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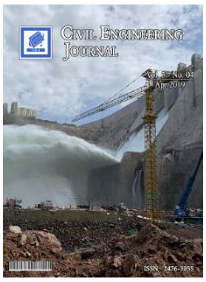

Evaluation the Moisture Susceptibility of Asphalt Mixtures Containing Demolished Concrete Waste Materials

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Abstract

The distress of moisture induced damage in flexible pavement received tremendous attention over the past decades. The harmful effects of this distress expand the deterioration of other known distresses such as rutting and fatigue cracking. This paper focused on the efficiency of using the waste material of demolished concrete to prepare asphalt mixtures that can withstand the effect of moisture in the pavement. For this purpose, different percentages of waste demolished concrete (0, 10, 20, 30, 50, 70 and 100) were embedded as a replacement for coarse aggregate to construct the base course. The optimum asphalt contents were determined depending on the Marshall method. Then after, two parameters were founded to evaluate the moisture susceptibility, namely: the tensile strength ratio (TSR) and the index of retained strength (IRS). To achieve this, the indirect tensile strength test and the compressive test were performed on different fabricated specimens. The results show that mixtures with a higher percentage of demolished concrete possess higher optimum asphalt content as this parameter increased from 3.9 % for control mixture to 4.5 % for mixture with coarse aggregate that fully replaced by demolished concrete. This work indicated that optimum percent of waste demolished concrete that can be utilized in the asphalt mixtures is 30 %, whereas this percent recorded higher value of increased increments for TSR and IRS by 10.6 % and 7.9 % respectively.

Keywords: Asphalt; Moisture Susceptibility, Recycled Concrete Aggregates; Indirect Tensile Strength; Compressive Strength.

1. Introduction

Recently, the increase of construction prices coupled with the increase of the environmental regulations and awareness has driven a strong movement toward the adoption of sustainable technology in various construction projects including the asphalt concrete pavement [1]. The concrete is the most significant component in the construction and demolition waste. The management of these huge waste quantities is considered as a serious challenge due to the landfill shortage and transport costs. This leads to the introduction of the RCA concrete aggregate as an alternative sustainable material for asphalt mixes. So far, recycle concrete aggregate has been utilized for the production of soil stabilization, new concrete, in addition to materials for the construction of the road pavement, mainly for sub-base and unbound base layers [2]. In the US, as much as 85% of RCA is used as road base [3]. Globally, "the amount of construction and demolition waste generated each year has been estimated to be 1183 million tonnes" [4]. In general, recycle concrete aggregate differs from natural aggregates because the newly created aggregate particles consist of natural aggregate combined with residual cementitious mortar. In addition, as a result of processing construction and demolition waste (C&D waste), it may also contain different impurities such as ceramic products, wood, glass and plastic This feature has a significant

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influence on the design, properties and performance of both concrete and asphalt mixtures made with RCA [5].

The main advantages of possible RCA application are based on sustainable development principles, including the reduction of waste quantities, and the aesthetic influence on the environment, conserving natural resources, and the collection of mineral waste through recycling of concrete and reduction of C&D waste disposal costs [5]. This has led to a significant increase in research on utilization of recycle concrete aggregate in HMA mixtures in the last years.

Paranavithana and Mohajerani (2006) studied the impact of recycle concrete aggregate on the properties of hot mix asphalt. Recycle concrete aggregate was utilized as coarse aggregate at 50% of the weight of the total aggregate. The results presented that the use of recycle concrete aggregate in hot mix asphalt reduced bulk density, voids filled with asphalt, voids in the mineral aggregate, elasticity modulus and asphalt film thickness of the mixture and increased voids in mixture and the stripping potential of the mix [6]**.**

Mills-Beale and You (2010) studied the behavior of asphalt mixture containing Recycle Concrete Aggregate (RCA) based on the superpave mix design method. They concluded that the voids filled with asphalt (VFA) and voids in mineral aggregates (VMA) were decreased as the percent of RCA was increased in the mix [7].

Rafi et al. (2011) conducted a study to estimate the results obtained from the utilize of RCA aggregate in hot asphalt mixtures as compared with reference mixtures made with RCA using the Marshall process. Their test results showed that the air voids, specific gravity and voids in mixes made by adding RCA were less than the reference mixes, and the ratio of stability/flow remained similar for all the mixtures [8].

Zhu et al (2012) the use of RCA in HMA has been reported to be associated with problems of low strength, low specific gravity, high absorption, and poor moisture resistance of asphalt mixtures. Replacing the whole aggregate skeleton or only its coarse proportion with RCA of same size in HMA, leads to a higher optimum asphalt content, lower Marshall stability, and lower indirect tensile strength than mixes with only natural aggregates [9].

Perez et al. (2012) studied the availability of using RCA in HMA. Two asphalt mixes of 50% containing RCA with additional two reference mixtures without recycled aggregate were prepared. It was observed that the mixtures with RCA had high water absorption level which result in open graded and had considerable potential for stripping, a characteristic and higher dynamic modulus. Also, a deterioration of the fatigue law was indicated as compared with the reference mixtures. They concluded that it was possible to use RCA in the design of flexible pavements for roads with medium to low volume of traffic and more research is required to cover the use of asphalt mixtures with different types of RCA [10].

Arabani et al. (2013) presented the re-use of recycled waste concrete in Hot Mix Asphalt (HMA) as a partial or total replacement of coarse aggregate (CA), fine aggregate (FA) and filler to evaluate the performance of HMA samples containing RCA materials. The test results revealed that the optimum formulation was a mixture of dacite CA and RCA-FA which achieved better results than other mixtures in terms of Marshall Stability, fatigue, permanent deformation (Rutting) and resilient modulus tests [11].

Nejad et al. (2013) investigations have shown that the RCA can be a good and economical alternative to fresh aggregates and can create asphalt mixtures withstand traffic load, especially in light and medium traffic [12].

Pasandin and Perez (2013) studied the impact of recycle concrete aggregate on the properties of HMA. The percentages of recycled RCA aggregates were utilized in mixtures: 0%, 5%, 10%, 20% and 30%. Results showed that optimum asphalt content increases with increasing RCA content because of the absorption of mortar attached to the surface of the recycle concrete aggregate. So, bulk density decreases as RCA increases. This is because RCA is a smaller amount dense than natural aggregate. In addition, they concluded increase in air voids can be described by the difficulty of compacting asphalt mixtures containing recycle concrete aggregate, because of the roughness of the attached mortar. So, hot mix asphalt made with RCA shows high Marshall stability values, but the indirect tensile strength decreases with RCA content, so the RCA content must be limited [13].

A study has been performed to evaluate RCA as a hot mix aggregate by Bhusal and Wen (2013) as a sustainable material in which six different percentages of RCA were used. Test results indicated that the optimum asphalt ratio increases due to the high absorption of RCA and a reduction in resistance to moisture damage [14].

Pasandin and Perez (2014) have stated that the heat treatment of hot mix asphalt with RCA in the oven for a curing time of at least four hours before compaction develops the water sensitivity performance of this type of mixture [15].

Al-Sarrag et al (2014) use five percentage of RCA by (0, 25, 50, 75,100) % from weight of coarse aggregate. Marshall mix design process was used to measure the optimum RCA content. results refers to the best content of recycled concrete aggregate percent that improving the Marshall stability, bulk density, flow, stiffness, air void of asphalt mixture are (50 then75)% by weight of coarse aggregate. Moreover, and the best content of recycled concrete aggregate percent that improving the tensile strength of asphalt mixture are (50)% by weight of coarse aggregate [16].

Al-Humeidawi (2014) study utilization of recycle concrete aggregate in production of Hot Mix Asphalt (HMA). The results showed that the using of RCA causes reduction in Marshall Stability and indirect tensile strength of the asphalt mix [17].

Motter et al. (2015) evaluated the use of fractions of RCA that were obtained from 30 MPa compressive strength concrete in hot mix asphalt instead of natural aggregate coarse with different ratios of replacement (0, 25, 50, 75, and 100%,). Test results for permanent deformation and durability by the moisture-induced damage test, were studied according to Marshall mix design method. Test results indicated that it is possible to use RCA as an asphalt concrete surface layer on low-volume roads in spite of high absorption, higher Los Angeles abrasion, and lower density for RCA rather than the crushed stone aggregates [18].

Qasrawi and Asi (2016) indicate that mixtures containing RCA appear less sensitive to water (stripping resistance) than RCA-free mixes and that the replacement rate of more than 50% of the RCA does not violate 80% of the TSR limit [19].

Ahlam K. Razzaq (2016) added RCA in various percentages (10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100%) were mixed with virgin crushed stone aggregates and compacted by using Marshall Compactor to produce HMA specimen then Marshall mix design method was utilized to measure the optimum RCA content. The results showed that mixes with 58% (optimum percent) of RCA that is obtained from a mix design gave improvements in Marshall Stability, flow, and ITS as compared with control mix [20].

Radevic et al (2017) studied the effects of recycle concrete aggregates on the properties of asphalt concrete. RCA was utilized as a coarse aggregate at 15%, 30% and 45% by weight of the total aggregate. The results indicated that O.A.C in hot mix asphalt was obtained using the Marshall process, increasing with increasing RCA contents, which can be explained by higher porosity and surface area of the RCA. The volumetric properties of asphalt mixtures, as well as the Marshall stability and flow, meet the relevant technical requirements [21].

Al-Bayati et al (2018) studied the influence of RCA on the volumetric properties of HMA. Test results showed that the replacement of natural aggregate by RCA concrete aggregate increases the optimum binder content for the mixtures, and the voids in mineral aggregates (VMA) is decreased [22].

Mahmoud et al (2018) use different percentages of RCA (0, 10, 20, 30, 40, 50, 60, 70 and 80) % from the weight of total mix were mixed with pure crushed aggregates and compacted using superpave mix design process to produce hot mix asphalt specimen to find the optimum asphalt content for these ratios. The results indicated that O.A.C of waste concrete aggregate is much higher compared with that of pure crushed aggregates and increased with increasing of RCA content in the mixtures due to greater porosity of waste concrete and higher attached mortars on the surface of the crushed concretes [23].

The primary objective of this work is to conclude the best percentages for replacement of the coarse aggregate in the skeleton of the base course gradation with respect to the efficiency in resistance the harmful effect of the moisture presence. Furthermore, the optimum asphalt will be determined. The adequacy of using demolished concrete in asphalt mixture in regard to the resistance of damage produced by water will be investigated.

2. The Research Methodology

This research methodology was divided into three stages, the first stage covered obtaining the properties of materials includes virgin aggregate such as coarse and fine aggregates and limestone dust. Beside, RCA and hot mix asphalt. The second stage includes the design of the asphalt mixture with various percent of RCA instead of virgin coarse aggregate by using the Marshall method and obtaining the optimum asphalt content for each percent of RCA. The third stage includes the measurement of indirect tensile strength and compressive strength of the mixtures and obtaining the tensile strength ratio (TSR) and the index of retained strength (IRS) for each percent of RCA to find optimum Recycle Concrete Aggregate (RCA) for resistance to moisture damage.

3. Materials and Methods

3.1. Asphalt Cement

The binder used in this research is asphalt cement (40-50) penetration grade which was obtained from Al-Durrah Refinery. All tests results meet the State Commission of Roads and Bridges (SCRB R/9, 2003) specification [24]. Table 1 shows the physical properties of asphalt cement which was used in this work.

Table 1. Physical properties of asphalt cement

Test	Result	SCRB Specification Limits [24]	ASTM Designation No. [25]
Penetration (25^{0}C, 100 gm, and 5sec)	42 (0.1mm)	40 - 50	D-5
Ductility, (25 ^{0}C and 5cm/minute)	170 (cm)	≥ 100	D-113
Softening point, (Ring and Ball)	49 (^{0}C)	-------	D-36
Flash point ,(Cleveland open Cup)	270 (^{0}C)	>232	D-92
Specific Gravity @ 25^{0}C	1.02	-------	D-70
		After Thin-Film Oven Test	
Retained penetration, of original, (%)	62(0.1mm)	>55	D-5
Ductility (25^{0}C and 5cm/minute)	96 (cm)	>25	D-11

3.2. Coarse and Fine Aggregates

The coarse and fine aggregates were brought from the hot mix plant of Amant Baghdad. The source of aggregate was from Al-Nibaee quarry. According to (SCRB R/9, 2003) specification [24], the sizes of coarse aggregate ranged between 11.2" (37.5 mm) and No.4 sieve (4.75 mm) for base course and the gradation of fine aggregate is between No.4 sieve size (4.75 mm) and No.200 sieve size (0.075 mm).The aggregates were tested for physical properties and Table 2 presents the test results.

Table 2. Physical properties of coarse and fine aggregates

Property	ASTM Designation No.	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity	C-127 & C-128	2.618	2.576
Percent Water Absorption	C-127 & C-128	0.435	0.562
(Los Angeles Abrasion) %	C-131	18	-------

3.3. Mineral Filler

Filler is a material passing sieve No.200 (0.075 mm).It is thoroughly, dry and free from lumps or aggregations of fine particles. It was decided to use limestone dust as a filler in preparing the asphalt mixture due to its availability and relatively lower cost. It was brought from lime factory in Karbala governorate. The physical properties of the mineral filler are listed in the Table 3.

Table 3. Physical properties of limestone dust

Property	limestone
% Passing No.200	98
Bulk Specific Gravity	2.68

3.4. Recycled Concrete Aggregate (RCA)

The recycled concrete aggregate was obtained from demolished building which has been built for more than 20 years in Baghdad, after crash reinforcement concrete and sieving to get requirement granular particle to make locally asphalt mixture depends on specification of (SCRB R/9, 2003)[24], with percent of (0,10, 20, 30, 50, 70 and 100)% from weight of coarse aggregate. The physical properties of the RCA are listed in the Table 4.

Table 4. Physical properties of RCA

Property	ASTM Designation No.	RCA Aggregate
Bulk Specific Gravity	C-127 & C-128	2.48
Percent Water Absorption	C-127 & C-128	2.3
(Los Angeles Abrasion) %	C-131	25

3.5. Selection of Aggregates Gradation

The selection of the aggregates in this work is following (SCRB R/9, 2003), [24] for base course with nominal maximum size of aggregate of 25 mm. Figure 1 presents the selected aggregates gradation for base course.

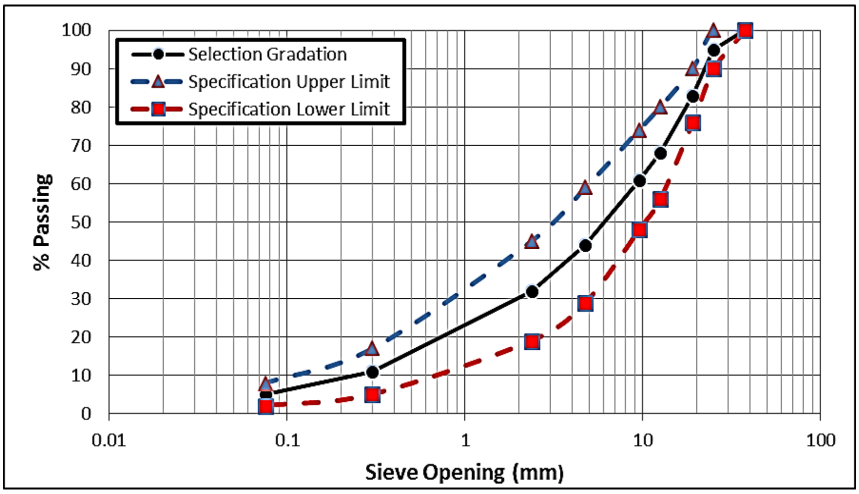

Figure 1. Gradation of the aggregates for base course according to SCRB [24]

4. Preparation of Marshall Mixtures

The coarse aggregates are replaced by RCA ratios of (0, 10, 20, 30, 50, 70 and 100) percent, and then dry first to a constant weight of 110 °C, separated into the desired size and recombined with the mineral filler in order to meet the required gradation for base course [24]. Then, heated to a temperature of 155 °C before mixing with asphalt cement which has already been heated to a temperature that produce a kinematic viscosity of (170 ± 20) centistokes (up to 163 °C as an upper limit).Then; the asphalt cement is weighed to the desired amount and added to the heated aggregates and mixed thoroughly until all aggregates particles are coated with asphalt. The asphalt mixtures poured in the mold with dimension of 4 inch, in diameter and 2.5±0.05 inch in height according to ASTM (D-6927), and spaded by spatula vigorously by (15 and 10) times for perimeter and interior respectively. The specimen applied to 75 blows by hammer weighting of 4.535 kg falling freely on both faces (top and bottom). Then specimens left to cool for (24 hrs.) at room temperature and then extracted by mechanical jack. Other Marshall properties were obtained for each percent of RCA (Stability, flow, Air voids, voids filled with asphalt (VFA) and voids in mineral aggregate (VMA)) and recorded. The Marshall properties presented in Table 5.

Figure 2. Group of the prepared Marshall specimens

5. Indirect Tensile Strength Test (ITS)

The indirect tensile strength test is used to determine the tensile properties of the asphalt concrete which can be further related to the moisture susceptibility. A set of six specimens is prepared for this purpose. The specimens were prepared for each mix according to Marshall procedure and compacted to 7±1 % air voids using different numbers of blows per face. Three specimens (unconditioned specimens) were tested for tensile strength after storing in water bath at 25 °C for a minimum of 30 minutes. The other three specimens (conditioned specimens) were placed in a vacuum container filled with potable water at 25˚C and apply a pressure about 70 kPa or 525 mm Hg (20 in. Hg) for a short time, then covered with a plastic bag and kept in the freezer at a temperature of -18±3°C for a minimum of 16 hours. After the freeze thaw cycle, specimens were transferred to the water bath at 60±1°C for 24 hours and the plastic bag was removed from the specimen as soon as it was placed in the water bath. Then, the specimens were transferred to a water bath and maintained at 25°C for 1 hour before testing for tensile strength. The tensile strength ratio is calculated as follows in accordance with ASTM D-4867, which should be a minimum of 0.8 (or 80%) as adopted by (ASTM D-4867).

$$I.T.S = \frac{2P}{\pi . t . D} \quad (1)$$

$$TSR = \frac{C.ITS}{UC.ITS} \quad (2)$$

Where,

P: ultimate applied load required to fail specimen

t: thickness of the specimen

D: diameter of specimen

C. ITS = Conditioned indirect tensile stress

UC. ITS = Unconditioned indirect tensile stress

6. Compressive Strength Test

This method covers measurement of the loss of cohesion resulting from the action of water on compacted bituminous mixtures. Specimens 4.0 in (101.6 mm) in diameter and 4 in. (101.6 mm) in height were prepared. A set of six specimens prepared for this purpose. Three specimens were tested for compressive strength after storing in air bath at 25 °C for about 4 hours. The other three specimens were placed in a water bath for 24 hours at 60 °C, then transferred to a water bath, and maintained at 25 °C for 2 hours before testing for compressive strength. The index of retained strength (IRS) is calculated as follows in accordance with ASTM D-1075, which should be a minimum of 0.7 (or 70 %) as adopted by (SCRB/R9, 2003) [24].

$$IRS = (S2/S1) * 100 \quad (3)$$

Where,

S1: compressive strength of dry specimen

S2: compressive strength of immersed specimen

7. Results and Discussion

7.1. Marshall Test

A series of properties for Marshall stability, flow, and density-voids analysis are carried out for the selected optimum asphalt content for mixture with different percent of RCA. Table 5 summarized the output of Marshall test. The optimum asphalt content for mixture with RCA percentages of 0, 10, 20, 30, 50, 70 and 100 are obtained as 3.9, 3.9, 4, 4.16, 4.27, 4.4 and 4.5 respectively. It is clearly shown that all of the RCA mixtures had a higher optimum percentage of asphalt content than the control mixture due to presence of residual cementitious mortar that makes the surface texture of RCA exceptionally rough and porous. Thus, the porosity of the mortar attached to the RCA makes the RCA absorb binder in proportion to the percentage of RCA in the HMA. Thus, HMA containing RCA requires more binder as the RCA content increases. This findings is in agreement with Pasandin and Perez (2013) and (Radevic et al. (2017) [15, 21].

Marshall test indicated that the stability of mixtures containing RCA was higher than those of control mixtures. Specimens containing RCA (10, 20, 30, 50, 70 and 100) % by weight of coarse aggregate had higher stability values than the control mixtures by (2, 8.3, 23, 32, 25 and 11.6) % respectively as shown in Table 5. Increase in stability values as the RCA content increase in the mixture, may be due to the rough surface texture of RCA as compared to the VA. The results are in agreement with Pasandin and Perez (2013) and Pérez et al. (2012) [10, 15].

The flow values increased with an increase in the RCA content. The values were significantly higher for 100% RCA content its value (3.9 mm) than the control specimens its value (3.21 mm) as shown in Table 5. This increase in flow values could be due to excessive asphalt content of mixtures containing RCA. All the flow values of mixtures containing RCA satisfy the requirement for the SCRB specification flow requirement (2-4 mm). The flow values findings is in agreement with Rafi et al. (2011) [8].

The bulk density of asphalt mixture decreased with an increase in RCA content. Specimens containing (10, 20, 30, 50, 70 and 100) % by weight of coarse aggregate had lower bulk density than the control mixture by (0.43, 0.85, 1.28, 1.92, 2.56 and 2.56) % respectively, as shown in Table 5. The reduction in the density of asphalt mixtures related to higher optimum asphalt contents of these RCA mixtures and increased RCA content. In addition, RCA has lower density than natural aggregates. Comparable behaviour that agree with this finding were obtained by Motter, et al. (2015) and Rafi et al. (2011) [8, 18].

The specimens without RCA had lower air void contents than the mixtures containing demolished concrete waste materials. It was also noted that the specimens made with 100 % RCA contents had higher air void contents than the specimen containing (10, 20, 30, 50, and 70) % RCA contents. Specimens containing (10, 20, 30, 50, 70 and 100) % of RCA by weight of coarse aggregate had higher air voids than the control mixture by (8.1, 18.4, 21.6, 26.8, 30 and 33) % respectively. Increase in air voids values as the RCA content increase in the mixture, may be due to air voids is determined as a function of density, so a decrease in bulk density leads to an increase in air. However, an increase in air can be explained by the difficulty of compacting HMA containing RCA, due to the roughness of the attached mortar. This finding is comparable whit that obtained by Motter et al. (2015) and Rafi et al. (2011) [8, 18].

The percent of voids filled with asphalt (V.F.A.) of mixtures containing RCA was lower than those of control mixtures. It is noticed that the specimens containing (10, 20, 30, 50, 70 and 100)% by weight of coarse aggregate had lower (V.F.A) than the control mixture by (1.9, 4.3, 4, 3.9, 3.2 and 3.9)% respectively, as shown in Table 5. The decrease of V.F.A due to the RCA has more surface pores (higher capillary pores reaching the surface) than natural aggregate, it tends to absorb more asphalt resulting in reduction in the effective bitumen content in the asphalt mix.

Table 5. Marshall Test Results

RCA, (%) by wt. of Coarse Aggregate	O.A.C., (%) by wt. of mix.	Stability (kN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)	V.M.A (%)	V.F.A (%)
0	3.9	9.6	3.21	2.34	3.7	13.51	72.61
10	3.9	9.8	3.3	2.33	4	13.87	71.16
20	4	10.2	3.61	2.32	4.38	14.34	69.45
30	4.16	11.83	3.72	2.31	4.5	14.85	69.69
50	4.27	12.7	3.81	2.295	4.69	15.49	69.72
70	4.4	12	3.83	2.28	4.81	16.17	70.25
100	4.5	10.71	3.9	2.28	4.92	16.25	69.72

7.2. Indirect Tensile Strength Test Results

Tensile Strength Ratio (TSR) has been used for predicting moisture susceptibility of mixtures. The recommended limit of (80%) for tensile strength ratio (TSR) is used to distinguish between moisture susceptible mixture and moisture resistance mixtures (ASTM D4867). High TSR values indicate that the mixture will probably perform better to resist moisture damage. Based on the results exhibited in Figure 3 it's obvious that there is a distinct trend for the increasing of dry indirect tensile strength (unconditioned) as the RCA replacement rate increase. Specimens containing (10, 20, 30, 50, 70 and 100) % RCA (by weight of coarse aggregate) have higher dry I.T.S. values than the control mixtures by about (10, 13.3, 21.2, 25.8, 31.2 and 37.8)% respectively. So, the mean wet I.T.S (conditioned) values of all the RCA mixtures were greater than the control mixtures. The mixtures with (10, 20, 30, 50, 70 and 100) % RCA content (by weight of coarse aggregates) were higher than control mixture by (10.6, 16, 34, 35.6, 36.6 and 37.3) % respectively as shown in Figure 4. The increase in tensile strength may be due to the surface texture of the RCA, which affects the bond between asphalt and aggregate particle. Where, it is thought that internal friction of RCA is higher than virgin aggregate because of rougher surface texture of RCA. TSR values of control mixtures were significantly lower than that of RCA mixtures. The mixtures with (10, 20, 30, 50 and 70) % RCA content (by weight of coarse aggregates) were higher than control mixture by (0.3, 2.2, 10.6, 7.7 and 3.9) % respectively as shown in Figure 5. Except, TSR values of mixtures with 100% RCA content were lower than control mixture by about 0.5%. This indicates that the 30% is the optimum RCA content that gives the highest TSR equivalent to 10.6. This finding was comparable with that obtained by Motter et al. (2015) and Paranavithana and Mohajerani (2006) [6, 18].

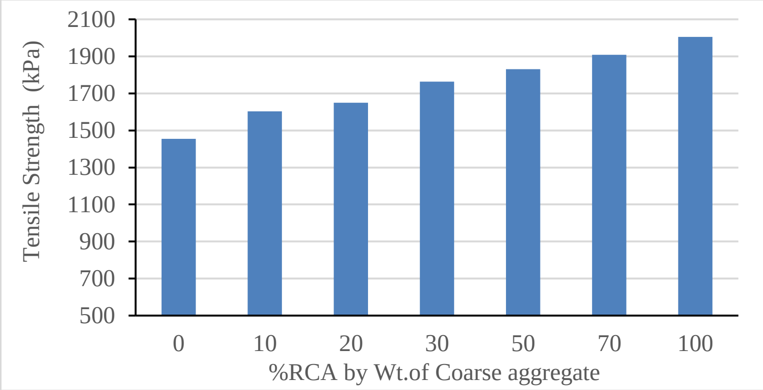

Figure 3. Unconditioned (dry) Indirect tension test results specimen

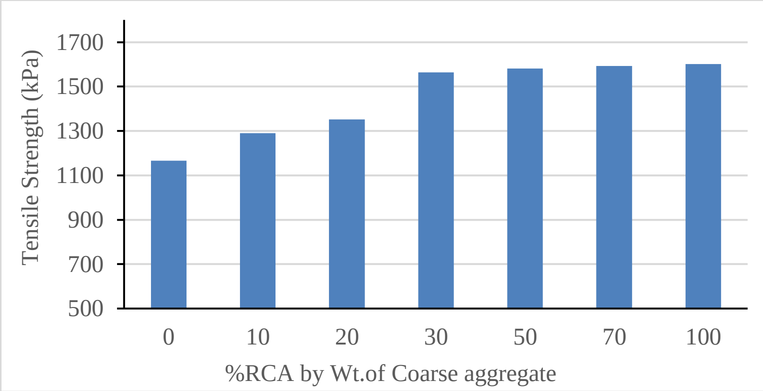

Figure 4. Conditioned (wet) Indirect tension test results specimen

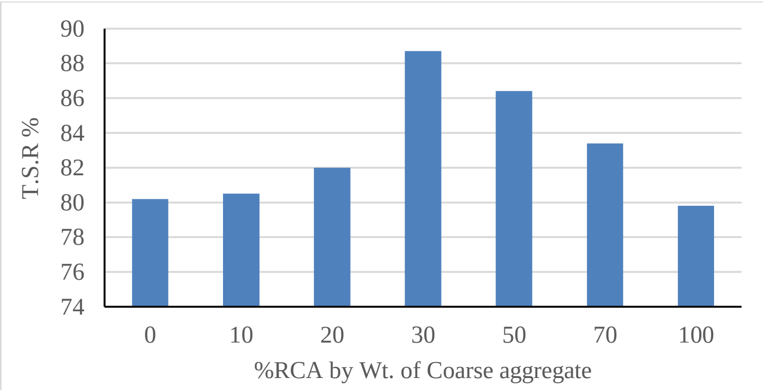

Figure 5. Tensile strength ratio results

7.3. Compressive Strength Test Results

In this test, the index of retained strength (I.R.S.) has been used to evaluate the resistance of mixture to water damage. The dry compressive strength values of the mixtures containing RCA were higher than the control mixtures. Specimens containing (10, 20, 30, 50, 70 and 100) % RCA (by weight of coarse aggregate) have higher compressive strength values than the control mixtures by about (1.7, 20.4, 29.6, 41.8, 48.7 and 54.8) % as shown in Figure 6.

Figure 7 showed that the mean wet compressive strength values of all the RCA mixtures were greater than the control mixtures. The wet compressive strength value of (10, 20, 30, 50, 70 and 100) % RCA content (by weight of coarse aggregate) increased by about (3.2, 25.6, 39.9, 49.4, 54 and 55)%, respectively, than the control mixture. Higher wet compressive strength of RCA mixtures could be related to increases the strength of the mixture and making the mixture more resistant to moisture damage indicating that the use of RCA decrease the moisture susceptibility of mixtures.

Figure 8 showed that the values of the index of retained strength (I.R.S.) of control mixtures were significantly lower than that of RCA mixtures. I.R.S values of RCA is increased by about (1.5, 4.3, 7.9, 5.3, 3.7 and 0.15) % for (10, 20, 30, 50, 70 and 100)% RCA content respectively, than the control value. I.R.S values of mixtures with 30% RCA content were higher than mixtures with (10, 20, 50, 70 and 100) % RCA content. This indicates that the 30% is the optimum

RCA content that gives the highest TSR equivalent to 7.9. Figure 8 also shows that all of the RCA mixtures are considered unsusceptible to moisture damage because each one has a value of I.R.S. more than (70%). These values meet the design criteria established by the Iraqi Specification, SCRB (2003) [24].

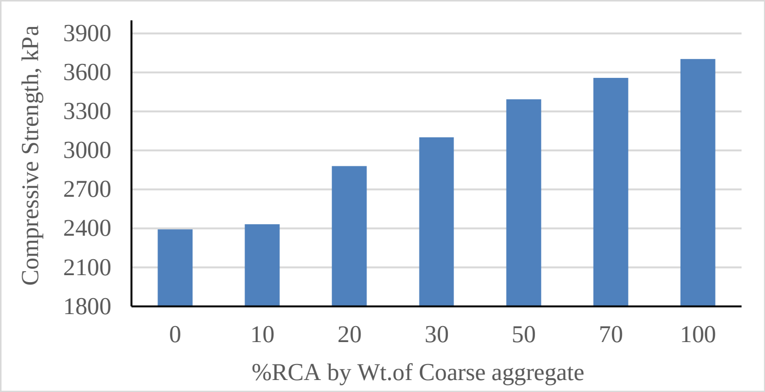

Figure 6. Unconditioned (dry) Compressive strength test results specimen

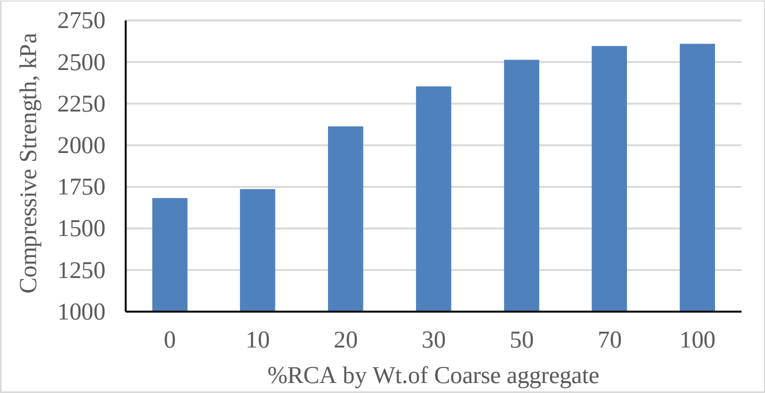

Figure 7. Conditioned (wet) Compressive strength test results specimen

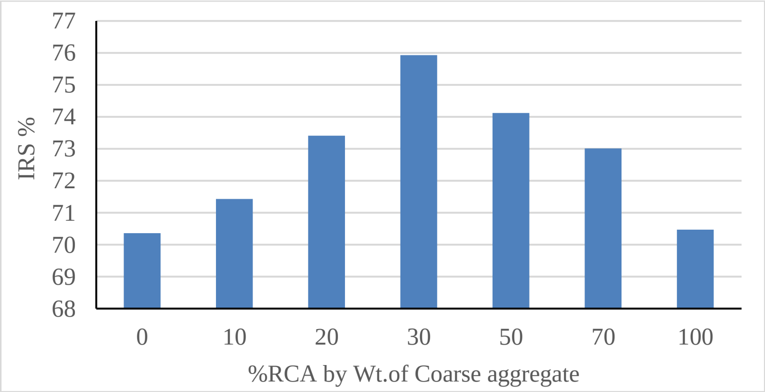

Figure 8. Index of retained strength results

8. Conclusions

The following conclusions can be drawn from this study:

- The volumetric properties of asphalt mixtures containing RCA such as AV, VFA, VMA, as well as the Marshall stability and flow, meet the Iraqi specification requirements SCRB (2003).
- Mixes containing RCA seems to be more consuming of asphalt binder content, approximately, 15.4% increase of asphalt binder is required when RCA increased from 0 to 100 % due to the absorptive character of RCA.
- The dry Indirect Tensile Strength values and the wet Indirect Tensile Strength values for mixtures containing RCA were higher than the control mixtures. The Tensile Strength Ratios for all RCA mixtures were higher than those of no RCA mixtures. Except, the Tensile Strength Ratios values of mixtures with 100% RCA content were lower than control mixtures by about 0.5%. This indicates that the use of RCA decreased moisture susceptibility of asphaltic mixtures. The 30 percent RCA content gives the highest value of Indirect Tensile Strength Ratio. For this percent of RCA the I.T.S./ratio value increased by 10.60 percent as compare to control mixtures.
- The dry compressive strength values and the wet compressive strength values of mixtures containing RCA were higher than of control mixtures. The Index of Retained Strength values for all RCA mixtures were higher than those of no RCA mixtures. This indicates that the use of RCA decreased moisture susceptibility of asphaltic mixtures. The 30 percent RCA content gives the highest value of Index of Retained Strength. For this percent of RCA the I.R.S. value increased by 7.90 percent as compare to control mixtures.
- The 30 percent is the optimum RCA content that gives the highest values of indirect tensile strength ratio, index of retained strength.

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10. Conflicts of Interest

The authors declare no conflict of interest.

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