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Effect of recycled course aggregate from concrete debris on the strength of concrete

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Abstract. The paper investigates the fresh and hardened mechanical properties of a concrete mix produced with partial or full substitution of natural aggregates with recycled aggregates from demolition works and crushed tested cubes concrete from laboratory. Recycled aggregate concrete (RAC) is the concrete that has been made from waste materials recycled as coarse and/or fine aggregate. One of the waste materials is the concrete that is taken from demolished buildings in Iraq due to military operations on 2014 and the other is crushed tested concrete cubes from laboratory. Choosing crushed concrete wastes from demolition works and crushed test cubes concrete from laboratory as source of recycling would result in reusing portion of the waste products of the concrete production industry. This study presents an experimental study on the performance of concrete that contains recycled coarse aggregate. The replacement percentages of natural coarse aggregate with the recycled coarse aggregate are (0, 33.3, 66.7 and 100) %. Moreover, silica fume was used as an admixture for all recycled aggregate concretes. Compressive and indirect tensile strength were studied for all of the reference and recycled aggregate concretes at (28) days age, by testing concrete cubes and cylinders specimens respectively. The results showed that the compressive strength and splitting tensile strength decreased for recycled waste concretes taken from demolished buildings and increased for recycled crushed tested cubes concretes from laboratory as compared to the reference concrete. When the silica fume was added, the compressive strength and tensile strength increased for all recycled aggregate concretes compared to those without the silica fume.

1. Introduction

As a result of military operations in Iraq since June 2014, thousands of homes, buildings and cities were completely destroyed. The reports of the United Nations (UN) reported that about 80 to 100 thousand houses and residential units were completely destroyed as a result of military operations and terrorist operations in the cities of Iraq (Anbar, Kirkuk, Tikrit, Beiji, Diyale and Baghdad), that's means a huge work to remove rubbish and reconstruct of these facilities [1].

The anthropogenic impact of construction on the natural environment is diverse in nature and occurs at all stages of construction activities, from the extraction and production of building materials and structures to the processing and reuse of construction waste from the demolition of buildings and structures [2, 3].

The main task of scientists around the world is to create a comfortable living environment human or optimization of the system "human - material - habitat" [4].

Recycled concrete aggregate (RCA) is defined as the aggregate which is produced by the crushing of sound and clean demolition waste contains at least (95) % by weight concrete, and has a total contamination level lower than (1) % of the bulk mass [5].

Recycled aggregate obtained from construction and demolition waste has received an increasing attention recently, due its promising potential use in environmentally friendly concrete structures. In many countries the deficiency of natural aggregates, increase of the transportation cost, shortage of dumping sites and the environmental pollution has led to the use of recycled aggregate as a replacement material in the production of concrete [6].

After the World War II, urgent rebuilding needs were faced in the devastated Europe, therefore; attempts were made to utilize the concrete's demolition wastes into recycled aggregate in new concrete. Back then, the recycling of waste material commenced on a massive scale where building rubble was used for construction with a good success in general [7].

Since then, especially after the (1992) world summit that was held in Rio De Janeiro and the promotion of agenda (21), there was a tendency for protection of the environment and treating the waste.

Thus; many studies were undertaken worldwide to show that the recycled waste could have a wide range of use in the industry of construction. Hence, both of Netherlands and Copenhagen district of Denmark recycled over (80) % of their demolition waste [8].

The waste is one of the largest waste problems in the European Union, it was estimated that the waste (obtained from buildings or civil engineering infra structures) amounts will be around (180) million tons a year [9, 15-19].

2. Materials and methods

2.1 Materials

The following sections provide information involving the different materials that were used in the present study.

2.1.1 Cement

An ordinary Portland cement (Type I) was used; this type of cement is commercially known as (Belgorod cement).

2.1.2 Fine aggregate

Quartz sands from Belgorod area which is widely used in construction works in Russia. Standard tests were performed on this aggregate in order to determine each of its physical properties, gradation and fineness modulus. The test results indicate the conformity of the grading and sulfate content to those required by the Iraqi specification (IQS No.45/1984 and its amendment No.2/2010).

2.1.3. Natural coarse aggregate

Well rounded quartzite sandstone crushed stone of (14) mm maximum size from Belgorod area was used as coarse aggregate in all concrete mixtures. The grading is conformed to the requirements of Iraqi specification (IQS No.45/1984 and its amendment No.2/2010).

2.1.4 Water

Ordinary tap water was used for all concrete mixtures. This water was also used to clean the recycled aggregates from dust and impurities, and cure concrete specimens. As required, this water was potable and free from organic materials and other visible impurities.

2.1.5. Super plasticizing admixture

HyperPlast PC260 was used for the production of Recycled Aggregate Concrete Mixtures as a high range water – reducing admixture (HRWRA). This admixture is a high performance super plasticizing admixture based on poly carboxylic ether polymers with long chains specially designed to enable the water content of the concrete to perform more effectively.

HyperPlast PC260 complies with (ASTM C494, type A and G) and has many positive effects on the properties of the fresh concrete such as increasing the slump, reducing water - cement materials ratio (w/cm) for a fixed slump and increase the workability of the concrete in general. In summation, HyperPlast PC260 has the following advantages:

- High density and impermeable concrete structure through very high water reduction.
- Optimization of cement utilization.
- Minimization of segregation and bleeding problems by improving the cohesion property.
- Improvement of shrinkage and creep behaviors.
- Increase in the durability and resistance to aggressive atmospheric conditions through the reduced permeability.
- Higher early and ultimate compressive strengths.

2.1.6. Silica fume

MS 610 silica fume was used to produce the self-compacting concrete and to improve the strength characteristics of the recycled aggregate concrete mixtures. This admixture is a high performance concrete admixture that changes the porous structure of the concrete making it denser and resistant to any external influences.

MS 610 can be used as filler and as a cementitious material where the fine particles of it fill the voids in the mixture in general. These particles also react with $Ca(OH)_2$ to form additional $CaCO_3$ during the cement hydration, Thus; producing denser concrete. MS 610 has the following features and benefits:

- Increased strength.
- Substantial resistance to chemical and mechanical attack.
- Preventing of bleeding and segregation in fresh concrete.
- Very thick layers are possible.

2.2. Method

The objective of the research reported in this paper was to perform different trial concrete batches to achieve optimum normal and high strength concrete mixes which fit the criteria of RAC as far as workability and performance. This research presents an experimental study on the performance of concrete that contains one of two types of recycled coarse aggregate, one from normal concrete from demolishing buildings wastes in Iraq and another from crushed tested cubes.

The main variables were the percentage replacement of natural coarse aggregates with recycled aggregates from demolishing buildings wastes in Iraq and crushed tested cubes and concrete strength. The replacement percentages of natural coarse aggregate with the recycled coarse aggregate are (0, 33.3, 66.7 and 100) %. Moreover, silica fume was used as an admixture for all recycled aggregate concretes. Compressive and indirect tensile strength were studied for all of the reference and recycled aggregate concretes at (28) days age, by testing concrete cubes, cylinders and prisms specimens respectively. The significance of the research was two-fold. Attaining a RAC mix while recycling and reusing the demolish waste and crushed tested standard concrete cubes would have positive economic and environmental implications on the concrete industry. Also, it was important to test the hypothesis that the partial or full substitution of natural aggregates with recycled aggregates from demolish waste and crushed tested concrete cubes would not lead to significant reduction in the mechanical properties of normal strength or high strength concrete.

2.2.1 Recycled demolished concrete waste coarse aggregate (RDA)

This aggregate was obtained manually by crushing concrete waste debris from demolished buildings in Iraq having a strength rounded about (21-30) MPa. Then, the crushed fractions were sieved using the sieve shaker and recombined in order to obtain a similar grading to that of the natural coarse aggregate.

Thereafter, the recycled aggregate was cleaned using water to remove dust and undesired materials. Eventually, it was packed in Nylon bags to save moisture content as saturated surface dry (SSD) and stored in laboratory. Physical and chemical properties of this aggregate are illustrated in table 1. Figure 1 shows photos of the waste concrete which was got from demolished house in Iraq and the recycling process.

Table 1. Physical and chemical properties of recycled waste concrete coarse aggregate.

Properties	Specifications	Test Results	Limits of (IQS No.45/1984)
Specific gravity	(IQS No.31/1981)	2.37	-
Absorption (%)	(IQS No.31/1981)	5.96	-
Dry loose unit weight (kg/m3)	(IQS No.31/1981)	1211	-
Sulfate content (as SO3) (%)	(RGD No.500/1994)	0.489	0.5 (Max.)

Figure 1. Recycling process of the concrete wastes from demolished home in Iraq: a – demolished home; b – concrete wastes; c – crushing machene; d– sieving work; e – recycled aggregate.

2.2.2. Reference concrete trial mixtures (REF)

A great attention has been paid for the reference concrete mixture proportioning as to obtain a certain slump of (75) mm. Thus; the trial mixtures were performed to reach the required slump and hence, mixture (REF) was selected as the reference concrete. It is important to mention that the slump value was chosen to be a reasonable value to maintain a good workability since later mixtures would contain angular recycled coarse aggregate which would certainly reduce the slump (severely in some cases), thus; the above slump value should be constant for all concrete mixtures for the comparing purposes. Details of this trial mixture are illustrated in table 2.

Table 2. Reference concrete trial mixtures (Ingredients for cubic meter) Quantities of Mixture Ingredients (kg/m^3).

Trial mixture symbol	Water	Silica fume	Cement	w/p ratio by wt.	Fine aggregate	Coarse aggregate	Slump (mm)	Density (kg/m3)
REF	194	-	471.264	0.412	598.9	1019.9	7.5	2150

2.2.3. Recycled aggregate concrete mixtures

For this type of concrete, six different mixtures were prepared. Each mixture with a different type and percentage of recycled coarse aggregate. Furthermore, additional six mixtures were prepared with the addition of silica fume with an amount of (10) % of cement's weight to enhance the strength characteristics of these mixtures. In total, twelve concrete mixtures were prepared to study the behavior of recycled coarse aggregate concrete. Detailed information of these mixtures are illustrated in Table 3.

Table 3. Recycled concrete mixtures (Ingredients for cubic meter).

Mixture symbol	Cement (kg)	Water (kg)	Fine aggregate (kg)	Natural Aggregate (kg)	Recycled Aggregate (type-kg)	Silica Fume (kg)
DC33	471.264	206.416	612.756	631.74	DC -332.863	-
DC66	471.264	205.511	643.447	292.351	DC -618.006	-
DC100	471.264	195.904	690.727	-	DC -853.243	-
TC33	471.264	206.41	610.936	629.139	TC - 331.492	-
TC66	471.264	194.281	650.441	289.75	TC -620.454	-
TC100	471.264	192.833	689.308	-	TC -852.408	-
DC33S	471.264	217.145	567.417	631.74	DC - 332.863	47.126
DC66S	471.264	215.243	598.881	292.351	DC - 618.006	47.126
DC100S	471.264	214.262	636.691	-	DC - 853.726	47.126
TC33S	471.264	217.176	565.306	629.139	TC - 335.841	47.126
TC66S	471.264	215.738	596.237	289.75	TC - 620.545	47.126
TC100S	471.264	214.29	635.106	-	TC - 852.408	47.126

Note: (DC) refers to recycled waste concrete mixture with aggregate from demolished building waste (RDA), while (TC) refers to recycled crushed tested cubes concrete mixture with aggregate from crushed tested cubes (RTA)

3. Results

3.1 Compressive strength test

The compressive strength of concrete specimens was tested and compared according to (BS 1881: Part 116: 1983). Standard cubes with dimensions of (150 × 150 × 150) mm were used for this test. A digital testing machine with a capacity of (2000) kN was used. The loading rate was (0.4) MPa / sec, concrete cubes were tested at an age of (28) days, the average of three cubes per test has been considered. The compressive strengths for the test specimens have been determined from the average of three (150) mm cube specimens except for the reference concretes. The development of the compressive strengths of the different recycled coarse aggregates concretes is shown in both of Fig. 2 and Fig. 3. From Fig. 2, it can be seen that the recycled demolishing waste aggregate concretes (DC) with (33.3, 66.7 and 100) % replacement of natural coarse aggregate exhibited a decrease in the compressive strength (compared to the reference concrete REF) by the amount of (3.18, 5.05 and 6.12) % respectively.

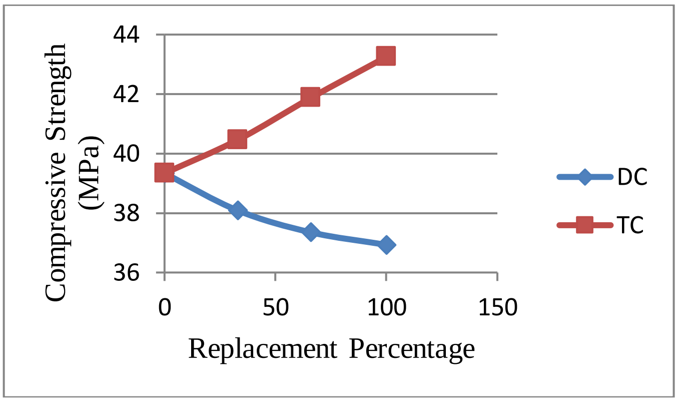

Figure 2. Development of compressive strength of recycled aggregate.

These results may be attributed to a number of reasons. First, the recycled concrete aggregate (RCA) possesses a higher porosity and a lower density of about (20) % than the natural coarse aggregate. Therefore, lower density of the coarse aggregate (which has the largest contribution to the concrete mass) leads to a lower strength of coarse aggregate and consequently, lower strength of the concrete.

Another reason for this reduction in strength is that the recycled coarse aggregate has a lower resistance to the mechanical action than the natural aggregate, so a weaker concrete is produced [10]. In addition, the recycled aggregate concrete (RAC) has significantly more weak bond areas than the corresponding normal concrete since it has bonding areas between the round gravel and old or new mortar in addition to the bonding areas between the old and the new mortar [11].

Finally, the angularity and the increased surface area of the recycled concrete aggregate lead to a lower workability then a higher water content to maintain the required workability of the mixture, and eventually a lower strength of the concrete.

On the other hand, the replacement of recycled coarse aggregate led to a significant increase in the compressive strength in (TC) mixtures by (2.85, 6.45 and 9.95) % for the aggregate replacement percentages of (33.3, 66.7 and 100) % respectively when compared to the reference concrete (REF). The above results can be interpreted as follows:

The (RTA) has much more resistance to mechanical action than the ordinary concrete; hence a better recycled aggregate is gained. Also, the recycled (RTA) coarse aggregate consists of strong angular particles which tend to improve the interlocking action of the coarse aggregate and increase the strength. In addition, it is important to mention that the (RTA) has stronger mortar attached to coarse aggregate, due to the increased fine aggregate content and the use of powders and super plasticizers that produce denser and stronger mortar than other types of concrete.

Referring to Fig. 3, it can be seen that the addition of silica fume to the concrete caused an increase in strength for the mixtures that have waste (RDA) by (7.49, 8.53 and 7.96) % for (33.3, 66.7 and 100) % replacement respectively comparing to those mixtures without the addition of the silica fume. This may be attributed to the many advantages of the utilized silica fume which prevented bleeding and segregation in the fresh concrete. The silica fume also acts both as a filler and as a pozzolanic material that fills the voids between the aggregate particles. It also accelerates and optimizes the hydration process, thus producing stronger, denser and both chemical and mechanical attack resistant concrete.

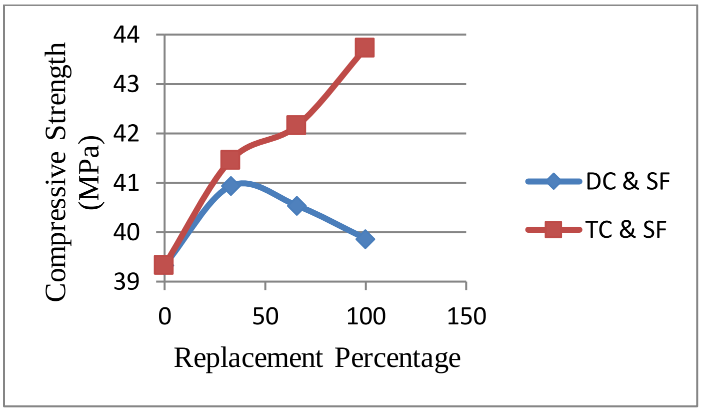

Figure 3. Development of compressive strength of recycled aggregate concretes containing silica fume.

As expected, the addition of silica fume to the (RAC) that contains (RTA) coarse aggregate, also increased the strengths as follows: (2.48, 0.68 and 1.11) % for (33.3, 66.7 and 100) % of replacement respectively when compared to the same mixtures without the silica fume. Fig. 4 summarizes the compressive strength results. As for (66.7 and 100) % of replacement, there was a lower increase than that of the corresponding strength.

This lower increase took place due to the high presence of this admixture in the concrete as an old adhered mortar to the aggregate and as a new addition to the mixture. This indicated high presence resulted in a higher water demand to maintain the required workability and eventually a less increase compressive strength. This reason also explains the lower increase in strength for the (33.3) % replacement mixture compared to that mixture where waste (RDA) was used.

3.2. Splitting tensile strength test

This test was carried out according to (ASTM C496 - 04) by using concrete cylinders with dimensions of (150 × 300) mm. The testing machine was A digital machine with (2000) kN capacity. For proper distribution of the load on the specimen, two plywood strips of dimensions (2 × 20 × 300) mm were placed above and under the specimen during the test. A diametric compressive force was applied along the length of the concrete cylinder at a rate of (1.4) MPa / min until failure occurred. The splitting tensile strength was taken as the average value of three specimens using the following equation:

$$f_t = 2P / \pi l d \tag{1}$$

where:

f_t is splitting tensile strength (MPa).
P is maximum applied load indicated (N).
L is length of the specimen (mm).
D is diameter of the specimen (mm).

The splitting tensile strength test results of all concrete mixtures are shown in Fig 6. These results show a slight decrease in strength when waste concrete aggregate (RDA) is used with (33.3) % of replacement, this decrease is of (0.35) % compared to the reference concrete. This decrease may be attributed to that the recycled aggregate contains a high percentage of natural aggregate particles with a less percentage of mortar attached on the aggregate particles forming angular particles that limitedly enhanced the interlocking and gave a similar strength [12].

After that, the increase in the replacement percentage of the (RDA) resulted in an obvious reduction in the tensile strength of (1.34 and 3.46) % for (66.7 and 100) % respectively. This reduction occurred due to the increase in the recycled concrete aggregate, or in other words, the increase in the weak adhered mortar which makes the (RDA) much more deformable than the corresponding natural aggregate. It is a fact that the considerable amounts of the porous old mortar forms weakness zones in the concrete composition.

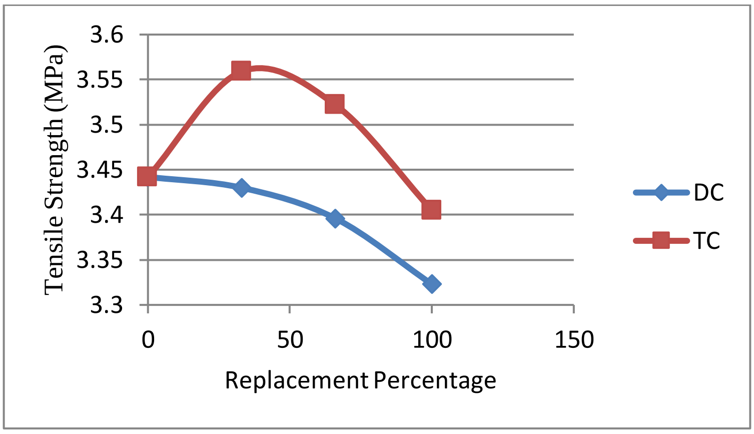

Figure 4. Development of splitting tensile strength recycled aggregate concretes.

Referring to Fig. 5, the addition of the silica fume increased the tensile strength beyond that of the reference concrete when (33.3) % and (66.7) % of replacement were considered for both types of (RDA) and RTA).

Nevertheless, compared to the mixtures without the silica fume, the use of this admixture resulted in an increase in the splitting tensile strength of (5.1, 2.8 and 1.05) % for (33.3, 66.7 and 100) % replacement of waste (RDA) in the same order. These results show that the use of the silica fume could result the same tensile strength of the reference concrete when the replacement of waste (RDA) is raised up to (66.7) %.

Moreover, the mixtures that contain recycled (RTA) coarse aggregate with the silica fume gave an increase of (7.08, 4.88 and 0.97) % for the corresponding (33.3, 66.7 and 100) % values respectively compared to those without the silica fume in.

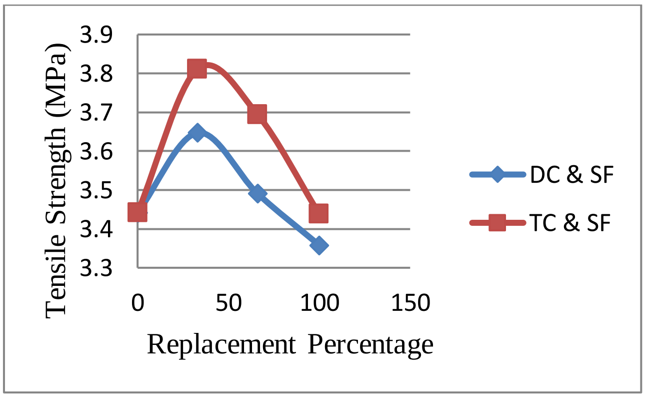

Figure 5. Development of splitting tensile strength of recycled aggregate concretes containing silica fume.

4. Discussion

This study presents an experimental study on the performance of concrete that contains recycled coarse aggregate. The replacement percentages of natural coarse aggregate with the recycled coarse aggregate are (0, 33.3, 66.7 and 100) %. Moreover, silica fume was used as an admixture for all recycled aggregate concretes. Compressive and indirect tensile strength were studied for all of the reference and recycled aggregate concretes at (28) days age, by testing concrete cubes and cylinders specimens respectively. The results showed that the compressive strength and splitting tensile strength decreased for recycled waste concretes taken from demolished buildings and increased for recycled crushed tested cubes concretes from laboratory as compared to the reference concrete. When the silica fume was added, the compressive strength and tensile strength increased for all recycled aggregate concretes compared to those without the silica fume.

Moreover, some of the (RCA) particles have a micro crack that occurs during the crushing of the original waste concrete. Considering this fact, it appears that the (RAC) is nearly showing a similar tendency as the light weight aggregate concrete, which were stated by [13] and [10]. It was also reported by [14] that the presence of the cracks in light weight concrete is entirely different from that in the natural aggregate concrete, and indicated that the fracture resulted tensile stress in the very aggregate particles, as well as the fracture in the matrix.

On the other hand, in the natural gravel concrete, the strength of the aggregate itself is usually high compared to the strength of the cement matrix. For this reason, failure in tension will rarely occur as a result of the fracture of the aggregate itself, but mostly due to the fracture of the matrix, or the breakdown of the bond between the aggregate and the matrix. By inspecting, it was found that the failure plane in the (RAC) in this work goes directly through and around the recycled aggregate particles, while the opposite was found in the reference (natural aggregate) concrete.

When the recycled (RTA) aggregate was used, the splitting tensile strength witnessed an increase of (3.4 and 2.33) % for (33.3 and 66.7) replacement percentages respectively. While for (100)% replacement, the tensile strength decreased for about (1.07) %. These results can be explained when the nature of (RTA) is considered. As mentioned before, the (RTA) has much more stronger mortar than the normal concrete due to the use of powders and super plasticizers.

Furthermore, the crushed particles of (RTA) are all of a similar appearance (crushed gravel particle and mortar on the surface), thus; the difference from waste (RTA) is produced hence, even when (100) % of replacement was adopted the reduction in tensile strength was remarkably less than the case of waste (RDA) and relatively close to the strength of the reference concrete

5. Summary

Based on the tests results which have been obtained from the research experimental program and the interpretation of these results, the following conclusions can be made:

1. With the increase of coarse (RCA) replacement percentage, the fine aggregate content increases in the mixture and the density of fresh concrete decreases.

2. The workability of (RAC) decreases with the increase of the replacement percentage of (RCA) for a constant cement and water content.

3. The addition of silica fume to the (RAC) mixtures increases the water demand to obtain a constant workability.

4. (RAC) made from waste coarse (RDA) showed a gradual decrease in the compressive strength for (33.3 , 66.7 and 100) % of replacement. While (RAC) made from recycled (RTA) aggregate exhibited a gradual increase in the compressive strength compared to the reference concrete. The addition of silica fume increased the compressive strength for all recycled aggregate concretes and even more than the reference concrete.

2. The splitting tensile strength decreased when waste (RDA) was used. The use of recycled (RTA) aggregate presented an increase and a slight reduction for (100) % of replacement, compared to the reference concrete. When the silica fume was used, the tensile strength of (RAC) increased beyond that of the reference concrete, except when (100) % replacement of (RCA) was adopted.

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