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Effect of Recycled Aggregate on Behavior of Tied and Spiral Reinforced Fibrous Circular Short Columns

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HIGHLIGHTS

- For Circular Tied Columns, Pcr decreased to (30% and 40%) when normal aggregate is replaced by (50% and 100%) of recycled aggregate, respectively, while Pu decreased by (43% and 47%).
- For Circular Tied Column with 100% recycled aggregate, when steel fiber is added, Pcr increased by (51% and 53%) if vf is (0.5% and 1%), respectively, while Pu increased by (46% and 57%).
- For Circular Spiral Columns, Pcr decreased to (6% and 15%) when normal aggregate is replaced by (50% and 100%) of recycled aggregate, respectively, while Pu decreased by (20% and 25%).

ABSTRACT

This study focuses on studying the behavior of fibrous circular short columns (tied and spirally reinforced) using recycled coarse aggregate (f'c, ft, Ec, and fr) by using recycled aggregates with comparison to normal aggregates with and without using steel fibers. For this purpose, ten (10) short columns were cast at five groups each of two circular columns(tied and spiral of 150 mm radius x 600mm height) with different percentages of recycled coarse aggregate (0%, 50%, and 100%) and different percentages of steel fiber (0%, 0.5% and 1%). The study showed that when adding the 50% normal aggregates with 50% recycled aggregates, decreases of (10%, 18%, 30% and 22%) for (compressive strength, splitting tensile strength, flexural strength and elasticity module), respectively were observed, and when replacing the 100% normal aggregates with 100% recycled aggregates, decreases of (30%, 35%, 58% and 63%) for (Compressive strength f'c, splitting tensile strength ft, flexural strength fr and elasticity module Ec), respectively were observed. The changes on the compressive strength of adding steel fibers to the RAC by a proportion of (0.5% and 1 %) resulted in a significant increase of about (14 % and 35 %), respectively.

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1. Introduction

Day by day the concrete wastes generation was getting increased [1]. Aggregate obtained by breaking waste concrete is called recycled aggregate [2]. Coarse aggregate obtained by demolished concrete provides the possibility to produce concrete in a more environmentally friendly way by reducing the consumption of natural resources and saving disposal sites of concrete waste [3]. Although using recycled concrete aggregate (RCA) does not lead to significant reduction of CO_2 emission, but it reduces using natural resources (natural aggregate) as well as reducing dumping construction and demolition wastes in landfills [4]. It is indicated that the recycling industry has been well developed in Europe since the beginning of the Second World War .Since 1982, the American Society for Testing and Materials (ASTM) concept of coarse aggregate has included broken hydraulic cement material, including the concept of sand produced with cracking concrete penalties [5].

A column is a compression member with a ratio of height to lateral dimension of three or more [6]. It is a structural element which is utilized mainly to support compressive loads when the design calculations indicate simultaneous bending moment to be present or not [7, 8]. Adding steel fiber to concrete helps not only to develop the tensile strength, but primarily to control cracking and to enhance the behavior of the cracked concrete by connecting crack sides by fibers [9]. Concrete columns are usually reinforced longitudinally and transversely with steel and it can be categorized into three types; tied column, spiral reinforced column and composite column [10]. In general, columns may be exposed to either (axial

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compression only) or (axial compressive load and uniaxial bending) or (axial compressive load and biaxial bending) [11]. Many experimental and numerical researches have been conducted to study the structural behavior of Recycled Aggregate Concrete (RAC) Short Column, however; most of these researches deal with the effect of replacement of natural coarse aggregate by recycled aggregate of different percentages on the compressive strength of one type of columns. In addition, only few studies were conducted to study the behavior of RAC short column strengthened with steel fiber, especially the ones totally replaced by RAC.

2. Materials

2.1 Cement

A (200) Kg of Ordinary Portland Cement (OPC) type (I) was used in this research which is manufactured in Bazyan, Al-Sulaimanya. The chemical constituents of Portland cement are as follows:

Lime (CaO) 60 to 67%
Silica (SiO_2) 17 to 25%
Alumina (Al_2O_3) 3 to 8%
Iron oxide (Fe_2O_3) 0.5 to 6%
Magnesia (MgO) 0.1 to 4%
Sulphur trioxide (SO_3) 1 to 3%
Soda and/or Potash (Na_2O+K_2O) 0.5 to 1.3%

2.2 Fine Aggregate

Fine aggregate of the AlKhaider area in Karbala was used in this study and it is ordinary river sand that meets the requirements of (Iraqi Standard Specification No.45:1984) [12], which has a fineness module of (2.6), sand's water absorption and density were 4.41 percent and 2556 kg/m^3, respectively. The chemical and physical properties of fine aggregate are shown in Table (1).

2.3 Natural Coarse Aggregate

Rounded gravel from the AL-Nibaee zone (AL-Anbar, Iraq) with a maximum size of 12 mm is used according to (Iraqi Standard Specification No.45: 1984) [12]. Table (2) demonstrates the physical characteristics of this aggregate conducted at The National Center for Construction Laboratories and Research performed test.

2.4 Recycled Coarse Aggregate

Recycled coarse aggregate was ready by gently splitting the cubes of ancient ordinary concrete, then smashing it to multiple volume fractions by using a crushing machine to offer a comparable grading similar to real crude aggregates. After sieving, it was rinsed with water to extract the dust and then it was hold after cleaning with air. Table (3) shows the chemical and physical properties of recycled coarse aggregate.

2.5 Steel Fiber

Steel fibers of micro size are utilized throughout this research with a tensile strength of 2600 Mpa and an aspect ratio of (75), as shown in Plate (1). The characteristics of steel fibers are shown in Table (4), which were supplied by the manufacturer.

2.6 Steel Reinforcement

Steel bars of (10mm) diameter are used as a main reinforcement and (8 mm) as a longitudinal reinforcement for tied and spiral reinforced circular columns. Table (5) shows the reinforcement bar results. Test results are according to ASTM A370-13 steel bars.

Table 1: Chemical and physical properties fine aggregate

Physical properties	Test result	Limit of Iraqi specification No.5:1984
Specific gravity	2.55	-
%Sulfate content	0.09%	≤ 0.50 %
%Absorption	2.89	-
Materials finer than75 μm sieve	2.56%	< 5%
Fineness Modulus	2.6	-

Table 2: Chemical and physical characteristics of organic coarse aggregates

Properties	Test result	Limit of Iraqi specification No.5:1984
Specific gravity	2.63	-
Absorption	2.6	-
Sulfate content	0.06%	≤ 0.1% max

Table 3: Chemical and physical properties of recycled aggregate

Properties	Test results	Limit of Iraqi specification No.5:1984
Specific gravity	2.54	-
Absorption %	3.5%	-
Sulfate content	0.07%	≤ 0.1% max

Table 4: Properties of micro steel fiber

Description	straight
Length	15mm
Diameter	0.2mm
Tensile strength	2600MPa
Density	7800 kg/m3
Aspect ratio	75

Table 5: Properties of reinforcing steel bars

Nominal bar diameter (mm)	Yield strength fy (MPa)	Ultimate strength Fu (MPa)	% Elongation	Yong's modulus Es (GPa)
10	535	633	11.8	202
8	574	666	7	200

3. Specimens Description

Five groups of short columns were cast using natural coarse aggregate with a maximum size of (12mm) and/or recycled coarse aggregate, each group consists of two columns as follows:

1. Circular tied columns of 150 mm radius and 600 mm height.
2. Circular spiral columns of 150 mm radius and 600 mm height.

These groups are different with their concrete mixtures according to the percentage of using recycled coarse aggregates, normal coarse aggregates and steel fibers (0%, 0.5% and 1%) volume fraction. The previous description can be detailed as follows (see Table 6):

- Group one: 100% normal coarse aggregate without adding steel fibers.
- Group two: 50% normal coarse aggregate, 50% recycled coarse aggregate without adding steel fibers.
- Group three: 100% recycled coarse aggregate without adding steel fibers.
- Group four: 100% recycled coarse aggregate with adding steel fibers with a percentage of 0.5% of the total weight of concrete.
- Group five: 100% recycled coarse aggregate with adding steel fibers with a percentage of 1% of the total weight of concrete.

4. Method of Work

Ten structural hollow formed plastic tubes with an outer diameter (D) of 150.3 mm are used. Control samples for each group are tested for compressive strength f'c. Three cubes and three cylinders are cast and tested to estimate the modulus of elasticity of concrete Ec, three cylinders to evaluate the splitting tensile strength ft and three prisms to estimate modulus of rupture fr.

Concrete is mixed in a drum laboratory mixer with a volume of 0.15m3. Before mixing, it is essential to maintain the oven smooth, humid and clear of water. Mixing processes were carried out as described in the following notes:

1. Add the fine aggregate with 1/4 of mixing water and mix for 1 minute.
2. Add cement with 1/4 of mixing water and mix for 1 minute.
3. Add the coarse aggregate with the third 1/4 of mixing water and after mixing (1.5 minutes) the mix is reserved for remainder (1.5 minutes).
4. After that, add the last 1/4 of water to the mix. During the mixing operation (5-10) minutes, steel fibers were gradually sprayed into the mixture.
5. Finally, the concrete was removed, cast, cured and tested for concrete characteristics.

After the process of casting models consisting of five circular tied columns and five circular spiral columns, 15 cubes, 30 cylinders and 15 prisms were placed in a water tank submerged in water for 28 days with the importance of compensating the lack of water due to evaporation. They were then removed from the burlap and held in the accessible room temperature due to (ASTM C31-03a-110) prior test process.

The workability for all mixtures was evaluated instantly after the mixing process in accordance with the slump test method (ASTM C-143). The result was (90±10) mm. All column samples were evaluated under monotonic strain until collapse using a 2500 KN hydraulic testing machine (Avery).

The following equations are used for the calculation of ft, Ec and fr:

$$\mathrm{ft} = 2\ \mathrm{N}\ /\pi DL \quad (1)$$

Where: N: is the applied compressive load, (N)
D: is the cylinder diameter, (mm).
L: is the cylinder length, (mm).

$$Ec = (\boldsymbol{S2 - S1}) / (\mathcal{E}\boldsymbol{2 - 0.00005}) \quad (2)$$

Where: Ec: is the modulus of elasticity, (MPa)
S1: is the stress corresponding to a longitudinal strain (0.00005), (MPa)
S2: is the stress corresponding to 40% of ultimate load, (MPa)
Ɛ2: is the longitudinal strain produced by stress S2

$$fr = PL/bd2 \quad (3)$$

Where: fr: is the flexural strength, (MPa)
P: is the maximum load, (N)
b: is the width of specimen, (mm)
d: is th depth of specimen, (mm)
L: is the clear span length, (mm)

5. Results of Tests

The mechanical characteristics investigated in this study are the compressive strength ($f'c$), splitting tensile strength (*ft*), Modulus of Elasticity and Flexural strength (modulus of rupture).

5.1 Compressive strength (f'c)

These measurements were achieved from an average of three cubes and six cylinders cast for each concrete mixture and tested at the same period as the column samples taken, as shown in Table (7), Figure (1):

Where: NAC: Mix with normal aggregate concrete
RAC50: Mix with 50% recycled aggregate concrete
RAC100: Mix with100% recycled aggregate concrete
RAC100-0.5: Mix with100% recycled aggregate concrete and vf (0.5%)
RAC100-1: Mix with100% recycled aggregate concrete and vf (1%)

5.2 Splitting Tensile Strength (ft)

Splitting tensile strength is a significant part of hardened concrete, as deformation in concrete is most commonly linked to the tensile stress that has taken place or having contributed to environmental variations. Table (8) and Figure (2) indicate the computed results of the splitting tensile strength experiment of all mixtures and the expected results calculated from Formula (4) [13]:

$$ft\,(\text{predicted}) = 0.56\,\sqrt{f'c} \quad (4)$$

Where: *ft* and $f'c$ are in MPa

Table 6: Columns specimens

Group	Columns	Stirrups mm	Recycled aggregates %	Steel fiber %
Group 1	NCCTC	Tied ø10 @150	0	0
	NCCSC	Spiral ø10 @40	0	0
Group 2	RCCT50	Tied ø10 @150	50	0
	RCCS50	Spiral ø10 @40	50	0
Group 3	RCCT100	Tied ø10 @150	100	0
	RCCS100	Spiral ø10 @40	100	0
Group 4	RCCT100 0.5	Tied ø10 @150	100	0.5
	RCCS100 0.5	Spiral ø10 @40	100	0.5
Group 5	RCCT 100 1	Tied ø10 @150	100	1
	RCCS 100 1	Spiral ø10 @40	100	1

Table 7: Results of concrete compressive strength

Mix	*f'c (cylinder) MPa*	*fcu(cube) MPa*	*f'c cylinder / f'cu cube*
NAC	26.5	33.5	0.79
RAC 50	25.3	31.4	0.80
RAC 100	23.7	28.9	0.82

RAC 100-0.5	25.1	30.98	0.81
RAC 100-1	27.2	33.5	0.81

Table 8: Measured and predicted results of tensile splitting strength

Mix	*ft* (experimental) MPa	*ft* (predicted) MPa
NAC	3.09	2.88
RAC 50	2.91	2.81
RAC 100	2.74	2.72
RAC 100-0.5	3.15	2.805
RAC 100-1	3.42	2.92

Plate (1): Micro Steel Fiber

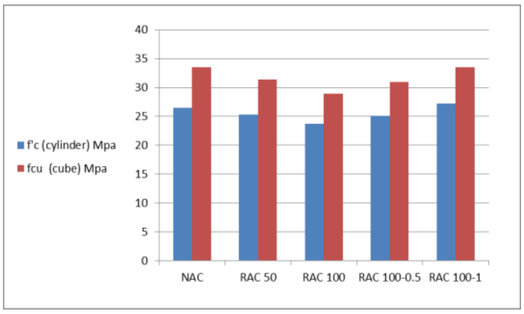

Figure 1: Concrete compressive control specimen strength

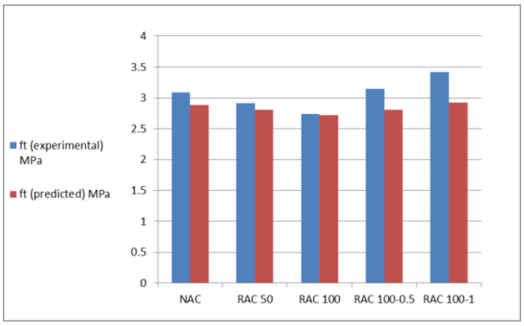

Figure 2: Concrete splitting tensile strength of the test specimen

5.3 Flexural Strength (fr)

The laboratory results mentioned before in this study are calculated using Equation (5) and Equation (6) [13]:

$$fr = 0.62\sqrt{f'c} \quad (5) \ \text{(Without steel fiber)}$$

$$fr = 0.75\sqrt{f'c} \quad (6) \ \text{(With steel fiber)}$$

Table (9) and Figure (3) indicate that all flexural mixtures stated that the laboratory values of (*fr*) were higher than the expected values for non-steel fiber mixtures and lower than the expected values for steel fiber mixtures. The increase in laboratory values of (*fr*) relative to the expected values of (*fr*) for (NA) is greater than that of (RA).

5.4 Modulus of Elasticity (Ec)

Experimental results show that the modulus of elasticity increases with the increase of compressive strength. Table (10) and Figure (4) demonstrate the elasticity modulus values for different sizes, and the expected results are as follows:

$$\mathrm{Ec} = 4700\sqrt{f'c} \quad (7)$$

Where: Ec and f'c are in MPa

5.5 Ultimate load (Pu) and Cracking load (Pcr)

The amount of cracking load to ultimate load (Pcr / Pu) was between (45% - 95%) as shown in Table (11). This percentage increases with normal aggregate concrete relative to recycled aggregate concrete and also increases with increasing steel fiber volumetric quantities.

Tables (12) and (13) illustrate the comparison in concrete behavior for the type of columns for the whole groups which are shown in Figures (5) and (6):

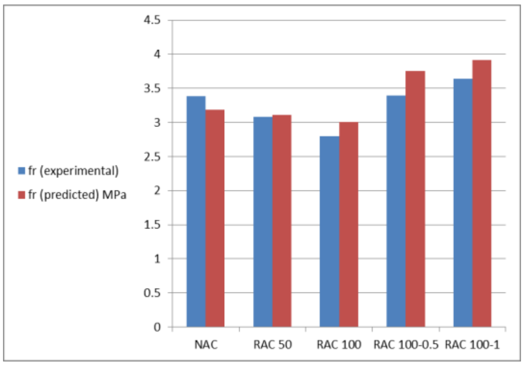

Figure 3: Concrete flexural strength of the test specimen

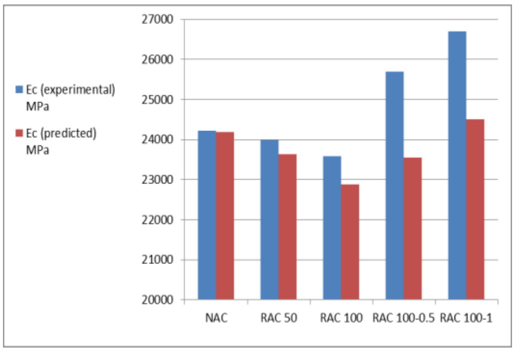

Figure 4: Modulus of Elasticity of concrete for tested specimen

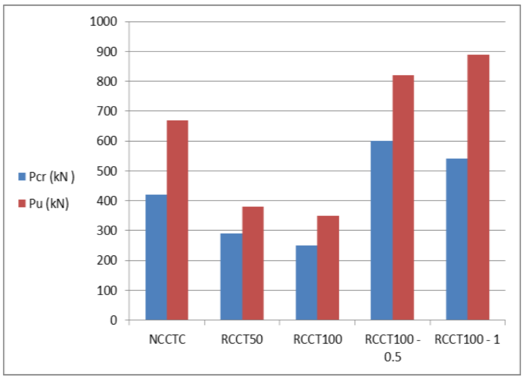

Figure 5: Ultimate and Ccracking loads of the tested circular tied columns

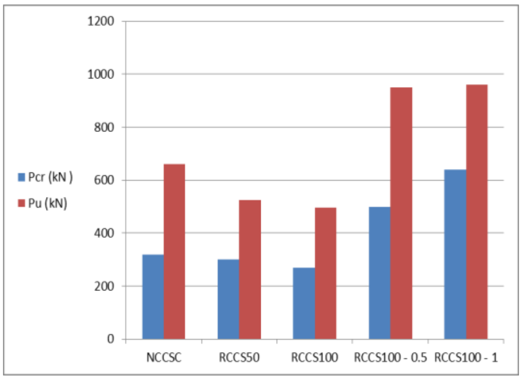

Figure 6: Ultimate and cracking loads of the tested circular spiral columns

Table 9: Measured and predicted flexural strength values

Mix	*fr* (experimental) MPa	*fr* (predicted) MPa Without steel fiber	*fr* (predicted) MPa With steel fiber
NAC	3.38	3.19	
RAC 50	3.08	3.11	
RAC 100	2.8	3.01	
RAC 100-0.5	3.39		3.75
RAC 100-1	3.64		3.91

Table 10: Measured and predicted Modulus of Elasticity values

Mix	Ec (experimental) MPa	Ec (predicted) MPa ACI 318M-2014
NAC	24213	24194.73
RAC 50	23990	23640.58
RAC 100	23582	22880.84
RAC 100-0.5	25696	23546.95
RAC 100-1	26704	24512.20

Table 11: Ultimate and cracking loads of the tested columns

Columns	Pcr (kN)	Pu (kN)	Pcr / Pu (%)
NCCTC	420	670	62.69
NCCSC	320	660	48.48
RCCT50	290	380	76.63

Columns	Pcr (kN)	Pu (kN)	Pcr / Pu (%)
RCCS50	300	525	57.14
RCCT100	250	350	71.43
RCCS100	270	495	54.54
RCCT100 - 0.5	600	820	73.17
RCCS100 - 0.5	500	950	52.63
RCCT100 - 1	540	890	60.67
RCCS100 - 1	640	960	66.67

Table 12: Ultimate and cracking loads of the tested circular tied columns

Columns	Pcr (kN)	Pu (kN)	Pcr / Pu (%)
NCCTC	420	670	62.69
RCCT50	290	380	76.63
RCCT100	250	350	71.43
RCCT100 - 0.5	600	820	73.17
RCCT100 - 1	540	890	60.67

Table 13: Ultimate and cracking loads of the tested circular spiral columns

Columns	Pcr (kN)	Pu (kN)	Pcr / Pu (%)
NCCSC	320	660	48.48
RCCS50	300	525	57.14
RCCS100	270	495	54.54
RCCS100 - 0.5	500	950	52.63
RCCS100 - 1	640	960	66.67

6. Conclusions and Discussion

1. When replacing the 50% normal aggregates with 50% recycled aggregates, decreases of (10%, 18%, 30% and 22%) in (compressive strength, splitting tensile strength, flexural strength and elasticity module), respectively were observed.
2. When replacing the100% normal aggregates with 100% recycled aggregates, decreases of (30%, 35%, 58% and 63%) in (compressive strength, splitting tensile strength, flexural strength and elasticity module), respectively were observed.
3. The changes on the compressive strength of adding steel fibers to the RAC by a proportion of (0.5%, 1 %) resulted in a significant increase of about (14 % and 35 %), respectively.
4. The addition of steel fibers to the (RAC) by a percentage of (0.5% and 1%) also increased the splitting tensile strength by about (41% and 68%), respectively.
5. The steel fibers improve the flexural strength by about (59% and 84%) when brought to the (RAC) by a volume fraction of (0.5% and 1%), respectively.
6. The same pattern was noted for adding steel fibers in two percentages of (0.5% and 1%), and when checking the elasticity module, an increase of (14% and 18%), respectively was observed.
7. For the columns cracking load (Pcr) and ultimate load (Pu), the percentage of ultimate and cracking loads of the tested columns were:

For Circular Tied Columns, it can be concluded that P_{cr} decreased to (30% and 40%) when normal aggregate is replaced by (50% and 100%) of recycled aggregate, respectively, while P_u decreased by (43% and 47%). For Circular Tied Column with 100% recycled aggregate, when steel fiber is added, P_{cr} increased by (51% and 53%) if v_f is (0.5% and 1%), respectively, while P_u increased by (46% and 57%).

For Circular Spiral Columns, it can be concluded that P_{cr} decreased to (6% and 15%) when normal aggregate is replaced by (50% and 100%) of recycled aggregate, respectively, while P_u decreased by (20% and 25%). For Circular Spiral Column with 100% recycled aggregate, when steel fiber is added, P_{cr} increased by (40% and 53%) if v_f is (0.5% and 1%), respectively, while P_u increased by (44% and 45%).

Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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