Evaluating Water Damage Resistance of Recycled Asphalt Concrete Mixtures

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ABSTRACT

Recycling process presents a sustainable pavement by using the old materials that could be milled, mixed with virgin materials and recycling agents to produce recycled mixtures. The objective of this study is to evaluate the impact of water on recycled asphalt concrete mixtures, and the effect of the inclusion of old materials into recycled mixtures on the resistance of water damage. A total of 54 Marshall Specimens and 54 compressive strength specimens of (virgin, recycled, and aged asphalt concrete mixtures) had been prepared, and subjected to Tensile Strength Ratio test, and Index of Retained Strength test. Four types of recycling agents (used oil, oil + crumb rubber, soft grade asphalt cement, and asphalt cement + Sulphur powder), were adopted to prepare recycled mixtures, and the recycling agent of (soft grade asphalt) was used to prepare mixtures with further old materials contents. It was found that the Tensile Strength Ratio exceeds 75% for all recycled mixtures, and the recycled mixture with (oil + rubber) and 50% old materials content, had the highest Tensile Strength Ratio value comparing to other recycled mixtures. Results of Index of Retained Strength showed that mixtures with (Soft Ac) and (Ac + Sulphur) and 50% old materials, exceeded the Index of Retained Strength value for virgin mixture. Index of Retained Strength values decreased as the old materials content increased, Index of Retained Strength was (80.5%, 74.5%, 71.6%, and 67.62%) for recycled mixtures with (50%, 60%, 70%, and 80%) old materials content respectively.

Key words: recycled asphalt concrete, water damage, tensile strength ratio, index of retained strength, recycling agent.

تقييم مقاومة التأثير الضار للماء لخلطات الخرسانة الاسفلتية المعاد تدويرها

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الخلاصة

ان عملية اعادة التدوير تقدم طبقة تبليط مستدامة عن طريق استخدام المواد القديمة التي يتم قشطها من هذه الطبقة، هذه المواد من الممكن مزجها مع المواد الجديدة ومعاملات اعادة التدوير لانتاج خلطات الخرسانة الاسفلتية المعاد تدويرها، ان الاهداف الرئيسية من هذه الدراسه هي تقييم التأثير الضار للماء على خلطات الخرسانه الاسفلتية المعاد تدويرها، وتاثير احتواء الخلطات المعاد تدويرها على كميات اكبر من المواد القديمه على مقاومة تاثير الماء. ٥٤ نموذج مارشال و ٥٤ نموذج مقاومة الانضغاط لكل من (الخلطات الجديدة، الخلطات المعاد تدويرها، والخلطات المتقادمه) تم تحضيرها، وتم تعريض هذه النماذج لفحص نسبة الشد غير المباشر، ولفحص مؤشر القوة المتبقية، لتقييم مقاومة هذه النماذج لتاثير الماء. اربع انواع من معاملات اعادة التدوير (الزيت المستعمل، الزيت+فتات المطاط، الاسفلت

السمنتي ذو تدرج الاختراق العالي، و الاسفلت السمنتي + مسحوق الكبريت)، تم استخدامها لتحضير الخلطات المعاد تدويرها، ومعامل اعادة التدوير (الاسفلت السمنتي ذو تدرج الاختراق العالي) تم استخدامه لتحضير خلطات بكميات اكبر من المواد القديمة. لقد تم ايجاد ان قيم نسبة الشد غير المباشر كانت اكبر من ٧٥% لكل الخلطات المعاد تدويرها، وان الخلطات المعاد تدويرها التي تحتوي على (الزيت+فتات المطاط) ومواد قديمة بنسبة ٥٠%، اظهرت قيمة اعلى لنسبة الشد غير المباشر مقارنة بانوع الخلطات المعاد تدويرها الاخرى. فحص مؤشر القوة المتبقية اظهر اداء جيد للخلطات المعاد تدويرها، حيث ان الخلطات التي تحتوي على (الاسفلت السمنتي ذو تدرج الاختراق العالي) و (الاسفلت السمنتي + مسحوق الكبريت) ومواد قديمة بنسبة ٥٠%، تجاوزت مؤشر القوة المتبقية للخلطة الجديدة. ان مؤشر القوة المتبقية تناقص مع ازدياد محتوى المواد القديمة في الخلطات المعاد تدويرها، قيم مؤشر القوة المحتجزة كانت (٨٠،٥ %، ٧٤،٥ %، ٧١،٦ %، و ٦٧،٦٢%) للخلطات المعاد تدويرها التي تحتوي (٥٠%، ٦٠ %، ٧٠ %، و٨٠ %) مواد قديمة بالتتالي.

الكلمات الرئيسية: خرسانة اسفلتية معادة ،الضرر بالرطوبة، معامل قوة الشد، معامل القوة المتبقية، معيد التاهيل

1. INTRODUCTION

The continuous process of construction and maintenance of pavement structures and the increasing costs of pavement materials had put the light on the recycling approach as a worthwhile technique to be considered, **Ramanujam, 2000**. Recycling is the process of reuse the existing pavement materials that are no longer serve the traffic effectively. Recycling could be considered as a step toward sustainable roadway construction, **Sarsam, 2011.** When the pavement mixture reaches its service life, milled materials still maintain considerable value. The milled materials, reclaimed asphalt pavement (RAP), can be reused in virgin hot asphalt mixture to reduce the amount of new material that needs to be used, **Al-Qadi et al., 2007**. The reclaimed asphalt pavement (RAP) is a removed and processed pavement material containing old aggregate and asphalt binder which is oxidized (aged) during service in the field. In a hot-mix recycling process, the RAP is combined with virgin (new) asphalt, virgin aggregate and, in some cases, recycling agent to produce a recycled asphalt mixture, **Doh et al., 2008**. **Colbert and You, 2012** investigated the influence of fractionated reclaimed asphalt pavement (RAP) materials on asphalt mixture performance. The RAP mixture percentages used were 15%, 35%, and 50% in the study**.** The asphalt mixture moisture susceptibility results for the TSR tes**t** showed that RAP mixtures of 35% RAP and 50% RAP have a TSR value greater than 0.80. The control mixture has a TSR value of 0.72. **Miro et al., 2011** studied the behavior of high modulus bituminous mixes with low penetration grade bitumen and high reclaimed asphalt pavement (RAP) percentages. Four mixtures with RAP percentages of 0%, 15%, 30% and 50%, respectively, were analyzed. In order to evaluate moisture sensitivity, specimens were conditioned by immersion in water for 72 hour at 40ºC. The Indirect Tensile Strength Ratio (ITSR) was determined for conditioned and non-conditioned cylindrical specimens at 15ºC. Values were higher than 80%, suggesting that mixtures had good resistance to the action of water. However, these values dropped with increasing RAP content. **Sarsam and Shujairy, 2015** Assessed the fatigue life of reclaimed asphalt concrete after it was recycled with Nanomaterial additives using roller compacted asphalt concrete specimens. **Sarsam and Al-Zubaidi, 2015** studied the resistance to moisture damage of recycled asphalt concrete pavement using indirect tensile strength test. **Sarsam and AL-Shujairy, 2016** investigated the influence of recycling agent type on resilient modules and rutting resistance of asphalt concrete pavement using wheel tracking test on slab specimens.

2. MATERIALS PROPERTIES

2.1 Virgin Materials

2.1.1 Asphalt Cement

Asphalt cement of penetration grade (40-50) was used as a virgin binder and introduced into mixtures, it was brought from Al-Duarah refinery**.** Tests conducted on asphalt cement confirmed that its properties complied with the specifications of State Commission of Roads and Bridges, **SCRB, 2003**. **Table 1** presents the physical properties of asphalt cement.

2.2 Coarse and Fine Aggregate

Crushed coarse aggregate (retained on sieve No.4) was obtained from AL-Nibaee quarry. Crushed sand was used as Fine aggregate (particle size distribution between sieve No.4 and sieve No.200), it was brought from the same source. It consists of hard, tough grains, free from loam and other deleterious substances. Coarse and fine aggregate were tested and the physical properties are listed in **Table 2**.

2.3 Mineral Filler

Mineral filler used in this study is limestone dust obtained from Erbil, the physical properties of the filler are listed in **Table 3**.

2.4 Selection of Aggregate Gradation

The selected gradation in this study followed the **SCRB, 2003** specification, with 12.5 (mm) nominal maximum size. **Table 4** and **Fig.1** show selected aggregate gradation.

2.5 Aged Materials

The Reclaimed asphalt mixture was obtained from milled highway in specific project in Al-Aadhamiya at Baghdad. This highway was constructed in 1988 by French company, before milling, the highway was heavily deteriorated with various cracks and ruts existing on the surface, the milling depth of the project was 5 cm. Reclaimed asphalt mixture obtained was assured to be free from deleterious substances and loam that gathered on the top surface. The reclaimed mixture was subjected to extraction test according to **ASTM D1856, 2009** procedure to obtain binder and filler content, gradation and properties of aggregate, **Table 5** presents the properties of aged materials after extraction test. Gradation for the old aggregate obtained from aged mixture was determined, ten samples has been selected randomly from the milled material stack, these samples were subjected to extraction test to isolate binder from aggregate, 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 ten samples obtained to be the old aggregate gradation as shown in **Table 6**.

2.6 Recycling Agents

2.6.1 Used Oil

Used oil obtained from gasoline motor vehicle with a run period of 3200 (km) have been used in this study as a recycling agent.

2.6.2 Used Oil Blended with Crumb Rubber

Crumb rubber was obtained from local market as a disposal of tires that grinded. It was blended with used oil and chlorine in the following components percentages: (77% used oil + 22% crumb rubber + 1 % chlorine) as addressed by **Sarsam, 2007**. The used oil was heated to nearly 100ºc and crumb rubber was added to it with stirring, then chlorine was added as a solvent to increase the homogeneity of blend. Particle size distribution of crumb rubber is presented in **Table 7**.

2.6.3 Soft Grade Asphalt Cement

Asphalt cement of penetration grade (100-110) from Al-Dora refinery was adopted in this study. Its physical properties are listed in **Table 8**.

2.6.4 Asphalt Cement Blended with Sulphur Powder

It was addressed by **Elian, 1989** that recycled mixes with Sulphur exhibit significantly better engineering properties than conventional mixtures. Iraq produce Sulphur, consequently it could be economically possible to use Sulphur in recycling process. Same type of AC (40-50) that was used as a virgin binder, was heated to nearly 110ºc, and the Sulphur powder was added to the AC with stirring until homogenous blend was achieved. It should be aware that this process conducted in good ventilated room. The component percentage of the blend was 20/80 Sulphur/asphalt. Its physical properties are listed in **Table 9.**

3. PREPARATION OF SPECIMENS

3.1 Preparation of Virgin Mixture

The combined aggregate was heated to a temperature of (160ºC) before mixing with asphalt cement. The virgin asphalt cement was heated to a temperature of (135ºC) to produce a kinematic viscosity of (170±20) centistokes. Then, asphalt cement was added to the heated aggregate to achieve the desired amount, and mixed thoroughly until all aggregate particles are coated with asphalt cement.

3.2 Preparation of Recycled Mixture

First, the mixing ratio of virgin/old material should be determined, to specify the amount of RAP, amount and gradation of virgin aggregate, amount of virgin binder and recycling agent that should be added. RAP was heated to approximately 140ºC. Coarse and fine aggregate was combined with mineral filler to meet the specified gradation, and then aggregate was heated to 160ºC. Virgin binder and recycling agent were heated to 130ºC separately before they were added to the heated RAP and aggregate at the desired amount, and mixed thoroughly until all aggregate particles were coated with asphalt cement and recycling agent. The recycled mixture was prepared with using Four mixing ratios of (50/50, 40/60, 30/70, and 20/80) virgin/old material were prepared, and Four types of recycling agents have been used in recycled mixture (used oil, used oil with crumb rubber, soft asphalt cement, asphalt cement with Sulphur).

3.3 Preparation of Aged Mixture

Aged mixture was prepared from the aged material obtained from field. It was heated to 145ºC. Aged mixtures were tested to investigate the improvement in performance after recycling of mixtures.

3.4 Compaction of Asphalt Concrete Specimens

3.4.1 Marshall Specimen

It is a cylindrical specimen of 4 inches (102 mm) in diameter and 2.5 ±0.05 inches (63.5 mm) in height. Marshall Mold, spatula, and compaction hammer were heated on a hot plate to a temperature between (120-150ºC). The temperature of mixture immediately prior to compaction temperature was (145-150ºC). The mold assembly was placed on the compaction pedestal and 75 blows on the top and the bottom of specimen were applied with specified compaction hammer.

3.4.2 Compressive Strength Specimen

It is a cylindrical specimen of 4 inches (101.6 mm) in diameter and 4 inches in height. It was compacted using gyratory compactor, because this method of compaction simulates field compaction in a progressive way. The mold of gyratory compactor was heated to 140ºC. The asphalt mixture was placed in the preheated mold at temperature of (140-150ºC). By introducing the necessary information about specimen height, mass, and theoretical density for the device software, the compaction process started. When specimen reaches the specified height, compaction process will stop automatically and the mold will be discharged from the device.

4. TESTING PROGRAM

The testing program include subjecting virgin specimens, recycled specimens of the four types of recycling agents and old materials content of 50%, recycled specimens with (soft grade AC) and different old materials contents (60%, 70%, 80%) , and aged specimens to tensile strength ratio test, and index of retained strength test.

4.1 Tensile Strength Ratio Test

The procedure followed **ASTM D-4867, 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 S_I (ITS for unconditioned specimens). The other three specimens were conditioned by placing in 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 S_{II} (ITS for moisture-conditioned specimens). The indirect tensile strength ratio could be calculated from the following equation:

$$TSR = \frac{S_{II}}{S_I} \times 100 \qquad (1)$$

TSR = indirect tensile strength ratio, %

S_I= average ITS for unconditioned specimens, kPa

S_{II} = average ITS for moisture-conditioned specimens, kPa

4.2 Index of Retained Strength Test

The test followed the procedure of **ASTM D1075-2009**. A set of six specimens were prepared for this purpose. Three specimens were stored at air bath for 4 hours at 25ºC, and then tested for compressive strength and the average value was recorded (S_I). The other three specimens were stored in a water bath at 60ºC for 24 hours, then they were stored in another water bath at 25ºC for 2 hours, and the compressive strength test was performed on these specimens, and also the average value was recorded (S_{II}). The index of retained strength could be calculated by the following equation:

$$IRS = \frac{S_{II}}{S_I} \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

IRS = Index of Retained Strength, %
S_{II} = average compressive strength of moisture-conditioned specimens, kPa
S_I = average compressive strength of dry specimens, kPa

5. RESULTS AND DISCUSSION

5.1 Tensile Strength Ratio Test

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 75% for all recycled mixtures with mixing ratio of 50/50 old/virgin materials, **Fig.2**., and the recycled mixture with (Oil + Rubber) had the highest T.S.R value comparing to other recycled mixtures, although T.S.R values for all recycled mixtures were lower than virgin mix, but the results revealed high improvement in tensile strength for these mixtures comparing to aged mixture. Results were close for mixtures with (Oil, and Ac + Sulphur) recycling agents, which were lower than mixture with (Soft Ac). Results revealed that tensile strength ratio values decreased when the old materials content increased into recycled mixtures, which means that recycled mixtures with higher old materials content might become more affected by water damage, and this result meets with the findings of **Miro et al., 2011**. **Fig.3** illustrates tensile strength ratio results for recycled mixtures with different mixing ratios.

5.2 Index of Retained Strength Test

Results of I.R.S showed a good performance for recycled mixtures, as mixtures with (Soft asphalt cement) and (asphalt cement + Sulphur) and old materials content of 50% exceeded the I.R.S value for virgin mixture, which indicates that these mixtures were less susceptible to moisture damage as compared with virgin mix. This behavior may be explained by the hardened binder contained in recycled mixtures and the role of recycling agents which lead to more water resistance mixture. All (I.R.S) values for recycled mixtures with mixing ratio (50/50) old/virgin materials, exceeded 70 %, and achieved the criteria of **SCRB, 2003** for index of retained strength. **Fig.4** presented the results for I.R.S. Index of retained strength values decreased as the content of old materials into recycled mixtures increased, that confirms the reduction in water resistance of mixtures with higher old materials content, however all recycled mixtures except mixture with 80%

old materials achieved the criteria of **SCRB, 2003** for I.R.S (> 0.7). **Fig.5** illustrates the result values of index of retained strength.

6. CONCLUSIONS

1- The recycled mixture with (Oil + Rubber) had the highest T.S.R value (79.72%) comparing to other recycled mixtures with mixing ratio of (50/50) old/virgin materials.
2- Tensile Strength Ratio results revealed high improvement for recycled mixtures with mixing ratio (50/50) old/virgin materials, comparing to aged mixture. The percentages of improvement for these mixtures were (60%, 57%, 56%, and 65%) for mixtures with (soft AC, AC + Sulphur, oil, and oil + rubber) respectively.
3- All (I.R.S) values for recycled mixtures with mixing ratio (50/50) old/virgin materials, exceeded 70 %, and achieved the criteria of (SCRB 2004) for index of retained strength.
4- Index of Retained Strength values decreased as the content of old materials into recycled mixtures increased, the values of Index of Retained Strength were (80.5%, 74.5%, 71.6%, and 67.62%) for recycled mixtures with (50%, 60%, 70%, and 80%) old materials content respectively.
5- Recycled mixture with (soft AC) and old materials content of 80% had I.R.S value of 67.62% and did not achieve the criteria of (SCRB 2003) for index of retained strength.

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NOMENCLATURE

Symbol	Definition
AC	Asphalt Cement
ASTM	American Society for Testing and Materials
IRS	Index of Retained Strength
ITSR	Indirect Tensile Strength Ratio
RAP	Reclaimed Asphalt Pavement
SCRB	State Commission of Roads and Bridges
TSR	Tensile Strength Ratio

Table 1 Physical Properties of Asphalt Cement.

Property	Test Conditions	ASTM Designation	Value	SCRB Specification
Penetration	25ºc, 100gm, 5sec	D5-06	42 (1/10mm)	40-50
Softening Point	(ring and ball)	D36-95	53 ºc	-
Ductility	25ºc, 5cm/min	D113-99	125cm	+100
Specific Gravity	25ºc	D70-97	1.04	-
Flash Point	Cleveland open cup	D92-05	280 ºc	>232
After thin film oven test properties D1754-97				
Retained Penetration of Residue	25ºc, 100gm, 5sec	D5-06	73 %	>55
Ductility of Residue	25ºc, 5cm/min	D113-99	67 cm	>25
Loss on Weight	163ºc, 50g,5 hrs		0.2 %	-

Table 2 Physical Properties of Coarse and Fine Aggregate.

Property	value	ASTM Designation No.
Coarse Aggregate		
Bulk specific gravity	2.564	C127-04
Apparent specific gravity	2.597	C127-04
Water absorption %	0.502 %	C127-04
Wear% (Los Angeles abrasion)	18.5%	C131-03
Fine Aggregate		
Bulk specific gravity	2.599	C128-04
Apparent specific gravity	2.826	C128-04
Water absorption %	3.092 %	C128-04

Table 3 Physical Properties of Mineral Filler**.**

Property	Value
Bulk Specific Gravity	2.87
% Passing Sieve No.200	99

Table 4 Properties of Aged Materials after Extraction Test**.**

Material	Property		Value
Asphalt binder	Binder content %		2.1%
Coarse aggregate	Bulk specific gravity		2.553
	Apparent specific gravity		2.6
	Water absorption %		1.2%
	Wear% (Los Angeles abrasion)		22%
Fine aggregate	Bulk specific gravity		2.590
	Apparent specific gravity		2.819
	Water absorption %		4.4%
Mineral filler	Percent passing sieve no.200		98%
	Specific gravity		2.82
Aged Mixture	Marshall Properties	Stability	3.6 kN
		flow	1.6 mm
		Air voids	7.4%
		Bulk density	2.192 gm/cm^3

Table 5 Gradation of Old Aggregate Obtained from Aged Mixture

Sieve no.	Sieve size (mm)	% passing by weight
3/4"	19	100
1/2"	12.5	95
3/8"	9.5	87
No.4	4.75	65
No.8	2.36	51
No.50	0.3	12
No.200	0.075	2

Table 6 Particle Size Distribution of Crumb Rubber

Sieve no.	Sieve size (mm)	% passing by weight
No.4	4.75	100
No.8	2.36	94
No.50	0.3	22
No.200	0.075	0

Table 7 Physical Properties of Soft Asphalt Cement Recycling Agent

Property	**Test Conditions**	**ASTM Designation No.**	**Value**
Penetration	25ºc, 100gm, 5sec	D5-06	104 (1/10mm)
Softening Point	(ring and ball)	D36-95	25 ºc
Ductility	25ºc, 5cm/min	D113-99	80 cm
Flash Point	Cleveland open cup	D92-05	250 ºc
After thin film oven test properties D1754-97			
Retained Penetration of Residue	25ºc, 100gm, 5sec	D5-06	66 %
Ductility of Residue	25ºc, 5cm/min	D113-99	46 cm
Loss on Weight	163ºc, 50g,5 hours		0.35 %

Table 8 Physical Properties of Asphalt Cement Blended with Sulphur powder

Property	**Test Conditions**	**ASTM Designation No.**	**Value**
Penetration	25ºc, 100gm, 5sec	D5-06	66 (1/10mm)
Softening Point	(ring & ball)	D36-95	42 ºc
Ductility	25ºc, 5cm/min	D113-99	110 cm
Flash Point	Cleveland open cup	D92-05	270 ºc
After thin film oven test properties D1754-97			
Retained Penetration of Residue	25ºc, 100gm, 5sec	D5-06	80 %
Ductility of Residue	25ºc, 5cm/min	D113-99	75 cm
Loss on Weight	163ºc, 50g,5 hours		0.15 %

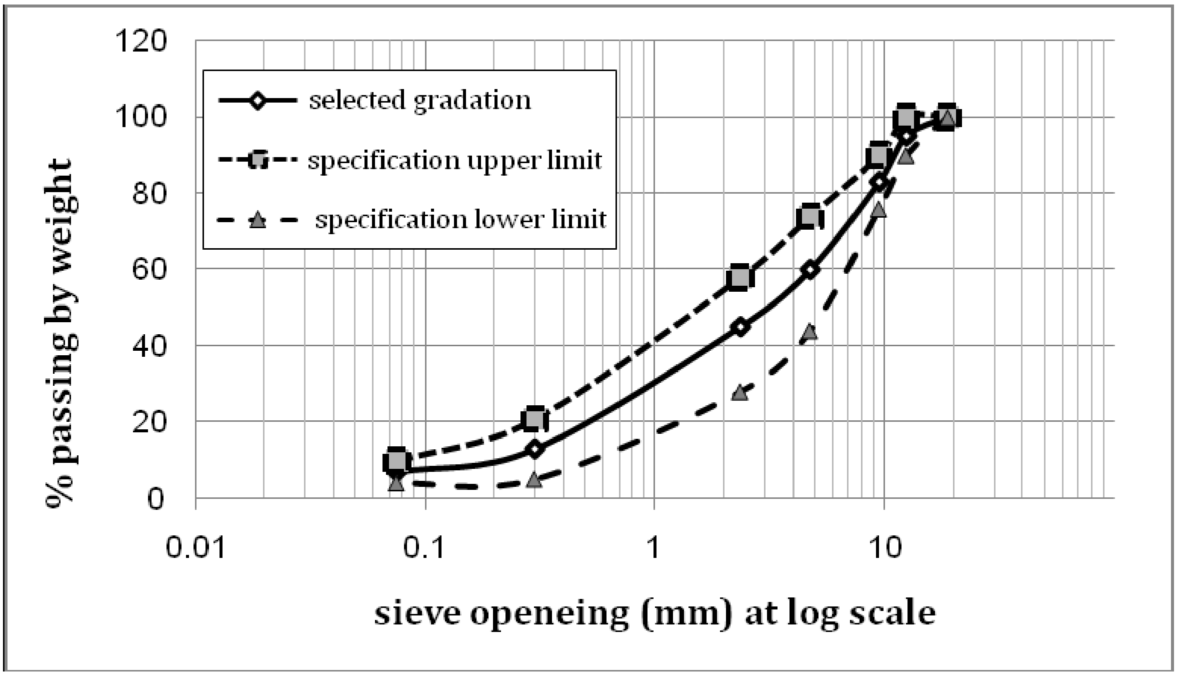

Figure.1 Selected Aggregate Gradation and Specification Limits.

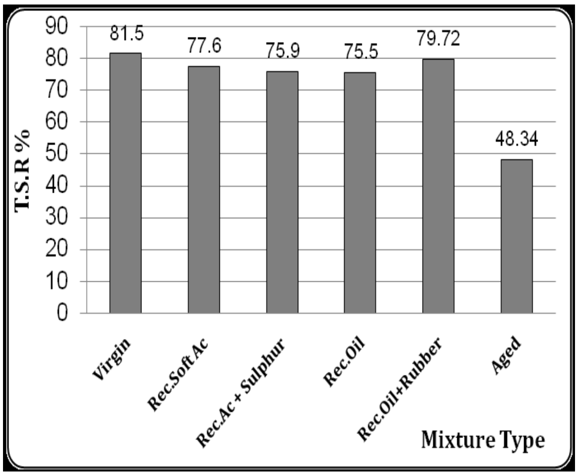

Figure. 2 TSR for various mixtures.

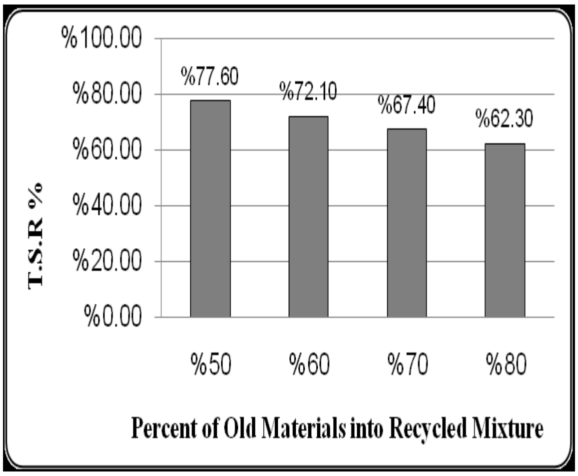

Figure. 3 TSR with Different Mixing Ratio

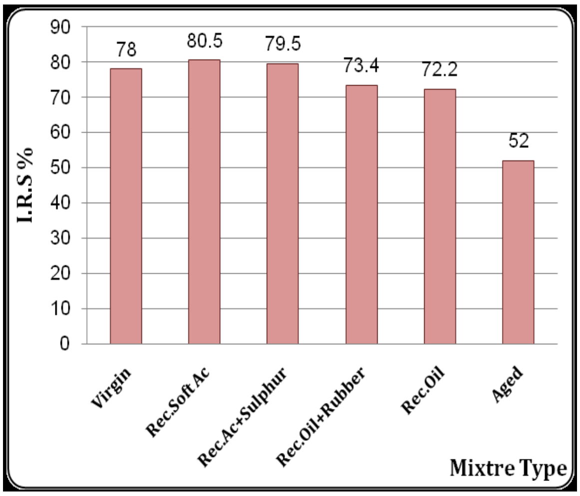

Figure. 4 IRS for various mixtures

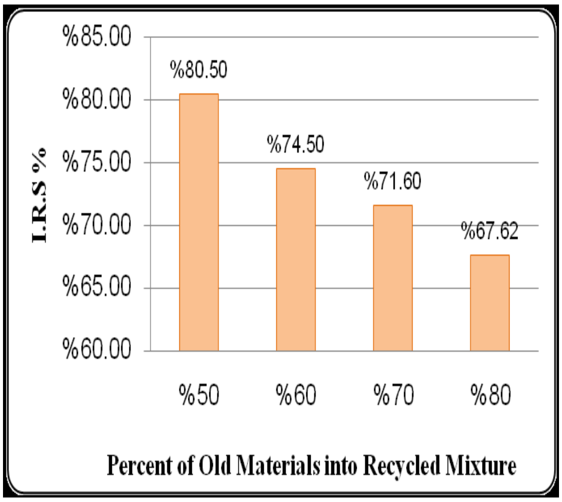

Figure.5 IRS with Different Mixing Ratio