Resistance to Moisture Damage of Recycled Asphalt Concrete Pavement

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ABSTRACT

Recycled asphalt concrete mixture are prepared, artificially aged and processed in the laboratory to maintain the homogeneity of recycled asphalt concrete mixture gradation, and bitumen content. The loose asphalt concrete mix was subjected to cycle of accelerated aging, (short –term aging) and the compacted mix was subjected to (long -term aging) as per Super-pave procedure. Twenty four Specimens were constructed at optimum asphalt content according to Marshall Method. Recycled mixture was prepared from aged asphalt concrete using recycling agent (soft asphalt cement blended with silica fumes) by (1.5%) weight of mixture as recycling agent content. The effect of recycling agent on aging after recycling process behavior of asphalt concrete was determine. Aged specimens after recycling process were prepared by subjecting the recycled asphalt concrete to accelerated aging and tested for resistance to moisture damage. The improvement in the resistance to moisture damage of aged mixture after recycling with (soft asphalt cement blended with silica fumes) was 76.17% as compared to the corresponding aged mixture before recycling process. The ITS for unconditioned specimens for aged after recycling process mixture was less than reference by 67.1%, and less than that of aged before recycling process mixtures by 64.1%.

Key words: aged asphalt concrete; moisture damage; recycled asphalt concrete; recycling agent.

مقاومة الضرر بالرطوبة لرصفة الخرسانة الاسفلتية المعاد تدويرها

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المستخلص

الخرسانة الاسفلتية المعاد تدويرها تم تعريضها الى تقادم صناعي وجهزت بالمختبر للمحافظة على تجانس التدرج لخلطة الخرسانة الاسفلتية المعاد تدويرها وعلى محتوى الاسفلت. تم تحضير النماذج عند نسبة الاسفلت المثلى بواسطة تعريض خلطة الخرسانة الاسفلتية المفتتة الى دورة واحدة من التقادم المسرع (تقادم قصير الامد) ثم تحدل وتعرض الى دورة اخرى من التقادم المسرع (تقادم طويل الامد) كما في طريقة الرصف المتفوق. النماذج تم تحضيرها عند نسبة الاسفلت المثلى حسب طريقة مارشال.

الخلطة المعاد تدويرها حضرت من الخرسانة الاسفلتية المتقادمة بعد معاملتها بمنشط اعادة التدوير المكون من (الاسفلت الإسمنتي ذو الاختراق العالي ممزوج مع غبار السليكا). كانت نسبة المنشط 1.5 بالمئة من وزن الخلطة. تأثير منشط اعادة التدوير على خواص التقادم تم ايجاده بواسطة تحضير العينات المتقادمة بالعمر بعد عملية اعادة التدوير بواسطة اعادة تعريض الخرسانة الاسفلتية المعاد تدويرها الى تقادم مسرع مرة ثانية وفحصها لمعرفة مقاومتها للضرر بالرطوبة. كانت نسبة التحسن في مقاومة الضرر بالرطوبة للخلطة المتقادمة بالعمر بعد اعادة التدوير مع منشط اعادة التدوير (الاسفلت السمنتي ذوتدرج الاختراق العالي الممزوج مع غبار السليكا) 76.17% مقارنة مع الخلطات المتقادمة بنفس العمر قبل عملية اعادة التدوير. كانت قيم مقاومة الشد غير المباشر للنماذج المتقادمة بعد إعادة التدوير تقل بمقدار 67.1% عن النماذج المرجعية كما كانت تقل بمقدار 64.1% عن النماذج المتقادمة قبل إعادة التدوير.

الكلمات الرئيسية : الخرسانة الاسفلتية المعاد تدويرها، التقادم ، التقادم بعد عملية اعادة التدوير ، الضرر بالرطوبة.

1. INTRODUCTION

Most of pavement design methods are focusing on the selection of pavement structure that will have resistance to traffic and environmental conditions. The ability of the recycled asphalt concrete materials to withstand the effects of environmental conditions, such as water, ageing and temperature variations without any significant deterioration is considered as essential issue in the decision of recycling.

2. BACKGROUND

Moisture damage in asphalt concrete pavements is considered as primary cause of distresses in the asphalt pavement layers. The exposure of asphalt pavement to water is often one of the major factors affecting the durability of HMA. The water induced damage in HMA layers may be associated with two mechanisms: loss of adhesion and/loss of cohesion. In the first mechanism, the water gets trapped between the asphalt and aggregate and strips the asphalt film away, leaving aggregate without asphalt film coverage. This happens because the aggregates have a greater affinity for water than asphalt binder. The second mechanism includes the interaction of water with the asphalt cement that reduces the cohesion within the asphalt cement. This will lead to a severe reduction in the asphalt mixture strength**, Wasiuddin, 2007.**

Moisture susceptibility generally causes poor mixture durability. It may be caused by the loss of cohesive bond between binder and aggregate, usually due to moisture intrusion. This is called stripping, and it often starts at the top of the pavement and progresses downward, resulting in raveling. Moisture susceptibility can be evaluated in the laboratory by performing stability, resilient modulus, or tensile strength testing on unconditioned and moisture conditioned samples. Loss of strength is due to the weakening of the bond between the asphalt cement and aggregate. To help protect the pavement structure against moisture damage, it is necessary to determine if a mixture is susceptible to water damage in the event of water penetration **, Sondag et al., 2002.**

,Al-Rousan, et al., 2008. studied the moisture damage of recycled mixtures. Two mixtures were prepared, the first mix was composed of 100% fresh aggregate and virgin asphalt and the second mix was composed of 30% RAP and 70% fresh aggregate and virgin asphalt. Water susceptibility of the asphalt concrete mixes due to RAP usage in asphalt mixes was evaluated by measuring the reduction of the Indirect Tensile Strength (ITS) after immersion in water for 24 hours at 60°C, They concluded that the loss in ITS for mixtures containing RAP is much lower than mixtures containing no RAP. This was attributed to the fact that RAP contains hardened asphalt that became more viscous as time passes.

Xiao et al., 2009, stated that the indirect tensile strength (ITS) and tensile strength ratio (TSR) test were conducted to evaluate the moisture susceptibility of an asphalt mixture. The results showed that the TSR values of all of the mixtures, except the virgin mix, were higher than 85%, the use of RAP in modified mixtures provided such benefits as decreasing the virgin asphalt binder content, increasing the ITS and TSR values, and thus improving the moisture resistance of HMA mixtures.

,Sarsam, and Alwan 2014, studied the impact of moisture damage on pavement properties, It was concluded that the moisture-conditioned mix has lower resistance to permanent deformation (at 1000 cycles) by 93% as compared with the unconditioned mixture. Superpave asphalt concrete was shown to be durable against moisture damage by 81% at optimum asphalt content when compared to the requirement of **,SCRB, 2007.**

,Sarsam, and Al-Janabi 2014, studied the recycling of asphalt Mixtures with Soft asphalt or with asphalt and Sulfur, they concluded that recycled mixtures were less susceptible to moisture damage by an average value of 53% as compared to reclaimed mix and exceeded the I.R.S requirement of 70% value for virgin mixture.

,Sarsam, and Alwan 2015, stated in the experimental results that, in general, the mixes subjected to moisture damage give low resistance to indirect tensile strength, low resilient modulus at 40 C, high permanent deformation at 40 C, low stiffness, and low fatigue life, by (19%, 21%, 93%, 62% and 70%) respectively as compared with unconditioned mixture.

3. RESEARCH OBJECTIVE

The main objectives for this study are evaluating the durability performance of recycled asphalt concrete mixture in terms of accelerated aging, moisture damage, and studying the effect of recycling agent on aging after recycling behavior of asphalt concrete, also investigating the effect of accelerated aging methods (Short-Term Aging) and (Long –Term Aging) on physical properties for recycled asphalt concrete.

4. MATERIALS

The Materials used in this study are locally available and selected from the currently used materials in road construction in Iraq. One type of asphalt cement (40-50) penetration grade from Dora Refinery was used in this study. Mineral aggregate (12.5 mm nominal maximum size gradation), with crushed coarse aggregate (retained on sieve no.4) was obtained from AL-Nibaae quarry. Crushed Sand and natural Sand are used as Fine aggregate (particle size distribution between sieve no.4 and sieve no.200). One type of mineral filler (Ordinary Portland Cement) has been used in this study, which is obtained from Badoush factory. **Tables 1, 2,** and **3** show the physical properties of Asphalt cement, Coarse and Fine Aggregate and Filler respectively. **Fig.1** illustrates Aggregate gradation and specification limits.

5. ASPHALT CONCRETE

5.1 Mix Preparation

Asphalt concrete mixtures (Reference mixture) were prepared at optimum asphalt content (4.7%) using Marshall Method. A total of 24 asphalt concrete specimens have been prepared and tested.

5.2 Aged Materials

Reclaimed asphalt pavement (RAP) incorporated in this work was laboratory-prepared, and subjected to aging and recycling, aged asphalt concrete mixture were prepared from asphalt concrete mixture by subjecting the mix to two cycle of accelerated aging (Short-Term Aging) and then (Long –Term Aging) as per Superpave procedure. Asphalt concrete mixture was spread in shallow trays with 3 cm thickness, and subjected to two cycles of accelerated aging process by storage inside the oven at 135°C for 4 hours (Short –term aging) then compacted in accordance with **,ASTM D1559, 2009** method. Specimens were subjected to accelerated aging process (Long – term aging) for five days at 85˚C as per Superpave procedure.

5.3 Recycling Agent

Asphalt cement of penetration grade (100-150) from Al-Dura refinery was adopted in this study and blended with 2% of silica fumes which is obtained from local market; it is an ultra-fine powder consisting of nearly spherical particles around 100 times smaller than a grain of cement. Other percentages of silica fumes were also tried by testing the blend to (penetration, softening point and ductility) and 2% of silica fume was selected. Soft asphalt was heated to nearly 110ºC, and the silica fumes were added to the asphalt cement with stirring until homogenous blend was achieved, the mixing and stirring was continued for 30 minutes by mechanical blender. **Tables 4 , 5** and **6** show the Physical properties of Silica Fumes, Physical properties of Soft asphalt Cement and Physical properties of recycling agent [Soft Asphalt Cement (100-150) blended with Silica fumes] respectively, Soft asphalt cement blended with silica fumes will be referred as "Soft AC+ Silica fumes" in this study.

5.3 Preparation of Recycled Mixture

Aged specimens were heated to 140° C to become loose. 1.5 % of the recycling agent based on previous work by **,Sarsam, 2007,** was added and mixed for two minutes until all mixture is visually coated with recycling agent. Marshall Specimens were constructed from the loose recycled mix after heating the material to 150°C.

5.4 Preparation of Aged Mixture after Recycling

Recycled specimens were also heated to 140°C to become loose, then spread in shallow trays with 3cm thickness and subjected to two cycles of accelerated aging process by storage inside the oven at 135°C for 4 hours (Short –term aging). The aged asphalt concrete was then compacted in accordance with **,ASTM D1559, 2009,** method and subjected to accelerated aging process (Long – term aging) for five days at 85˚C as per Superpave procedure.

6. LABORATORY EVALUATION OF MOISTURE DAMAGE

6.1 Indirect Tensile Strength Ratio Test

The test was performed to evaluate the moisture damage resistance of mixtures, and the procedure followed **,ASTM D4867, 2009.** 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 of 25˚C, then a vacuum of 28mm Hg (3.74 kPa) was applied for 5to 10 min. to obtain 55 to 80 % degree level of saturation. The specimens then placed in deep freeze at -18˚C for 16 hours. The frozen specimens 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 was calculated by Eq.(1)

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

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 indirect tensile strength ratio was calculated using Eq. (2).

$$TSR= \frac{SII}{SI} * 100 \qquad \text{......... (2)}$$

Where:

TSR = Indirect tensile strength ratio, %
SI = Average ITS for unconditioned specimens, kPa
SII = Average ITS for moisture-conditioned specimens, kPa

7. ANALYSIS AND DISCUSSION OF TEST RESULTS

The ITS for unconditioned specimens for aged mixture was lower than reference mixture by 8.37%, it may be attributed to the fact that failure plane was different from that of Marshall test and it was very stiff mix in moderate temperature so it fails faster than others. For recycled mix, specimens showed higher deformation on failure (higher flexibility) of recycled mix when compared with the reference mixture, it was lower than that of reference by 42.21%, this might be related to the density of recycled mix which is lower than reference mix, and the higher viscosity of binder in recycled mix compared to reference mix. This agrees well with the findings addressed by **Celauro et al., 2010, ,Silva et al., 2012** and **,Sarsam, 2007.** The tensile strength for aged after recycling process was less than reference by 67.1%, and less than aged mixtures by 64.1%, such behavior was related to decrease of stiffening of mixture in (STA and LTA) mix due to the effect of recycling agent.
Fig. 2 illustrates the ITS values for each mixture type.
Tensile strength ratio shows low values as compared with reference mixtures, (57.58%) for (STA+ LTA) mixture. This could be due to aging process so the resistance to water damage decrease. On the other hand, the recycled mix shows higher values when compared with aged mixtures. This was due to recycling process so the resistance to water damage increase and become more susceptible to temperature due to the increase in binder content of this mixture, such finding agreed with **,Sondag et al., 2002** ,**Xiao and ,Amirkhanian, 2007.** TSR was lower than that of reference about 16.47%.

The result showed that tensile strength ratio of aging after recycling mixture shows good resistance to the action of water when compared to the aged mixture before recycling process. TSR was more than that of (STA+LTA) mixture by 76.17% and less than that of reference mix by 25.26%. **Fig.3** illustrates TSR for each mixture type.

8. CONCLUSIONS

1. The ITS for unconditioned specimens for aged after recycling process mixture was less than reference by 67.1%, and less than that of aged before recycling process mixtures by 64.1%, it was related to decreasing of stiffening of mixture in aged mix due to the effect of recycling agent.
2. Aged mixtures showed lower resistance to moisture damage, the percentages of variation for (STA+LTA) mixture as compared to reference mixture was -57.58%, On the other hand, an improvement in mixtures properties when recycled with (Soft Ac+ Silica Fume) recycling agent, properties was noticed when the percentages of variation of mixtures properties compared with reference mixture is about -16.47%.
3. Aged after recycling mixtures had good resistance for water damage, the percentage of improvement for aged after recycling process mixture was 76.17% as compared to aged mixture before recycling process.

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Table 1. Physical properties of asphalt cement.

Property	Test Conditions	ASTM Designation No.	Value	SCRB Specification
Penetration	25˚C , 100gm , 5 sec	D5-06	41	40-50
Softening point	(ring &ball)	D36-895	49 ºC	-
Ductility	25˚c ,5cm/min	D113-99	>150	+100
Specific gravity	25˚C	D70	1.04	-
Flash point	Cleveland open cup	D92-05	275 ºC	>232
After thin film oven test properties D1754-97				
Retained penetration	25˚C , 100gm , 5 sec	D5-06	60%	55>
Ductility of residue	25˚C ,5cm/min	D113-99	85cm	25>
Loss on weight	163ºC, 50g, 5 hrs.		0.3	_

Table 2. Physical properties of coarse and fine aggregate.

Property	Value	ASTM Designation No.
Coarse Aggregate		
Bulk specific gravity	2.584	C127-01
Apparent specific gravity	2.608	C127-01
Water absorption %	0.57%	C127-01
Wear %(los Angeles abrasion)	13.08%	C131-03
Fine Aggregate		
Bulk specific gravity	2.604	C128-01
Apparent specific gravity	2.664	C128-01
Water absorption %	1.419%	C128-01

Table 3. Physical properties of filler (cement).

Property	Value
Bulk specific gravity	3.14
% Passing Sieve No.200	96

Table 4. Physical properties of silica fumes.

Property	Value
Bulk specific gravity	2.134
% Passing Sieve No.200	100

Table 5. Physical properties of soft asphalt cement.

Property	Test Conditions	ASTM Designation No.	Value
Penetration	25˚C , 100gm , 5 sec	D5-06	120
Softening point	(ring &ball)	D36-95	25 ° C
Ductility	25˚C ,5cm/min	D113-99	80cm
Flash point	Cleave land open cup	D92-05	250 ºC
After thin film oven test properties D1754-97			
Retained penetration of residue	25˚C , 100gm , 5 sec	D5-06	66%
Ductility of residue	25˚C ,5cm/min	D113-99	30cm
Loss on weight	163˚C,50g,5hr		0.35%

Table 6. Physical properties of soft asphalt cement (100-150) blended with silica fumes.

Property	Test Conditions	ASTM Designation No.	Value
Penetration	25˚C , 100gm , 5 sec	D5-06	163
Softening point	(ring &ball)	D36-95	35° C
Ductility	25˚C ,5cm/min	D113-99	88cm
Flash point	Cleveland open cup	D92-05	260 ºC
After thin film oven test properties D1754-97			

Retained penetration of residue	25˚C , 100gm , 5 sec	D5-06	53%
Ductility of residue	25˚C ,5cm/min	D113-99	22cm
Loss on weight	163˚C,50g,5hr		0.2%

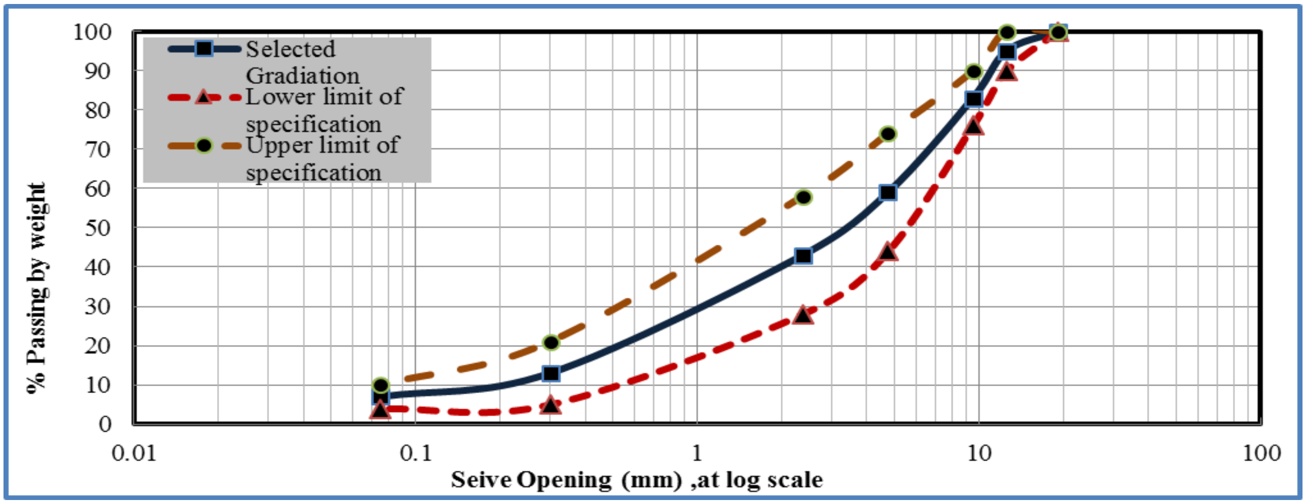

Figure 1. Selected aggregate gradation and specification limits.

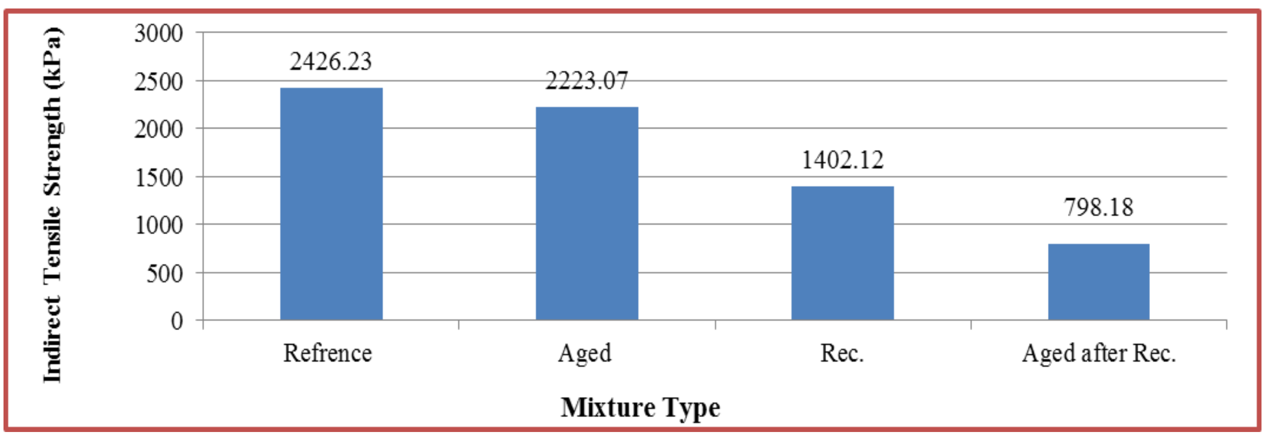

Figure 2. ITS values for each mixture type.

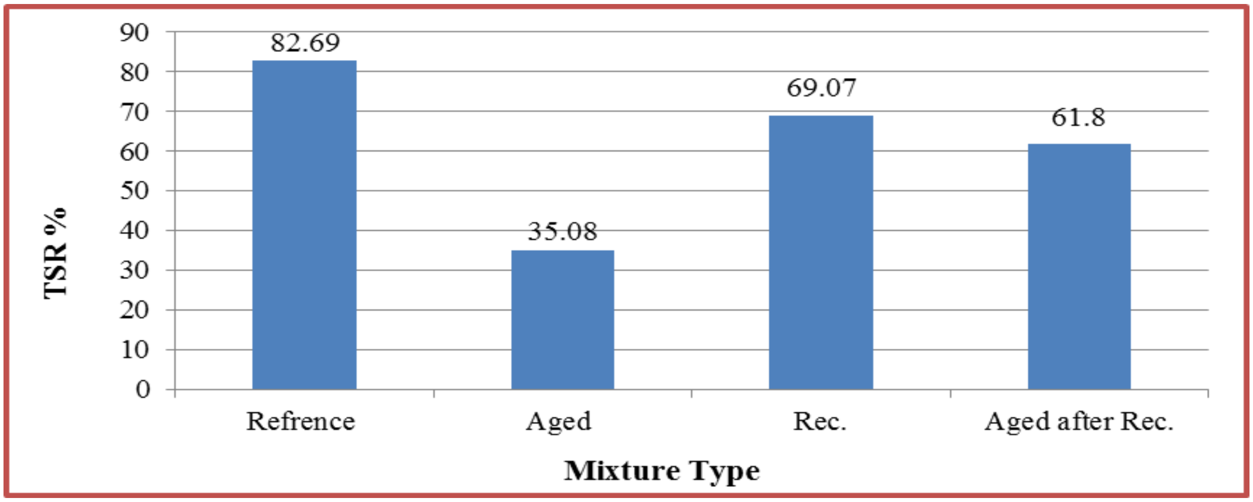

Figure 3. TSR for each mixture type.