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The possibility of reusing recycled aggregates in the production of hot mix asphalt

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ABSTRACT

The use of aggregates resulting from destroyed concrete as a substitute for natural aggregates in the production of hot mix asphalt for roads with high traffic loads reduces natural consumption and the amount of scattered waste. The study was conducted by designing the hot mix asphalt using the Marshall method with different proportions of recycled aggregate. The results showed an improvement in the stability, flow and indirect tensile tests of the aggregate compared to the conventional mixture. An increase in the recycle aggregate leads to an increase in the proportion of air voids, but it also leads to a decrease in the proportion of voids in the aggregate and asphalt-filled voids. The optimum bitumen content increases with the amount of recycled concrete. Recycled aggregate can be used as a substitute for natural aggregate in hot mix asphalt design successfully. The study found that increasing the percentage of recycled concrete (RCA) in hot bituminous mixtures led to an increase in air voids (VA) and a decrease in voids in mineral aggregates (VMA) and voids filled with asphalt (VFA). However, these percentages decreased with the increase in RCA due to the behavior of the recycled aggregates under load. The optimum bitumen content (OBC) also increased with the increase in RCA. The asphalt mixture's resistance to tensile stress increased with the increase in RCA up to 50% and at 25˚C and RCA 40˚C by up to 8%. The process of using recycled aggregates as an alternative to natural aggregates in hot bituminous mixtures is applicable up to a certain percentage.

1. Introduction

(Huang et al., 2007) Recycled aggregate concrete (RCA) is a sustainable alternative to conventional natural aggregates (NA) and is derived from construction and demolition wastes. The disposal of demolished buildings as RCA in flexible pavement has been proposed as an effective solution for waste management. The utilization of RCA offers economic and environmental benefits in new constructions. (Zoorob and Suparma. 2000) With the majority of asphalt pavement mixtures consisting of aggregate (90-95% by weight or 75-85% by volume), incorporating RCA can lead to significant aggregate savings. (Khalaf and DeVenny 2004)Initially implemented in Germany after

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World War II, the use of demolition waste has gained traction for its sustainable advantages.

(Akbulut and Gürer 2007)The original aggregate sources have been reduced in recent years due to the development of construction and the increased use of materials. Consequently, waste disposal sites decreased and regular sources of aggregate decreased, prompting researchers to consider using recycled concrete from old concrete structures as a new source of aggregate. Using recycled concrete is a good solution for the environment and reducing construction costs Recycled concrete (coarse, fine) aggregate (R.C.A.) is being utilized in several infrastructure applications such as in base aggregate. With rising transportation and disposal-related costs, R.C.A. comes from the debris of the builds, bridges, concrete, runways (airport), and concrete roadbeds.

Researchers in Iraq have investigated the use of construction and demolition waste in new concrete asphalt.

Al-Sarrag and Saleh (2014) found that incorporating 50% to 75% of recycled concrete aggregates (R.C.A.) improved the Marshall properties of asphalt mixtures. Hassoon and Al-Obaedi (2014) studied the utilization of recycled concrete as a sub-base material for highways and observed acceptable density and higher C.B.R. values. Kareem (2014) examined the use of recycled cement concrete (R.C.C.) as filler in asphalt mixtures, emphasizing the need for quality control measures. Razzaq (2016) analyzed the effect of adding R.C.A. to asphalt concrete, noting a slight decrease in Marshall Stability and Flow but higher Marshall Stiffness with 10% R.C.A. Majeed (2017) explored the impact of adding kaolin to asphalt mixtures with natural and recycled coarse aggregates, observing improved stability and bonding with asphalt materials. Various studies worldwide have investigated the use of recycled waste materials in pavement, including Aljassar et al. (2005) on local asphalt mixtures with rounded concrete aggregate and Mills-Beale and You (2010) on asphalt mixtures using recycled concrete aggregate.

Cho et al. (2011) examined the possibility of applying recycled aggregates in hot asphalt mixtures, while Pérez et al. (2012) investigated designing hot asphalt mixtures using recycled aggregates from demolished buildings. Alfaqawi (2012) studied the use of recycled aggregates in hot asphalt mixtures, noting changes in specific gravity, absorption, and mix stability. Motter et al. (2015) evaluated the use of recycled aggregates in hot asphalt mixtures and Mostafa et al. (2015) assessed their effect on hot asphalt mixtures. Ektas and Karacasu (2012) examined the use of concrete waste in hot asphalt production, observing changes in specific gravity, optimum asphalt content, and mix stability.

1.1 Scope of Work

The following missions will be considered to complete the required aims of this study.

To study the possibility of using (RCA) in flexible pavement as an effective alternative to the conventional aggregate of flexible pavement in Iraq.

Utilize the Marshall test to produce asphalt mixtures by using (recycled concrete aggregate and original aggregate) mixture and to show the relationship between them with many parameters such as bulk density (GB), Air voids (AV), VMA, VFA.

Determining the design Asphalt Content using RCA in hot asphalt mixtures, based on the Marshall test & ITS test.

Reusing recycled aggregates in hot mix asphalt production promotes environmental responsibility and sustainability in building and road infrastructure sectors. This strategy conserves natural resources, reduces waste, reduces energy and emissions, and saves on transportation costs. Recycled aggregates also improve pavement performance, making them more resilient and long-lasting. Regulatory compliance is achieved through the use of recycled materials in construction projects. The integration of recycled aggregates in hot mix asphalt contributes to the development of sustainable infrastructure, meeting societal demands with less environmental impact. The goal is to create a more economical, ecologically friendly, and sustainable method of building roads in line with sustainable development and the circular economy.

2. Materials and Experimental Work

2.1 Materials

The materials used in this study are divided into two categories:

Pure materials include: asphalt cement, natural aggregate and Filler.

Asphalt Cement (AC) of (40-50) was used according to the suggestion of standard performance grade of the Al- Dura binder which usually used in Baghdad, as shown in the Table1.

The crushed aggregates brought up from graded aggregate stockpiles are used for a regionally asphalt concrete batch plant located in Baghdad (Al-Nabaie). This aggregate is widely used in Baghdad for asphalt mixtures as shown in Tables 1.

The filler utilized in this work is ordinary Portland cement from Al- Mass Company that is locally production, shown in Table 1.

Table 1: Physical properties of asphalt binder, coarse aggregate, fine aggregate, filler

Test	Test Conditions	ASTM Designation	Test Value (measured)	SCRB Spec. R9, (2003)
Penetration	25°C, 100 gm.,5 sec, (0.1mm)	D113	44	40-50
Ductility, cm	25°C, 5cm/min	D36	139	>100
Softening Point (Ring & Ball Test), °C	(4±1) °C/min.	D70	51.5	-
Specific Gravity of Asphalt	25°C	D92	1.04	-
Flash Point, °C	Cleveland Open Cup	D92	314	>232
Fire Point, °C	Cleveland Open Cup	D4402-15, 2015	321	-
Rotational Viscosity Pa.sec	135°C		0.51	-
	165°C		0.15	-
Apparent Specific gravity Of course agg.		ASTM C127	2.620	
Apparent Specific gravity of fine agg.		ASTM C128	2.661	
Bulk Specific gravity of fine agg			2.625	
Bulk Specific Gravity of filler			3.18	
Passing Sieve No.200 (0.075 mm) filler			97	

Recycled Concrete Aggregate (R.C.A.).

Recycled concrete R.C.A. was brought from the crushed of old buildings. The ages of these buildings are more than 20 years, four percentages of R.C.A. are used to prepare specimens of laboratory testing (25, 50, 75 and 100%) by weight replacement of pure aggregate the quantities of replacement between natural aggregates and recycled aggregates, showing in Table 3.

Table 2: Physical properties of RCA aggregate

Laboratory Test	Results
Apparent Specific gravity	2.612
Bulk Specific gravity	2.343

Table 3: Replacement between natural (NA) and recycled aggregates (RCA) (gm.)

Sieve	%	Aggregate	4%	4.5%	5%	5.5%	6%
"1/2	%25 RCA	RCA(gm.) NA(gm.)	14.4 43.2	14. 25 42.97	14.2 5 42.7 5	14.17 5 42.52 5	14.1 42.3
"3/8		RCA(gm.) NA(gm.)	34.56 103.6 8	34.38 103.14	34.2 102. 6	34 102	33.8 101. 4
"1/2	%50 RCA	RCA(gm.) NA(gm.)	28.8 28.8	28.65 28.65	28.5 28.5	28.35 28.35	28.2 28.2
"3/8		RCA(gm.) NA(gm.)	69.12 69.12	68.76 68.76	68.4 68.4	68 68	67.6 5 67.6 5
"1/2	%75 RCA	RCA(gm.) NA(gm.)	43.2 14.4	42.9 14.25	42.7 5 14.2 5	42.52 5 14.17 5	42.3 14.1
"3/8		RCA(gm.) NA(gm.)	103.6 8 34.56	103.14 34.38	102. 6 34.2	102 34	101. 4 33.8

2.2 Materials proportions and Tests / specimens preparation

The test methods employed in this study in order to investigate the viability of different percentage of recycling building demolition waste as coarse aggregate in hot mix asphalt include indirect tensile strength test and Marshall test to determine the optimum asphalt contents, stability, mix resistance to plastic flow. The Marshall Mix design method uses various techniques to estimate the optimum asphalt binder content. Samples are prepared in proportions of 4%, 4.5%, 5%, 5.5%, and 6% at increments of 0.5% by weight of mix, with some samples above and below the estimated binder content. The standard preparation procedure follows AASHTO T245 and ASTM D 6926-10.

Specimens are prepared for each percentage using about 1200g of mixture. Aggregates are heated, mixed with a dry blend, and then the required amount of bituminous material is added. The mixture is thoroughly coated and placed in an oven at a specific temperature. It is then placed in a mold and compacted using a specified number of blows.

The relationship between the asphalt binder viscosity and temperature depending on the rotational viscosity at temperatures of (135) Cº and (165) Cº for binder utilizing the test of

Brookfield viscometer according to (ASTM D4402-15).

The asphalt mixtures are mixed and compacted at temperatures corresponding to specific viscosity ranges. The mixture is placed in the mold, compacted, and subjected to the required number of blows (75 blows of each side) with the specified compaction hammer.

Indirect Tensile Experiment

These experiments aim to monitor the resistance of bituminous mixtures to indirect tensile under the influence of traffic loads. Furthermore, climatic conditions and thus determine the resistance of the bumps to cracks of all kinds and grooves.

By loading the samples, the Marshall cylindrical samples are tested according to (ASTM-D4123).

Plate (1) indirect tensile strength tester

Compressive verticality acting parallel to the axis of the sample after being immersed in water at temperatures (25 and 40) 50 mm/min is recorded. It ensures a uniform distribution of the tensile strengths that increase until the sample collapses at a test speed as shown in Plate (1).Shows the method of loading the sample. Breaking load the tensile strength is calculated by the relationship shown. Equation (1)

This equation assumes that the bituminous mixture sample is flexible and homogeneous, and as we know that this is not true, but it can give an approximate model of the tensile strength properties of the tested bituminous samples.

$$St = 2000\ p / \pi\ t\ d \qquad \text{..... (1)}$$

Where,

St = Tensile strength, kPa

P = Maximum load, N

t = Specimen height immediately before tensile test, mm

D = Specimen diameter, mm

3. Results and Discussion

The test results of hot mix asphalt specimens with and without RCA materials for the 4, 4.5, 5, 5.5 and 6 of binder content. The Test results included Marshall Test (Density, Air voids, VMA, VFB, Stability, and Flow) for hot mixtures. All results of mechanical tests are described below.

Figure1 shows the effect of using RCA on the bulk density results after adding it at rates of 25%, 50%, 75% and 100%.

Whereas, Figure1 shows Marshall Density increased and improved compared to the traditional mixture, when inclusion of RCA up to 25% in the hot mixes tends to increase the bulk density properties but the addition of

RCA beyond 25% results decreases of the bulk density properties compared to the traditional mixture, because of the porosity of the recycled aggregate from the demolition of concrete and this was confirmed by previous studies (Al-Sarrag and Saleh 2014), conducted research with the aim of conducting a preliminary assessment of the reuse of C&D concrete building waste as coarse aggregate in hot asphalt mixtures according to the Marshall method using asphalt (40- 50) , As for the results of the study, it indicated an increase in the optimum bitumen content and a decrease in the specific gravity of the asphalt mixture With an increase in the proportion of R.C.A. , as well as an increase in stability with an increase in R.C.A. until the proportion of the mixture is 50% of the recycled aggregate, The stability decreases with the increase in the replacement of aggregates. The study also showed an increase in the indirect tensile strength by increasing the recycled aggregate to 50%, and then it begins to decrease. The study indicated that the use of recycled aggregates from demolishing concrete may improve the properties of the hot mix asphalt to a certain percentage.

Also, (Motter, Miranda et al. 2015) conducted a study with the aim of evaluating the use of recycled aggregates resulting from demolishing concrete in the design of hot asphalt mix instead of natural aggregates, and studying the effect of different proportions of recycled aggregates on the volumetric properties of mixtures prepared by Marshall method, the results showed the study found that R.C.A. has high absorption, low specific gravity, and high wear. The results of the Marshall test showed a decrease in the value of Gm, Gmm. with an increase in the recycled aggregates, as well as an increase in the value of (VA, V.M.A., and VFB), as well as an increase in the content of optimum asphalt (O.B.C.).

The increase in the proportion of recycled aggregates in the hot bituminous mixtures, the study also showed a decrease in the stability and flow of the bituminous mixtures with the increase in the proportion of recycled aggregates. Compared to the traditional mixture, but it was within the required specifications

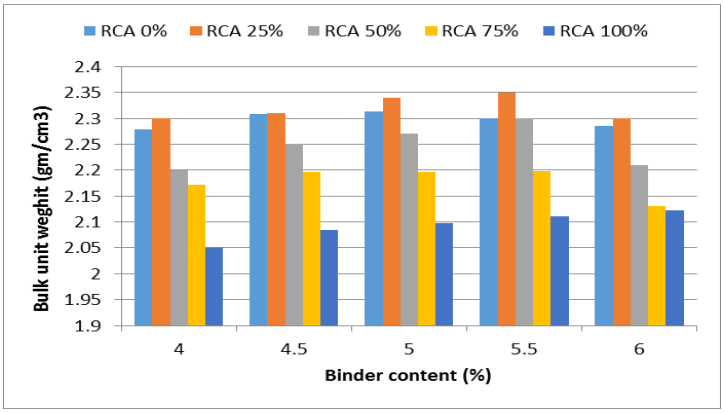

Figure1: Effect of RCA utilization on Bulk Density

Figure 2 shows the effect of using RCA on the stability results after adding it at rates of 25%, 50%, 75% and 100%.

Whereas, Figure2 shows the relationship between stability and the proportion of RCA recycled aggregates, an improvement and an

increase Stability at the adjustment rate 25% RCA to 50% NA compared to the traditional mixture, and then it begins to decrease with an increase in the recycled aggregate, but it achieved the technical requirements required in the general conditions and specifications.
As well as an increase in stability with an increase in R.C.A. until the proportion of the mixture is 50% of the recycled aggregate, the stability decreases with the increase in the replacement of aggregates.

(Al-Sarrag and Saleh 2014), conducted research As for the results of the study, it indicated increase in stability with an increase in R.C.A. until the proportion of the mixture is 50% of the recycled aggregate, The stability decreases with the increase in the replacement of aggregates.

(Alfaqawi 2012) to investigate the possibility of using recycled aggregates in the production of a hot-prepared asphalt mixture according to the Marshall method, as for stability, the results of the study, it indicate for it decreased with an increase in R.C.A. After a certain limit of adding recycled aggregate, this is what, (Motter, Miranda et al. 2015) referred to in his study decrease in the stability and flow of the bituminous mixtures with the increase in the proportion of recycled aggregates. Compared to the traditional mixture, but it was within the required specifications

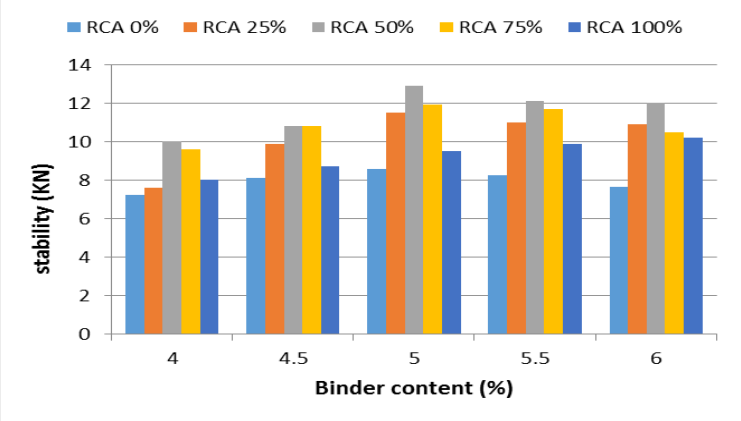

Figure 2: Effect of RCA utilization on average stability

Figure 3 shows the effect of using RCA on the results of air voids after adding it at rates of 25%, 50%, 75% and 100%.
Whereas, Figure3 shows relationship between the percentage of air voids and the percentage of recycled aggregates in the mixture From the figure, we notice an increase in the proportion of air voids with the increase in the proportion of RCA, this increase in the proportion of air voids is due to the high porosity of recycled aggregate compared to natural aggregate, for example(BC4RCA0) , for as a control hot asphalt mixture , after adding of RCA (25%, 50%,75% and 100%) by total weight of aggregate there was an increase in Air voids results by (19.3% , 2.4% , 19.3% and 19.1%) respectively ,compared to the result of the traditional mixture this is also shown by studies Previous.

(Alfaqawi 2012) to investigate the possibility of using recycled aggregates in the production of a hot-prepared asphalt mixture according to the Marshall method, the study indicated a decrease in the specific gravity of recycled aggregates R.C.A. Conducted research as for the results of the study, it indicated an increase in the content of optimum asphalt O.B.C. when increasing the R.C.A. compared to conventional

mixtures.The air voids VA and V.M.A. also increased, (Mills-Beale and You 2010), conducted a study to determine the mechanical properties of asphaltic mixtures. Prepared using recycled aggregate from the product of demolishing the concrete and the study showed that the type of R.C.A. Increasing the proportion of recycled aggregate increases the air voids.

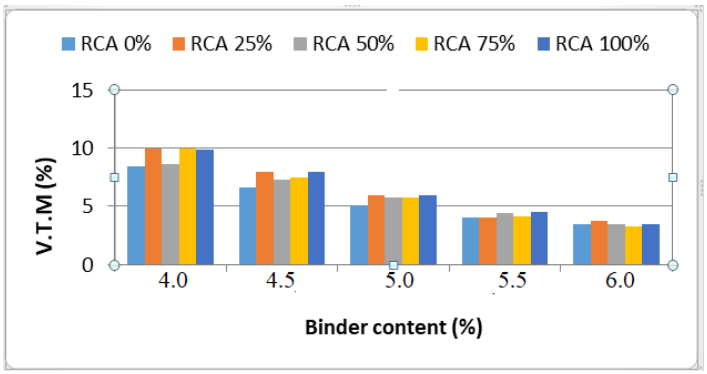

Figure 3: Effect of RCA utilization on Air voids

Figure 4 shows the effect of using RCA on the flow results after adding it at rates of 25%, 50%, 75%, and 100%.

Whereas, Figure4 shows the flow results are affected by ratio RCA were increasing RCA from 25% to 75 % led to increase flow results compared with control mixture, then after ratio 75% was decrease because of increasing proportion of RCA It gave better cohesion and adhesion with bitumen (Motter et al., 2015), conducted a study with the aim of evaluating the use of recycled aggregates resulting from demolishing concrete in the design of hot asphalt mix instead of natural aggregates, and studying the effect of different proportions of recycled aggregates on the volumetric properties of mixtures prepared by Marshall method, the results showed the study found decrease in the stability and flow of the bituminous mixtures with the increase in the proportion of recycled aggregates. Compared to the traditional mixture, but it was within the required specifications.

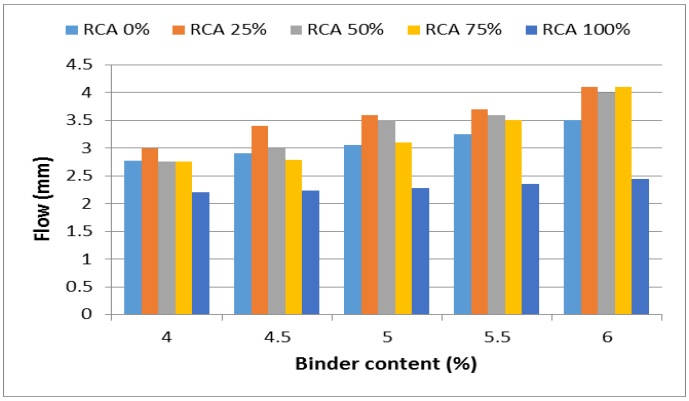

Figure 4: Effect of RCA utilization on Flow

Figure 5 shows the effect of using RCA on the voids in the aggregate materials results after adding it at rates of 25%, 50%, 75%, and 100%.

Whereas, Figure5 shows increased in the percentage of VMA compared with control mixture then a decrease in the percentage of voids in the aggregate materials with the increase in the proportion of RCA and this is due to the behavior of the recycled aggregate. Under the influence of loads that lead to the fragmentation of the cement mortar layer into soft materials that fill the voids in the materials aggregate and this will lead to a decrease in the percentage of VMA with the increase in the percentage of RCA. Despite this decrease, its percentage is still within the permissible and approved values in the general conditions and specifications for road and bridge works issued by the General Corporation for Road Transport. consistent with the results of previous research(Mills-Beale et al., 2010, Cho et al., 2011, Alfaqawi 2012, Pérez et al., 2012). (Alfaqawi 2012) to investigate the possibility of using recycled aggregates in the production of a hot-prepared asphalt mixture according to the Marshall method, the study indicated the air voids VA and V.M.A. also increased. (Mills-Beale and You 2010), conducted a study to determine the mechanical properties of asphaltic mixtures. Prepared using recycled aggregate from the product of demolishing the concrete and the study showed that the type of R.C.A. Increasing the proportion of recycled aggregate increases the air voids and VMA compared with control mixture then a decrease in the percentage of voids in the aggregate materials with the increase in the proportion of RCA

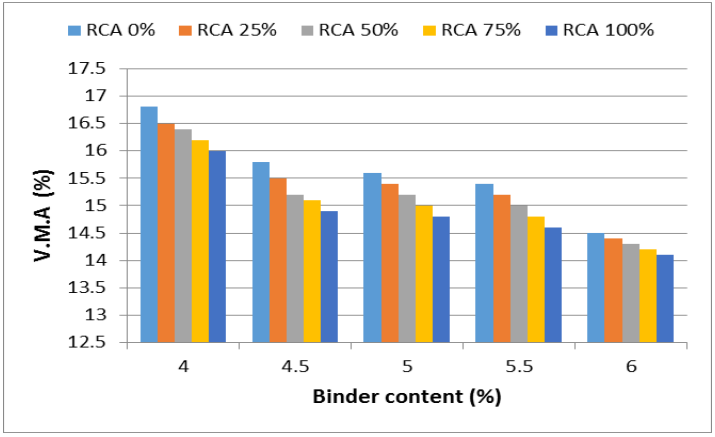

Figure 5: Effect of RCA utilization on V.M.A

Figure 6 shows the effect of using RCA on the voids filled with bitumen VFB results after adding it at rates of 25%, 50%, 75%, and 100%.

Whereas, Figure6 shows the proportion of voids filled with bitumen VFB decreases with the increase in the proportion of RCA recycled aggregates in the mixtures. The reason for this decrease is attributed to the porosity and high absorbency of the aggregate Recycled RCA compared to natural aggregate NA. (Alfaqawi 2012) The study indicated to the voids filled with bitumen decreased with the increase in the percentage of R.C.A.

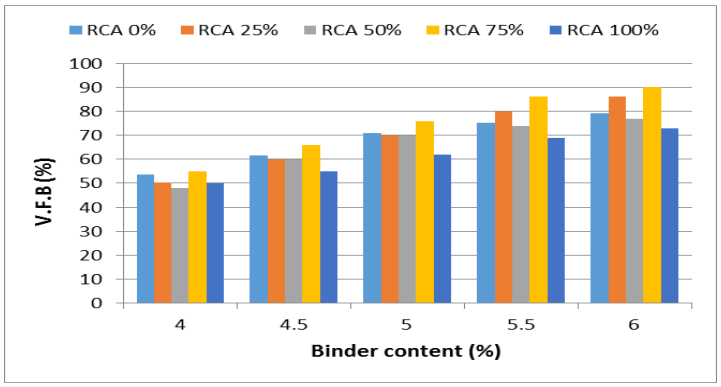

Figure 6: Effect of RCA utilization on V.F.B

An indirect tensile test was performed on Marshall Samples at each modification rate of recycled aggregate according to ASTM-D6931. In order to determine the resistance of the bituminous mixture to cracks of all kinds under the influence of traffic loads and climatic changes, the results of the experiment were as shown in Table (4).

Table (4): Indirect tensile strength test results

RCA%	0	25	50	75	100
ITS 25 ˚C	1033	1113	1114	940	836
ITS 40˚C	636	715	752	611	532

The change in the resistance of the bituminous mixture to the indirect tensile strength is largely deboned on the proportion of the recycled aggregate in the mixture, as well as on the temperature. Where the results showed an improvement in the resistance of the mixtures to indirect tensile strength when the RCA increases at (50%) and begins to decrease as for the temperature, the indirect tensile force decreases when the temperature increases.

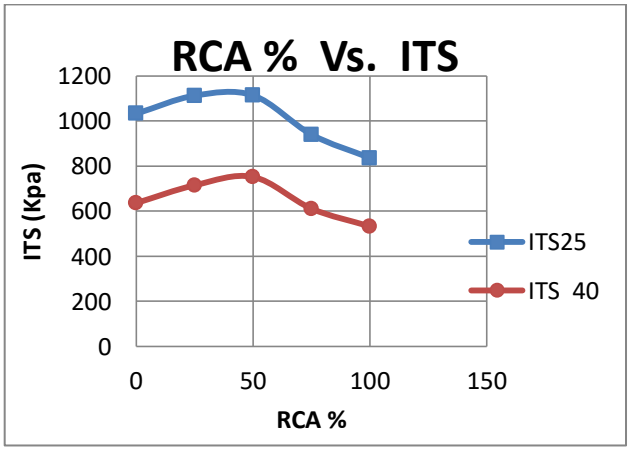

Figure (7) the relationship between RCA and ITS

4. Conclusions

1. An increase in (RCA) led to an increase in the proportion of air voids (VA) due to the high porosity of recycled concrete compared to natural aggregates NA.
2. The mixture RCA 25% gave an improvement in the percentage of voids in mineral aggregates (VMA) and voids filled with asphalt (VFA) by 2%, but these percentages decreased with the increase of (RCA) and this is due to the behavior of the recycled aggregates under the influence of loads that lead to the fragmentation of the cement mortar layer to fine material As the voids fill in the mineral aggregate and this will lead to a decrease (VMA) with an increase in RCA. And despite this decreasing, the percentage it's still within the permissible and approved values in the general conditions and specifications for road works.
3. The optimum bitumen content (OBC) also increased by increasing the recycled concrete aggregate (RCA) due to the high absorption properties of the recycled aggregate.
4. The results of the RCA-25% mix had a higher value in terms of stability and flow compared to the standard mix by 13.5%, but it decreased after 25% due to the increase in recycled concrete aggregates. Despite that, it achieved the required specifications at all modification rates.
5. As for the resistance of samples to indirect tensile strength ITS, the resistance of the asphalt mixture to tensile stress increased with the increase of the recycled concrete aggregate up to the percentage RCA 50% and at a temperature of 25˚C and RCA 40˚C by up to 8%, then the resistance to tensile stresses decreased with the increase of RCA Whereas, the resistance of mixtures to tensile stresses decreased with increasing temperature at all ratios of adjustment with recycled aggregates.
6. Based on the previous results, the process of using recycled aggregates resulting from demolition of concrete RCA as an alternative to natural aggregates in the design of hot bituminous mixtures is applicable up to a certain percentage, ensuring properties that achieve specifications and better performance, taking into account the increase in the optimum bitumen content required for the mixture.

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