Effect of recycled aggregate on behaviour of tied reinforced fibrous rectangular short columns

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Abstract. This study focuses on studying the behaviour of fibrous rectangular short columns (tied reinforced) using recycled coarse aggregate (f’c, ft, Ec, fr) is found by using recycled aggregates with comparison to normal aggregates with and without using steel fibres. For this purpose, five (5) tied short columns were cast (150 mm length x 150 mm width x 600mm height) with different percentage of recycled coarse aggregate (0%, 50%, 100%) and different percentage of steel fibre (0%, 0.5% and 1%). The study resulted that when adding the 50% normal aggregates with 50% recycled aggregates, a decrease of (10%, 18%, 30% and 22%) (compressive strength, splitting tensile strength, flexural strength and elasticity module) respectively was observed, when replacing the100% normal aggregates with 100% recycled aggregates, a decrease of (30%, 35%, 58% and 63%) (Compressive strength f’c, splitting tensile strength ft, flexural strength fr and elasticity module Ec) respectively was observed. The changes in the compressive strength by adding steel fibres to the RAC by a proportion (0.5%, 1%) resulted in a significant increase of about (14 %, 35 %), respectively.

Keywords: short column, recycled aggregate, steel fibre, tied reinforcement.

1. Introduction

Coarse aggregate obtained by demolished concrete allows for more environmentally sustainable concrete production by reducing natural resource consumption and reducing waste disposal sites of concrete waste [1]. Although using recycled concrete aggregate (RCA) does not lead to significant reduction of CO₂ emission, but it reduces using natural resources (natural aggregate) as well as reducing dumping construction and demolition wastes in landfills [2]. 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 [3]. The use of recycled aggregates in concrete works is one of the most important topics that the majority of existing countries have tended to for several economic and environmental reasons [4]. Recycled aggregate consists of fractured and non-graded particles and treatment of materials used in construction debris and demolition [5].

Given the circumstances that Iraq is going through at the moment of improvement in the security situation and the lack of the need for existing concrete blocks to protect the ministries and all important government buildings, it is necessary to take advantage of these bulbs for the use of recycled mulch instead of disposal in the landfill areas. In fact, the necessary measures have been taken by governments in most countries of the world with the primary aim of reducing or limiting the use of the natural aggregate and the use of recycling materials, taking into consideration that they should be biologically, economically and technically acceptable [6][7]. As a consequence, recycling companies in many areas of the world transform low-value waste into secondary building products such as a multitude of aggregate grades, road products and penalties (dirt) accumulate [8].

The application of concrete recycled aggregates is necessary as it helps to encourage sustainable development in the conservation of organic materials and decreases the waste of demolition waste from ancient concrete [9]. XIAO (2017), Gastaldi and Canonico (2017) and others concluded that it is feasible to apply RAC as an ecological material used in building structures, noted that Construction and
demolition waste recycling is generally limited to the use of the coarser fraction as aggregate for new concrete [10][11][12][13].

A study curried out Geng et al. (2015) with investigations on the fatigue behavior of the axial and eccentric compression performance of recycled aggregate reinforced concrete specimens, containing recycled aggregate proportions of 0%, 50%, 100% with multi-scale (micro-structural and macro-structural) observations of the specimens. Based on the analysis of the experiment result, it was concluded that the total deformation of the Recycled aggregate concrete–filled steel tube (RACFST) members increased up to 50% after 5 months under sustained loading, which is 20% higher than the normal CFST ones, however; it was proven that it is feasible to apply recycled concrete in practical engineering [14].

Hastemoglu (2015) prepared and tested 12 specimens with three different lateral reinforcement ratios (0.022, 0.012 and 0.007) and four replacement ratios (0%, 30%, 50% and 100%) The effect of recycled coarse aggregate and lateral tie reinforcement ratio (ρ) on the compressive behavior of a confined recycled aggregate concrete (RAC) column was tested under pure axial load. The results of the study are recorded and compared with the predicted values obtained from Mendel's model, which was established for conventional confined concrete to evaluate the applicability of model of interest. The study concluded that there was no effect to addition of recycled aggregate on compressive strength behavior up to 600 KN in the ascending branch of the load strain curve, while for stress-strain curve, the effect was increased in both ascending and descending branches of RAC [15].

Tam et al. (2014) investigated the activity of RAC with stainless steel column and carbon steel column, a small amount of tiles and bricks (less than 10%) were used in all type of columns. The recycled coarse aggregate replacement ratios were estimated to be (0, 25, 50, and 100) percent, where the zero percent was considered as a control specimens. The study concluded that the effect of RAC on the compressive strength of stainless steel column was higher than its influence on carbon steel column [16].

The experimental program conducted by Mathews and Moorthy (2016) involve casting of 54 cubes of various replacement of the Recycled Coarse Aggregate RCA as (0, 10, 20, 30, 40, 50) %, which is used for determining the compression strength, 12 numbers of cylinder to determine the split tensile strength. Fresh concrete testses such as slump test, compaction factor test were carried out. Experimental testing of short columns were conducted in compression testing machine to determine ultimate axial failure load, determine strain value as following loads applied failure cracks in column were observed. The study concluded that up to (30-40) % replacement Of RCA in Concrete can provides Sufficient Strength for use of Recycled Coarse Aggregate that is obtained from demolished building and can be reused. So the RCA can use for column in construction building and other structures in construction field that can sustain our resources such as natural coarse aggregate (NCA) for our future generation. Adoption of such reusability can be resulted in sustainable construction [17].

2. Experimental Program

I. Cement

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

| Constituent       | Percentage |
|-------------------|------------|
| Lime (CaO)        | 65%        |
| Silica (SiO₂)     | 20%        |
| Alumina (Al₂O₃)   | 7%         |
| Iron oxide (Fe₂O₃)| 3%         |
| Magnesia (MgO)    | 2%         |
| Sulphur trioxide (SO₃)| 2%     |
| Soda and/or Potash (Na₂O+K₂O) | 1% |

II. Fine Aggregate
Fine aggregate of the AL-Ukhaider area in Karbala used in this study is ordinary sand that meets the requirements of (Iraqi Standard Specification No.45:1984) [18]. It 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).

### Table 1: Chemical and Physical properties Fine aggregate

| Physical properties                  | Test result | Limit of Iraqi specification No.5:1984 (Zone II) |
|-------------------------------------|-------------|--------------------------------------------------|
| Specific gravity                    | 2.55        | -                                                |
| %Sulfate content                    | 0.09%       | $\leq$ 0.50 %                                    |
| %Absorption                         | 2.89        | -                                                |
| Materials finer than75 μm sieve     | 2.56%       | $< 5\%$                                          |
| Fineness Modulus                    | 2.6         | -                                                |

### II. Natural Coarse Aggregate

Crushed gravel from the AL-Nibae zone (AL-Anbar, Iraq) with maximum size of 12 mm is used according to (Iraqi Standard Specification No.45: 1984) [18]. Table (2) demonstrates the physical characteristics of this aggregate conducted at The National Center for Construction Laboratories and Research performed test.

### Table 2: Chemical and Physical characteristics of normal coarse aggregates

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

### III. 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 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 hold it after cleaning with air. Table (3) shows the chemical and physical properties of recycled coarse aggregate.

### Table 3: Chemical and physical properties of recycled coarse aggregate

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

### V. Steel Fiber

Steel fibers of micro size are utilized throughout this research with tensile strength 2600 MPa and aspect ratio of (75). The characteristics of steel fibers are shown in Table (4), which supplied by manufacturer.

### VI. Steel Reinforcement

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

### Table 4: Properties of micro steel fiber
2.1 Specimens Description
Five short columns were cast using normal coarse aggregate with a maximum size (12mm) and/or recycled coarse aggregate and dimensions of (150 mm length, 150 mm width, 600 mm height). These columns are different with their concrete mixtures according to the percentage of recycled coarse aggregates, normal coarse aggregates and steel fibers (0%, 0.5% and 1%) volume fraction. The previous description can be detailed in Table (6) below:

| Table 6: columns specimens |
|-----------------------------|
| No. | Columns | Lateral reinforcement (Mm) | Recycled aggregates % | Steel fiber % |
|-----|---------|---------------------------|-----------------------|--------------|
| 1.  | NCRTC   | Tied ø10 @150             | 0                     | 0            |
| 2.  | RCRT50  | Tied ø10 @150             | 50                    | 0            |
| 3.  | RCRT100 | Tied ø10 @150             | 100                   | 0            |
| 4.  | RCRT100 - 0.5 | Tied ø10 @150 | 100                  | 0.5          |
| 5.  | RCRT100 - 1  | Tied ø10 @150             | 100                   | 1            |

2.2 Method of work
Five rectangular molds were manufactured to use in the casting of five columns for each mix. Each mold was produced using 18 mm thick plate wood and their ends parts are linked by pins that can be readily separated and mounted. Control samples are tested for compressive strength $f'_c$ & $f_{cu}$ three cubes according to (BS 1881:part116) and three cylinders in accordance with (ASTM C 39/C 39M-03), three cylinders are cast and tested to estimate the modulus of elasticity of concrete $E_c$ as recommended by (ASTM C469-02a), three cylinders to evaluate the splitting tensile strength $f_t$ according to the (ASTM C496/C496M-11) and three prisms to estimate modulus of rupture $f_r$ according to (ASTM C78-02).
Concrete is mixed in a drum laboratory mixer with a volume of 0.15m³. Before mixing, it is essential to maintain the mixer smooth, humid and clear of water. Mixing processes were carried out according to a study carried out by Raoof, 2019 [19] 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 rectangular tied columns, 15 cubes, 45 cylinders and 15 prisms which 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 mix process in accordance with the slump test method (ASTM C-143). The result was (90±10) mm. All column samples were tested under monotonic strain until collapse using a 2500 KN hydraulic testing machine (Avery).

The following equations are used for calculation of $f_t$, $E_c$ and $f_r$:

$$f_t = \frac{2N}{\pi DL} \quad \text{(1)}$$

Where:

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

$$E_c = \frac{(S2-S1)}{(\varepsilon 2-0.00005)} \quad \text{(2)}$$

Where:

- $E_c$: Modulus of elasticity, (MPa)
- $S1$: Stress corresponding to a longitudinal strain (0.00005), (MPa)
- $S2$: Stress corresponding to 40% of ultimate load, (MPa)
- $\varepsilon 2$: Longitudinal strain produced by stress $S2$

$$f_r = \frac{PL}{bd^2} \quad \text{(3)}$$

Where:

- $f_r$: Flexural strength, (MPa)
- $P$: Maximum load, (N)
- $b$: Width of specimen, (mm)
- $d$: Depth of specimen, (mm)
- $L$: clear span length, (mm)

3. Results and Discussion

The mechanical characteristics investigated in this study are the Compressive strength ($f'_c$) and $f_{cu}$, splitting tensile strength ($f_t$), Modulus of Elasticity($E_c$) and Flexural strength (modulus of rupture) ($f_r$).

I. Compressive strength ($f'_c$) and $f_{cu}$

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

| Mix          | $f'_c$ (cylinder) | $f_{cu}$ (cube) | $f'_c$/cube | $f_{cu}$ cube |
|--------------|------------------|-----------------|-------------|--------------|
|              | MPa              | MPa             |             |              |
| 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        |              |

Where:

- NAC: Mix with normal aggregate concrete
- RAC50: Mix with 50% recycled aggregate concrete
- RAC100: Mix with 100% recycled aggregate concrete
- RAC100-0.5: Mix with 100% recycled aggregate concrete and vf (0.5%)
RAC100-1: Mix with 100% recycled aggregate concrete and vf (1%)

![Figure 1: Concrete Compressive Strength of Control Specimen](image)

**II. 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) illustrate the computed results of the splitting tensile strength experiment of all mixtures and the expected results calculated from formula (4) [20]:

\[
ft (\text{predicted}) = 0.56 \sqrt{f'c}
\]

Where: \(ft\) and \(f'c\) are in MPa

| Mix         | \(f'c\) (cylinder) MPa | \(f_{cu}\) (cube) 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                  |

*Table 8: Measured and predicted results of tensile splitting strength*
**III. Flexural Strength \((fr)\)**

The laboratory results found in this study are compared with the result of equation (5) and equation (6) [13]:

\[
fr = 0.62\sqrt{f'c}
\]  
(Without steel fiber) \hspace{1cm} (5)

\[
fr = 0.75\sqrt{f'c}
\]
(With steel fiber) \hspace{1cm} (6)

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

| 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                                       |                                        |
III. 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 modulus of elasticity values for different sizes, and the predicated results are as follows:

\[ Ec = 4700\sqrt{f'c} \]  

(7)

Where: \( Ec \) and \( f'c \) are in MPa

| Mix      | Ec (experimental) MPa | Ec (predicted) MPa |
|----------|------------------------|--------------------|
| 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           |
V. Ultimate load (Pu) and Cracking load (Pcr)

The ratio of cracking load to ultimate load (Pcr / Pu) was between (45% - 95%) as shown in Table (11) and Figure (5). This percentage increases with the percentage of normal aggregate concrete relative to recycled aggregate concrete and also increases with increasing of steel fiber volumetric quantities.

**Table 11: Cracking and Ultimate loads of the tested columns**

| columns       | Pcr (kN) | Pu (kN) | Pcr / Pu (%) |
|---------------|----------|---------|--------------|
| NCRTC         | 430      | 490     | 87.78        |
| RCRT50        | 200      | 410     | 48.78        |
| RCRT100       | 180      | 395     | 45.57        |
| RCRT100 - 0.5| 390      | 460     | 84.78        |
| RCRT100 - 1   | 500      | 690     | 72.46        |

**Figure 4:** Modulus of Elasticity of Concrete for tested specimens

**Figure 5:** Ultimate and Cracking loads of the tested rectangular tied columns
From previous results, it was found that:

1- When replacing the 50% normal aggregates with 50% recycled aggregates, a decrease of (10%, 18%, 30% and 22%) in (compressive strength, splitting tensile strength, flexural strength and elasticity module) respectively was observed.

2- When replacing the 100% normal aggregates with 100% recycled aggregates, a decrease of (30%, 35%, 58% and 63%) in (compressive strength, splitting tensile strength, flexural strength and elasticity module) respectively was observed.

3- The changes in the compressive strength due to adding steel fibers to the RAC by a proportion (0.5%, 1%) is a significant increase of about (14 %, 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%, 68%) respectively.

5- The steel fibers improve the flexural strength by about (59%, 84%) when added to the (RAC) by a volume fraction of (0.5%, 1%) respectively.

6- The same effect was noted for adding steel fibers in two percentages (0.5%, 1%) for the tests of the modules of elasticity, an increase of (14%, 18%) respectively was observed.

7- The results of ultimate and Cracking loads of the tested columns were concluded that $P_{cr}$ decreased (53%, 58%) when normal aggregate is replaced by (50% and 100%) of recycled aggregate respectively, while $P_u$ decreased by (16%, 19%). For Rectangular Tied Column with 100% recycled aggregate, when steel fiber is added, $P_{cr}$ increased by (48%, 60%) if $v_f$ is (0.5% and 1%) respectively, while $P_u$ increased by (10% and 40%).

4. Conclusions

1- In the light of the international concern for the preservation of the environment and the reduction of pollutants resulting from industrial activities, the use of recycled aggregates in concrete is one of the ways to preserve the environment and the sustainability of natural resources that are continuously depleted in the establishment of concrete structures for these activities.

2- The study concluded through the results that there was an environmental and economic benefits resulting from the use of recycled aggregates in concrete with the possibility of improving its behavior through the addition of steel fibers.

3- There was possibility of using additives that improve the performance of concrete in which recycled aggregates are used instead of increasing the steel fibers.

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