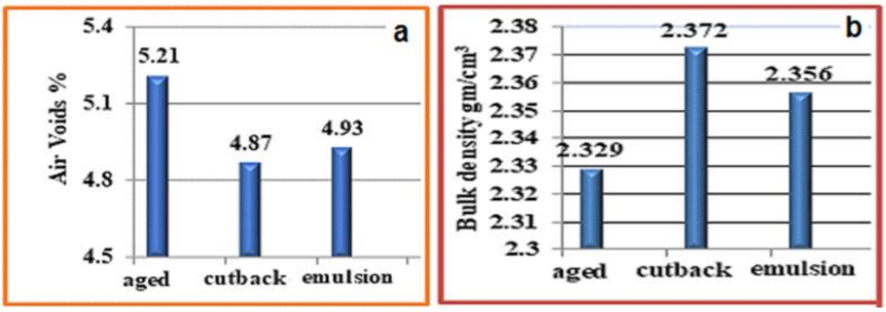

Figure 3. *Variation of air voids and bulk density for Aged and Recycled Mixture.*

Mixtures with recycling agents (cutback) showed higher stability than (emulsion), which indicates that bonding effect for (cutback) is higher than emulsion. It can be noted that all mixtures exhibit stability values more than the minimum requirement of (7 kN) which represent stability of binder course layer according to the specification limits of roads and bridges by SCRB, [17]. Recycling revealed a pronounce increase in Marshall Flow value corresponding to aged mixture. The flow value increases by (22 and 10) % for cutback and emulsion treated mixtures respectively as compared to reclaimed mixture. All the types of liquid asphalt mixes satisfies Marshall flow criteria of (2-4) mm. the flow value for mixture with (cutback) was higher than mixture with (emulsion), this could be attributed to the presence of cutback which makes the mixture more flexible and the volatile materials dissolves the aged asphalt and reduces its viscosity, which leads to the increase in flow value. Figure3-b clarifies the flow results.

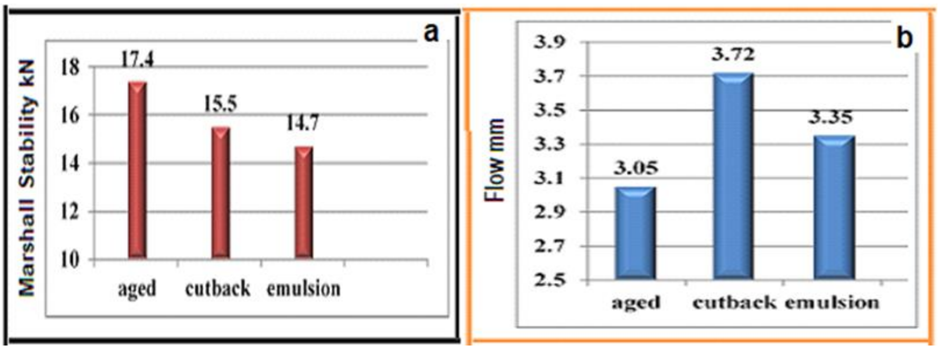

Figure 4. *Variation of Marshal Stability and flow for Aged and Recycled Mixture.*

3.3. Effect of Recycling Agent Type on Indirect Tensile Strength (ITS)

Recycled asphalt concrete mixtures were subjected to indirect tensile strength test at 25 ℃, 40 ℃, and 60 ℃. Three specimens for each mixture type and testing temperature were tested, and the average value was obtained to represent the tensile strength of this type at the specified temperature. Also, the temperature susceptibility for each mixture type was obtained. Results indicated that tensile strength at 25oC for recycled mixtures with cutback and emulsion was lower than aged mixture value by (11.11 and 21.49) % respectively as compared with aged mixture. Also Mixtures treated with liquid asphalt of (cutback) showed higher indirect tensile strength value than those treated with (emulsion). Figure 5-a presents the (ITS) values. The Tensile strength values at 40oC for recycled mixtures was still lower than that of aged mixture. The percent of reduction in (ITS) value for recycled mixtures with (cutback and emulsion) was (12.29, and 19.64) % respectively as compared with aged mixture. The recycled mixture with (cutback) revealed higher tensile strength value as compared to recycled mixture with (emulsion), but it was lower than (ITS) the value for aged mixture. The tensile strength At 60 ℃ for aged mixture was higher than that of recycled mixtures. The percent of decrease in (ITS) value for recycled mixtures with (cutback and emulsion) was (20.61% and 10.9%). The recycled mixture with (emulsion) had higher tensile strength value than (cutback).

3.4. Effect of Recycling Agent Type on Temperature Susceptibility

Figure 5-b shows the temperature susceptibility results. Mixture with (emulsion) revealed the lower temperature susceptibility value than those with (cutback). The temperature susceptibility value for aged mixture was high due to the nature of aged and hardened asphalt cement which leads to a mixture more susceptible to temperature variation. The temperature susceptibility results of recycled mixtures exhibit lower influence than aged mixture by (9.12 and 24.62) %for recycled mixtures with cutback and emulsion) respectively. On the other hand, it can be seen that (ITS) value for all mixtures decreased when temperature increased, while (ITS) value at (25˚C, 40˚C and 60˚C) for aged mixture was higher than (ITS) value for recycled

mixtures. Also the (ITS) value for recycled mixture with (cutback) was higher than (ITS) value for recycled mixture with (emulsion).

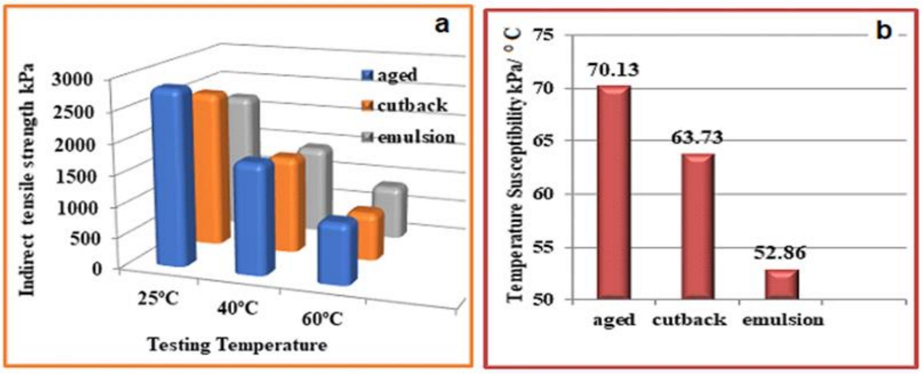

Figure 5. *(ITS) and Temperature Susceptibility for Aged and Recycled Mixtures.*

3.5. Impact of Recycling Agent on Resistance to Moisture Damage in Terms of Tensile Strength Ratio (TSR)

The results of tensile strength ratio showed that recycled mixtures had good resistance to the action of water. The tensile strength ratio was higher than 80% for all recycled mixtures as demonstrated in Figure 6, and the recycled mixture with (emulsion) had the highest (T.S.R) value as compared to recycled mixture with (cutback). The results revealed high improvement in tensile strength ratio for recycled mixtures with (cutback and emulsion) by (23.13 and 28.44) % as compared with aged mixture. This could be attributed to better coating of aggregates after the addition of recycling agent, and lower voids content.

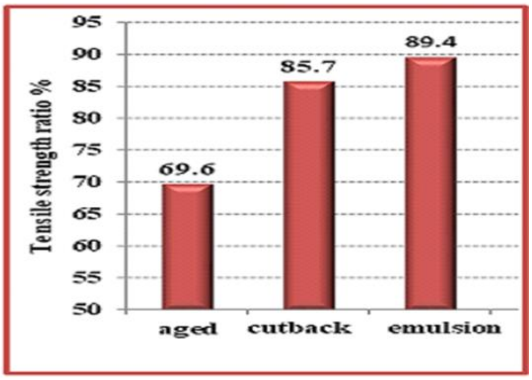

Figure 6. *Tensile Strength Ratio for Aged and Recycled Mixtures.*

4. Conclusions

Based on the testing results and limitations, the following conclusions could be addressed:

1-Significant reduction in Marshall Stability was noticed for recycled mixtures when compared to aged mixture. The percent of reduction was (10.91% and15.5%) for recycled mixtures with cutback and emulsion respectively.

2- 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 (11.11% and 21.49%) and at 40˚C was (12.29% and 19.64%) and at 60˚C was (20.21% and 10.97%) for recycled mixtures with cutback and emulsion , respectively.

3- Recycled mixtures shows less influence of temperature susceptibility by (9.12% and 24.62%) for recycled mixtures with cutback and emulsion, respectively as compared to aged mixture.

4- The results of tensile strength ratio showed that recycled mixtures had good resistance to moisture damage by (23.13% and 28.45%) for recycled mixtures with cutback and emulsion, respectively as compared with aged mixture.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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