International Journal of Scientific Research in Knowledge, 2(8), pp. 352-361, 2014
Available online at http://www.ijsrpub.com/ijsrk
ISSN: 2322-4541; ©2014 IJSRPUB
http://dx.doi.org/10.12983/ijsrk-2014-p0352-0361

Full Length Research Paper

Assessing Shear and Compressive Strength of Reclaimed Asphalt Concrete

Saad Issa Sarsam*, Ihsan Ali Hasan AL-Janabi

Department of Civil Engineering, College of Engineering, University of Baghdad, Iraq
*Corresponding Author: Email saadisasarsam@coeng.uobaghdad.edu.iq

Received 22 May 2014; Accepted 06 July 2014

Abstract. The prime objectives for this study are evaluating the performance of recycled asphalt concrete, investigating the effect of recycling agent type and amount on mixture performance, and studying the effect of inclusion of more reclaimed materials content into recycled mixtures. For this purpose, reclaimed materials milled from field, filler, virgin asphalt cement, and four types of recycling agents (used oil, oil + crumb rubber, soft grade asphalt cement, and asphalt cement + sulfur powder), have been implemented and were used to prepare recycled mixtures with nominal maximum size of 12.5 mm. The recycling agent that showed the best mixture performance was used to prepare recycled mixtures with different reclaimed materials contents. Mixtures were subjected to Double Punch shear, Compressive Strength, and index of retained strength Test. It was found that using soft grade asphalt cement as a recycling agent revealed better performance than other types of recycling agents. For recycled mixtures with mixing ratio of (50/50) virgin/reclaimed materials, the optimum recycling agent contents were (0.56%, 1%, 1.3%, and 1.5%) by weight of mixture for (used oil, oil + crumb rubber, soft grade asphalt cement, and asphalt cement + Sulfur) recycling agent respectively. Recycled Mixtures with reclaimed materials content, up to 70 %, and soft asphalt recycling agent, showed good performance. The percentages of variation for mixtures properties compared to mixtures with 50 % reclaimed materials were +3.6 %, +4.8 % for double punch shear, and compressive strength respectively, and the reduction in mixtures properties as compared to virgin mixture was in acceptable extent.

Keywords: Compressive strength; Double punch shear; Retained strength; Recycling agent; Reclaimed asphalt concrete

1. INTRODUCTION

This recycling process presents a sustainable solution by using the reclaimed materials milled from the pavement. Such materials could be mixed with virgin materials and recycling agents to produce recycled mixtures. The important benefits of recycling process are the economical savings, reduction of environmental impact, and conservation of natural resources. As the rehabilitation and construction process of highways expand, the costs of pavement materials increase, and there is shortage in the resources of good quality materials. Recycling process is one of the important solutions for this problem. The recycling of existing asphalt pavement materials produces new pavements with considerable savings in material, money, and energy. Aggregate and binder from old asphalt pavements are still valuable even though these pavements have reached the end of their service lives (Al-Qadi et al., 2007). Using Reclaimed Asphalt Pavement (RAP) has become a common practice in many countries. Experience indicated that the recycling of asphalt pavements is very advantageous from different perspectives. Some of the advantages of utilizing RAP include conservation of asphalt and aggregate resources, conservation of energy and reduction in life-cycle cost, (Al-Rousan et al., 2008).

When the pavement mixture reaches its service life, milled materials still maintain considerable value. The milled materials 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 RAP materials on asphalt mixture performance. (Miro et al., 2011) studied the behavior of high modulus bituminous mixes with low penetration grade bitumen and high RAP percentages, four mixtures with RAP percentages of 0%, 15%, 30% and 50%, were analyzed.

In Iraq, the approach of recycling has not yet been adopted, although there is strong need for rehabilitation and construction of pavement structures in all over the country at economical basis. There are few local studies on recycling process, (Sarsam, 2007). The durability of recycled asphalt concrete was investigated by (Sarsam and AL-Zubaidi, 2014); they concluded that the recycled mixture had good resistance to deformation under load repetition than that of reference mixture at temperature (25˚C and 40˚C).

The objectives of this work is to explore the effect of type and amount of recycling agents on reclaimed asphalt mixtures shear, stripping and compressive properties, and to provide some valuable data on the proper materials to be used, and the performance of recycled mixtures. The effect of inclusion of variable percentages of reclaimed materials after recycling into recycled mixtures was also investigated.

2. MATERIALS PROPERTIES

2.1. Asphalt Cement

Asphalt cement of penetration grade (40-50) was used as virgin binder; it was brought from Al-Dura refinery**.** Tests conducted on asphalt cement confirmed that its properties complied with the specifications of State Commission of Roads and Bridges (SCRB, 2007). Table 1 presents the physical properties of asphalt cement.

Table1 Physical Properties of Asphalt Cement

Property	Test Conditions	ASTM Designation No.	Value	SCRB Specification
Penetration	25ºc, 100gm, 5sec	D5-06	42	40-50
Softening Point	(ring & ball)	D36-95	53 ºc	-
Ductility (cm)	25ºc, 5cm/min	D113-99	125	+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 %	-

2.2. Coarse and Fine Aggregate

Crushed coarse aggregate (retained on sieve No.4), and crushed sand (particle size passing sieve no.4 and retained on sieve No.200), were brought from AL-Nibai quarry. 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.

Table 2: Physical Properties of Coarse and Fine Aggregate

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

2.3. Mineral Filler

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

Table 3: Physical Properties of Mineral Filler

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

2.4. Selection of Aggregate Gradation

The Selected gradation in this study followed the (SCRB, 2007) binder course specification, with 12.5 mm nominal maximum size of aggregates. Fig. 1 shows selected aggregate gradation.

2.5. Reclaimed Materials

The Reclaimed asphalt concrete was obtained from milled pavement of Al-Aadhamiya cornice arterial, at Baghdad as shown in fig.2. This roadway was constructed in 1988. It was heavily deteriorated by various cracks, potholes, and ruts existing on the surface, the milling depth of the project were 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 Marshal Property's determination, extraction test according to ASTM D1856 procedure to obtain binder & filler content, gradation and properties of aggregate.

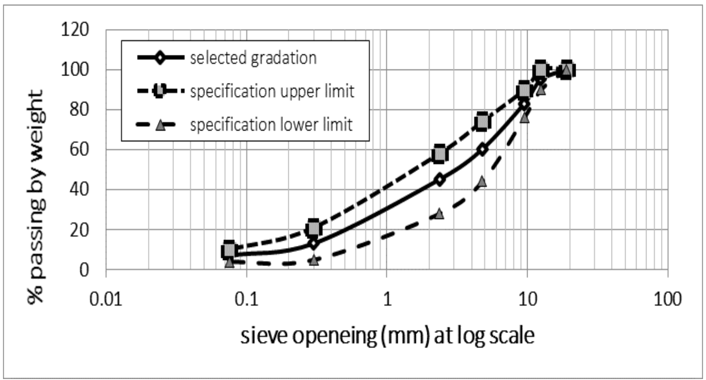

Fig. 1 Selected aggregates gradation

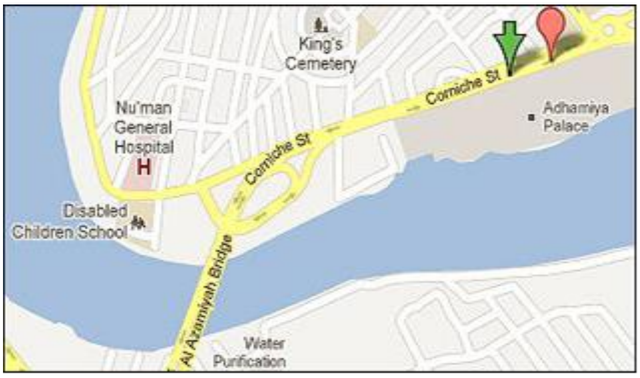

Fig. 2 Location map of reclaimed asphalt concrete

Table 4 presents the properties of reclaimed material after extraction test. The physical properties of the reclaimed asphalt concrete are illustrated in table 5. Gradation of aggregate obtained from reclaimed mixture was determined; ten samples were selected randomly from the milled material stack. It was subjected to extraction test to isolate binder from aggregate, and then aggregate samples were sieved for determination of gradation. The differences between samples were in a minor extent, and the average gradation of the ten samples obtained to be the old aggregate gradation is shown in table 6.

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
	Water absorption %	1.2%
	Wear% (Los Angeles abrasion)	22%
Fine aggregate	Bulk specific gravity	2.590
	Water absorption %	4.4%
Mineral filler	Percent passing sieve no.200	98%
	Specific gravity	2.820

Table 5: Physical properties of reclaimed Materials

Aged Mixture Properties (Reclaimed)	Marshall Stability	3.6 kN
	Marshall flow	1.6 mm
	Air voids	7.4%
	Bulk density	2.192 gm/cm^3

Table 6: Gradation of old Aggregate obtained from reclaimed Mixture

Sieve size (mm)	19	12.5	9.5	4.75	2.36	0.3	0.075
Percentage finer by weight	100	95	87	65	51	12	2

2.6. Recycling Agents

Four types of laboratory prepared recycling agents are implemented in this investigation. Their properties are as shown below.

2.7. Used Oil

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

2.8. Used Oil Blended with Crumb Rubber and chlorine detergent

Crumb rubber was obtained from local market as a disposal of tires that grinded. It was blended with used oil and chlorine detergent in the following components percentages: (77% used oil + 22% crumb rubber + 1 % chlorine) as addressed by (Sarsam, 2007). The used oil was heated to 100ºc and crumb rubber was added with stirring, then chlorine was added as a solvent to increase the homogeneity of blend and support the chemical reaction, which was figured by the swelling of the mixture and bubble formation. Table 7 shows its Particle size distribution.

Table 7: Particle Size Distribution of Crumb Rubber

Sieve size (mm)	4.75	2.36	0.3	0.075
% passing by weight	100	94	22	0

2.9. Soft Grade Asphalt Cement

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

2.10. Asphalt Cement blended with Sulfur Powder

It was addressed by (Sarsam, 2007) that recycled mixes with sulfur exhibit significantly better engineering properties than conventional mixtures. Iraq produce sulfur, consequently it could be economically possible to use sulfur in recycling process. Same type of asphalt cement grade 40-50 that was used as a virgin binder was heated to nearly 140ºc, and the sulfur powder was added with stirring for 30 minutes until homogenous blend was achieved. The component percentage of the bled was 20/80 sulfur/asphalt. Its physical properties are listed in table 9.

Table 8 Physical Properties of Soft Asphalt Cement Recycling Agent

Property	Test Conditions	ASTM Designation No.	Value
Penetration	25ºc, 100gm, 5sec	D5-06	104
Softening Point	(ring & 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 hrs.		0.35 %

Table 9: Physical Properties of Asphalt Cement Blended with sulfur powder

Property	Test Conditions	ASTM Designation No.	Value
Penetration	25ºc, 100gm, 5sec	D5-06	66
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 hrs.	--------	0.15 %

3. PREPARATION OF ASPHALT CONCRETE 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 (140ºC) 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 thoroughly coated with asphalt cement.

3.2. Preparation of Recycled Mixture

RAP was heated to approximately 150ºC and the recycling agent was added and mixed thoroughly. On the other hand, Virgin Coarse and fine aggregate wee combined with mineral filler to meet the specified gradation, and then heated to 160ºC. Virgin binder was heated to 140ºC separately then added at the desired amount, and mixed thoroughly until all aggregate particles were coated with asphalt cement. The mixing ratio of virgin/old material was determined, the recycled RAP mixture was mixed with the virgin asphalt concrete prepared using Four mixing ratios of (50/50, 40/60, 30/70, 20/80) virgin/reclaimed material. Four types of recycling agents were implemented to recycle reclaimed mixture as mentioned before.

3.3. Compaction of Asphalt Concrete Marshal Specimens for shear test

Cylindrical specimens of 102 mm in diameter and 63.5 mm in height were prepared for the double punch shear test. Marshall Mold, spatula, and compaction hammer were heated on a hot plate to a temperature between (140-150ºC). 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. Fig.3 show part of the prepared specimens for double punch shears determination.

3.4. Compaction of Asphalt Concrete Specimens for Compressive Strength test

Cylindrical specimens of 101.6 mm in diameter and 101.6 mm in height were 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 marshal specimens density, compaction process stop automatically and the mold was discharged from the device. Fig.4 shows part of gyratory compacted specimens for compressive strength determination, while Fig.5 shows the gyratory compactor.

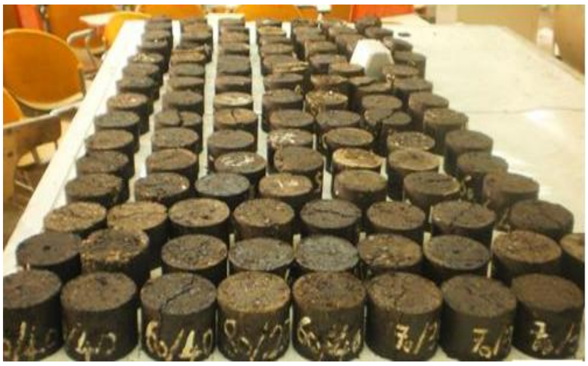

Fig. 3: Part of (double punch shear test) specimens

Fig. 4: Part of (compressive strength) specimens

4. TESTING PROGRAM

The testing program include subjecting virgin specimens, recycled specimens of the four types of recycling agents, and virgin mixture with different percentages of reclaimed materials content of (50%,60%, 70%, 80%) to shear and compressive strength test, and determination of stripping behavior through index of retained strength IRS test.

4.1. Double Punch shear Test

This test procedure was developed and used to measure the stripping of the binder from the aggregates; this test was reported by many studies (Jimenez, 1974; Solaimanian, 2004; Sarsam, 2006). Marshall Specimen was used for this test; it was conditioned by placing in water bath at 60ºC for 30 min. The test was performed by centrally loading the cylindrical specimen, using two cylindrical steel punches placed on the top and bottom surface of the sample. The specimen was centered between the two punches (2.54 cm in diameter), perfectly aligned one over the other, and then loaded at a rate of 2.54 cm/minute until failure. The reading of dial gage at the maximum load resistance was recorded. Figure 6 illustrates the double punch test apparatus.

4.2. Compressive strength test

This test was conducted to determine the suitability of these mixtures in pavement under given loading and environmental conditions. The test followed the procedure of (ASTM D1074-02). Compressive specimens which were prepared and compacted, was stored in air bath at 25ºC for 4 hours, then, the test was performed by applying a compressive load at a constant rate of 5.08 mm/min to measure the maximum resistance to load at failure.

Fig. 5: Gyratory compactor of asphalt concrete

Fig. 6: Double punch shear test

4.3. Index of Retained Strength Test

This method covers measurement of the loss of cohesion resulting from the action of water on compacted bituminous mixtures. The test followed the procedure of (ASTM D1075-07). A set of six specimens for each variable was 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. 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. The index of retained strength was then determined as the percentage of difference between the specimens of each set.

5. DISCUSSION OF TEST RESULTS

5.1. Effect of Recycling Agent Type on Punching shear Strength

Results of double punch test confirmed the improvement of punching strength of recycled mixtures when compared to reclaimed (aged) asphalt concrete. Double punch test indicates the shear resistance behavior between binder and aggregate. The punching strength for virgin mix was higher than recycled mixtures. This may be related to the fact that recycling agent has a softening effect in the mixture, which reduces the viscosity. Recycled mix with (Soft asphalt cement) had the highest punching strength value comparing to the other recycled mixtures, and recycled mix with (Oil) revealed the lowest value. Punching strength values for all recycled mixtures were higher than aged mixture; this could be attributed to changing the stiff mode of the reclaimed mixture to more flexible mode by the addition of recycling agent. Such results agrees well with (Sarsam, 2007) findings. Fig. 7 presents double punch test results for virgin, recycled, and aged mixtures.

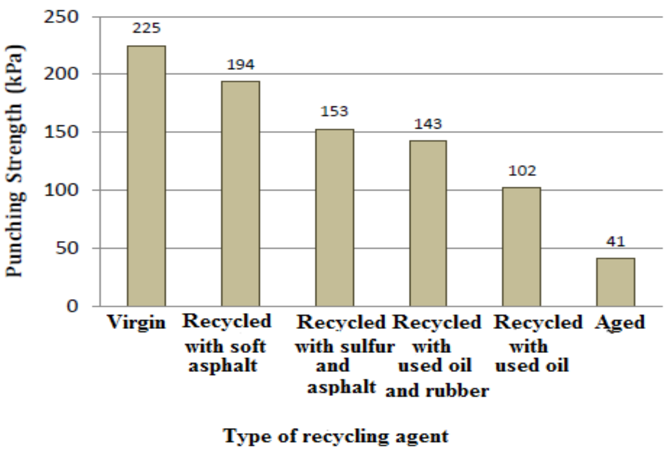

Fig. 7: Variation of punching shear with recycling agent

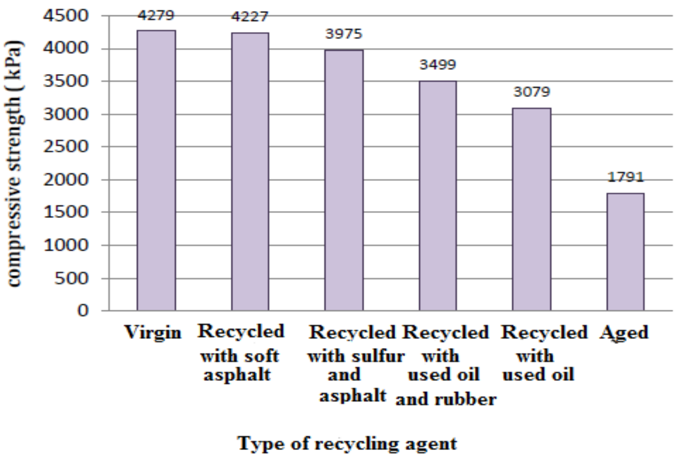

Fig. 8: Variation of compressive strength with recycling agent

5.2. Effect of Recycling Agent Type on Compressive Strength

Compressive strength test results revealed a pronounced improvement for recycled mixtures when compared to aged mixes. Virgin mixture had higher compressive strength than recycled mixtures, but the compressive strength for recycled mixture with (Soft Ac) was slightly lower than that of virgin mix as illustrated in Fig.8. The inclusion of crumb rubber or sulfur in recycling agent increased the compressive strength of the mixes as compared to reclaimed mixes.

5.3. Effect of Recycling Agent Type on Index of Retained Strength

Index of Retained Strength (I.R.S) is an indication for mixture resistance to water damage. Fig.9 shows a good performance for recycled mixtures when compared to aged or virgin mixes. Mixtures with Soft asphalt or asphalt with Sulfur exceeded the I.R.S value for virgin mixture, which indicates that these mixtures were less susceptible to moisture damage as compared to virgin mix. This behavior may be explained by the better coating of aggregates by recycled binder. All of (I.R.S) values for recycled mixtures exceeded 70 %, and achieved the criteria of (SCRB 2007) for index of retained strength.

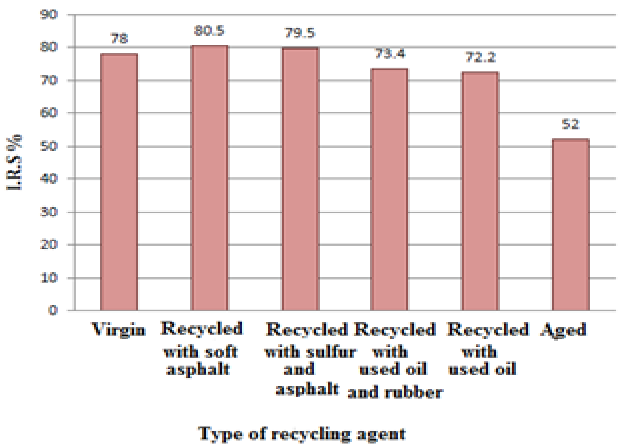

Fig. 9: Variation of index of retained strength with recycling agent

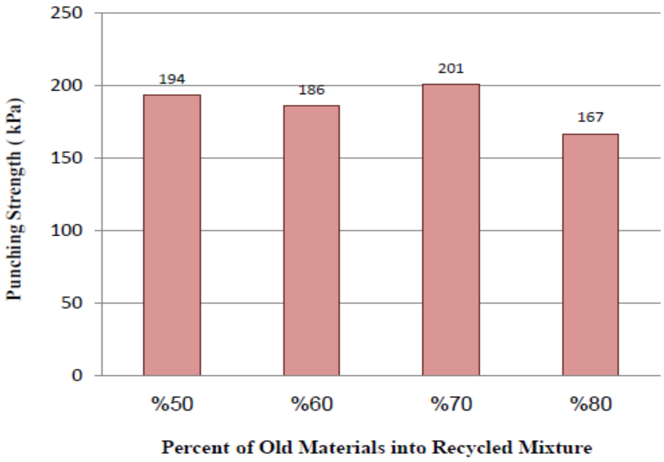

Fig. 10: Variation of punching shear with mixing ratio

5.4. Effect of the Inclusion of More Old Materials on Punching Strength

Double punch test results confirmed that recycled mixtures with high percentages of old materials performed well. The punching strength value for recycled mix with 70% old materials was the highest, comparing to the corresponding mixtures with 50 % and 60 %, reduction in test value was noticed for mixture with 80% old materials. These results indicate that recycled mixtures with old materials up to 70 % could perform well in term of punching strength. Fig.10 illustrates the punching strength results.

5.5. Effect of the Inclusion of More Old Materials on Compressive Strength

Compressive strength results showed that with the increase of old materials content up to 70% into recycled mixtures, the compressive strength values for dry specimens increased. For mixture of 80 % old materials content, the value of compressive strength decreased. That's could be explained by the action of aged materials which result into more stiff and hard mixture, when the old materials content increased extensively, the bonding between mixture particles was affected which may result into less resistance to compressive force. This may indicate the reduction in the asphalt concrete quality from load sustaining point of view. Such material may be recommended for lower pavement layers and not for tire sustaining layer. Such finding was in agreement with (Al-Rousan et al, 2008; Al-Qadi et al, 2007). Fig.11 illustrates the results of compressive strength test.

5.6. Effect of the Inclusion of More Old Materials on Index of Retained Strength

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 2007). Fig.12 illustrates the result values of index of retained strength.

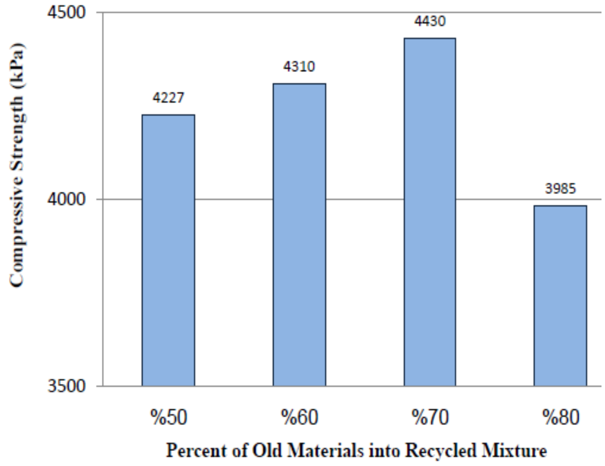

Fig. 11: Variation of compressive strength with mixing ratio

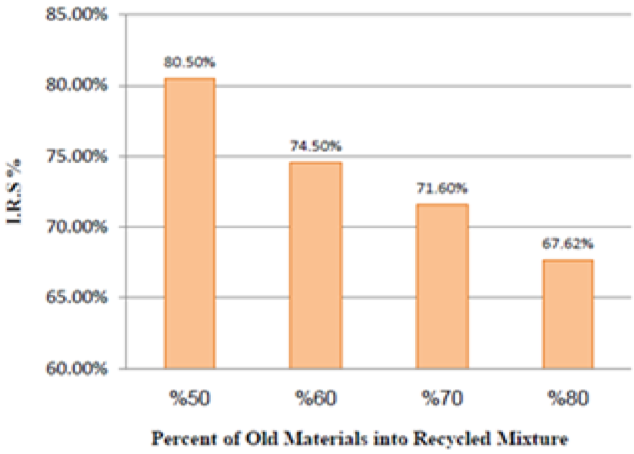

Fig. 12: Variation of IRS with mixing ratio

5.7. Total impact of Recycling on Mixtures Performance

The total positive impact of recycling was explored by comparing tests results of recycled mixtures for the different types of recycling agents, with results of reclaimed (aged) mixture as it appears in table 10. The percent of improvement in the pavement quality, and these performance aspects was concerned to establish the full picture that clarifies the advantages of each recycling agent in recycling process. The selection of the desirable recycling agent to be adopted for the next step will be based on the economic justification of these comparable results. On the other hand, table 11 demonstrates the comparative performance and differences gained by using different types of recycling agents as compared to virgin mixture. The recycled asphalt concrete was still have lower quality when compared to virgin mix from the load sustaining abilities, this is in agreement with (Colbert and You, 2012; Sarsam, 2007).

Table 10: Improvement in physical properties of recycled mixture as compared to aged mixture

Recycling agent	Bulk density	Double punch shear	Compressive strength	Index of retained strength
Soft asphalt	+5.1%	+375%	+136%	+54
Soft asphalt + sulfur	+4.4%	+275%	+122%	+52
Soft asphalt + used oil	+6.4%	+150%	+72%	+38
Soft asphalt + used oil + rubber	+3.1%	+250%	+95%	+41

Table 11: Changes in physical properties of recycled mixture as compared to virgin mixture

Recycling agent	Bulk density	Double punch shear	Compressive strength	Index of retained strength
Soft asphalt	-2.3%	-13.7%	-1.2%	+3.2
Soft asphalt + sulfur	-2.9%	-32%	-7.1%	+1.9
Soft asphalt + used oil	-1.27%	-54.6%	-28%	- 7.4
Soft asphalt + used oil + rubber	-4.23%	-36.4%	-18.2%	- 5.8

Table 12 shows the impact of using more reclaimed asphalt concrete in the recycling process, the physical properties of the mixture of 50/50 reclaimed to virgin material are illustrated in the table indicating an acceptable quality. The percent variation in the quality when the mixing ratio changes, is also indicated in the table.

Table 12: Variation in mixture properties according to virgin/old mixture ratio

Mixing ratio of material (virgin/old)	**(50/50) test results**	**Percent variation in properties**		
		(40/60)	**(30/70)**	**(20/80)**
Optimum recycling agent content (%)	1.3%	-15.3%	-27.2%	-67.5%
Marshal stability (KN)	10.29	-11.5%	+3.3%	-21.2%
Marshal flow (mm)	3.14	+4.3%	-39%	-39.5%
Bulk density (gm/cm^3)	2.305	-0.08%	-1.1%	-1.0%
Double punch shear strength (KPa)	194	-4.1%	+8%	-16.9%
Compressive strength (KPa)	4227	+1.9%	+2.7%	-10%
Index of retained strength (%)	80.5%	- 7.4%	- 3.8%	-5.5%

6. CONCLUSION

1- Double punch test confirmed the improvement of punching strength of recycled mixtures when compared to reclaimed (aged) asphalt concrete, while the punching strength for virgin mix was higher than recycled mixtures. Recycled mix with Soft asphalt cement had the highest punching shear strength when compared to the other recycling agents.

2- The inclusion of crumb rubber or sulfur in recycling agent increased the compressive strength of the mixes as compared to reclaimed mixes.

3- Mixtures with Soft asphalt or asphalt with Sulfur 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.

4- Recycled mixtures with old materials from 50% to 70 % could perform well in term of punching strength, and compressive strength. The index of retained strength values decreased as the percentage of old materials into recycled mixtures increased.

5- The recycled asphalt concrete have lower quality when compared to virgin mix from the load sustaining abilities point of view, and may be recommended for lower pavement layers which are not tire sustaining layer.

REFERENCES

Al-Rousan T, Asi I, Al-Hattamleh O, Al-Qablan H (2008). Performance of Asphalt Mixes Containing RAP. Jordan Journal of Civil Engineering, 2(3): 218-227.

Al-Qadi I, Elseifi M, Carpenter S (2007). Reclaimed Asphalt Pavement—A Literature Review. Report No. FHWA- ICT-07-001, Illinois Center for Transportation, Rantoul, IL.

American Society for Testing and Materials (2009). Annual Book of ASTM Standards, Road and Paving Materials; Vehicle-Pavement System. (04):03.

Celauro C, Bernardo C, Gabriele B (2010). Production of Innovative, Recycled and High-Performance Asphalt for Road Pavements", Resources, Conservation and Recycling, 54: 337-347.

Colbert B, You Z (2012). The Determination of Mechanical Performance of Laboratory Produced Hot Mix Asphalt Mixtures Using Controlled RAP and Virgin Aggregate Size Fractions", Construction and Building Materials, 26: 655-662.

Doh YS, Amirkhanian SN, Kim KW (2008). Analysis of Unbalanced Binder Oxidation Level in Recycled Asphalt Mixture Using GPC. Construction and Building Materials, 22: 1253–1260.

Jimenez RA (1974). Testing for Debonding of Asphalt from Aggregates", Transportation Research Record 515, TRB, National Research Council, Washington, D.C., pp. 1–17.

Miro R, Valdés G, Martinez A, Segura P, Rodriguez C (2011). Evaluation of High Modulus Mixture Behaviour with High Reclaimed Asphalt Pavement (RAP) Percentages for Sustainable Road Construction", Construction and Building Materials, 25: 3854–3862.

Sarsam SI (2007). A Study on Aging And Recycling of Asphalt Concrete Pavement", University of Sharjah Journal of Pure & Applied Sciences, 4(2): 79-96.

Sarsam SI (2006). Improving Asphalt Concrete Quality for Ramps and Approaches. Indian Highways, 3 (34): 61-66.

Sarsam S, AL-Zubaidi I (2014). Resistance to Deformation under Repeated Loading of Aged and Recycled Sustainable Pavement. American Journal of Civil and Structural Engineering AJCSE 2014, 1(2): 34-39.

Solaimanian M, Harvey J, Tahmoressi M, Tandon V (2004). Test Methods to Predict Moisture Sensitivity of Hot-Mix Asphalt Pavements. Moisture Sensitivity of Asphalt Pavements CD-ROM, Transportation Research Board, National Research Council, Washington, D.C., pp. 77-110.

State Commission of Roads and Bridges (SCRB) (2007). Standard Specification for Roads & Bridges. Ministry of Housing & Construction, Iraq.

Prof. Saad Issa Sarsam was born in Baghdad (1955), got his BSc. In Civil Engineering (1977), Post graduate diploma in Transportation Engineering (1978); MSc in Transportation Engineering (1980).

He worked as senior material Engineer for NCCL (1982-1992); He joined the academic staff at University of Mosul (1992-2005) and got the Assistant Professor degree at (2002); He joined the academic staff at University of Baghdad (2005 until now) and got the Professor degree at (2007).

Areas of specialization and interest: (Roller compacted concrete; modified asphalt concrete; Asphalt stabilized embankment models; Road user characteristics).

Ihsan Ali Hasan AL-Janabi was born in Baghdad, (1987), got his BSc. in civil engineering (2010); MSc. In civil engineering, Transportation (2012). He worked as site engineer with Golden House Company in roads rehabilitation project in the year of 2009 in (Al-Obaidy) residential area; then as site engineer with Al-Saifi Company in various facilities construction project in north Baghdad entrance in the year of 2012-2013.

Worked as materials Engineer with the Iraqi-Italian Group in highway rehabilitation and construction project in Um-Qasser / Basra in the year of 2013 – 2014. He worked as Engineer in the Faculty of Technical Education, Scientific services and consultations Bureau, in the year of 2014 – until now.