Properties of Concrete Containing Recycled Demolition Aggregate

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Abstract. The purpose of this research is to investigate the properties of Recycled Demolition Aggregate (RDA) concrete. Five RDA concrete ratios are prepared experimentally by substituting, 0%, 25%, 50%, 75% and 100% of the gravel weight with RDA. While, the 10% of cement is substituted by silica fume (Si). Adding steel fibres (SF) (0.5 %, 1.0 % and 1.5 %). Treated RDA with cement mortar and superplasticizer (SP) admixture added to (1%) of total cementitious materials (TCM). The concrete properties exams performed such as; density, compressive strength, splitting tensile strength, and modulus of rupture. The tests concluded that the compressive strength, splitting tensile strength and rupture modulus values of RDA concretes are reduced with an increased RDA ratio relative to normal concrete. Density of RDA concrete reduces around 9% of normal concrete. The RDA is suitable in concrete and meets specifications.

1. Introduction
Natural materials containing coarse aggregate, fine aggregate and cement, with an average density of 2300 kg/m³, are traditional materials considered to be concrete. Concrete is strong of compression but weak of tension. Concrete has many advantages, including high elasticity, resistance to bend, and low creep, shrinkage and permeability [1]. Several investigators of the properties of concrete have carried out studies. A variety of influences, such as the compressive strength of concrete and the tensile strength and density [2]. Recycled demolition aggregate (RDA) is the aggregate that is produced and processed from demolition waste after collapse. A cheap and widespread material requires a solution for recycling to minimize its negative effects on the environment, as presented in figure (1). For both structural and non-structural construction, RDA concrete may be used. As a means of economic practicality and environmental realization, the use of RDA in construction work as structural grade concrete can occur alongside the greater reduction of waste materials [3].

Due to its weak distribution of particle size, RDA is typically weakly graded. Because of crushing and handling using various kinds of grinders, it could be too coarse or too fine. In RDA, the quantity of finer fractions is greater. Attributed to the existence of the old attached paste or cement mortar surrounding it, it has an old adsorption transition zone [4]. RDA has lower mechanical properties than natural aggregate [4-6]; such as low crushing strength, low impact resistance and lower abrasion resistance. RDA, which is produced by the treatment of demolition of waste construction, has been considered as a probable substitute for natural aggregate. Nonetheless, RDA has a higher porosity, lower density, higher water absorption, lower resistance to abrasion and higher layer content [7-8].

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Figure 1. Demolition waste

Large tons of waste concrete are produced by many countries; such a massive amount of waste has a significant effect on the environment [9-10]. Thereby, waste concrete recycling, which can solve this problem and conserve landfill space, protect natural resources and reduce the release of carbon. In Iraq, from 2014 to 2017, several buildings were demolished or exploded during military activities. Due to the very large amount of natural resources used during concrete processing, the accomplishment of waste concrete is certain. It could lead to a major reduction in the inactive waste that is sent to landfills, and natural resources will be safe in effect. The arrangement of recycled aggregate (RA) with mortar on their surface enhanced a significant part of this waste, resulting in high water absorption, decreased strength and increased capacity to penetrate chloride [11-12].

This study purposes to explore the mechanical properties of RDA concrete. As a partial substitute of gravel, the concrete samples used include various RDA ratios, at weights of 0 %, 25 %, 50 %, 75 % and 100 %. Addition of steel fibres (0.5 %, 1.0 % and 1.5 %) and cement mortar treated RDA. Partial silica fume replacement by cement weight (10%) and superplasticizer (SP) mixture added to (1%) of total cement materials (TCM). The RDA concrete properties are studied, for example density, compressive strength, splitting tensile strength and modulus of rupture.

2. Materials and Experimental Work
The cement was used an ordinary Portland (Type I). The cement tests on the (chemical and physical) conducted agreeing to the ASTM C150 / C150M-19a [13]; as demonstrated in tables (1) and (2). A river fine aggregate (sand) was used. The experiments results of the grading, chemical and physical properties, accomplished agreeing to specifications ASTM C778-17 [14]; are displayed in tables (3-4). A normal coarse aggregate (gravel) is utilized, measuring a dimension of (12.5) mm. Tables (5–7) show the experiment outcomes of the gravel features agreeing to reference [15].

Coarse RDA was sourced from a building demolition and replaced natural aggregate at five weight ratios: 0 %, 25 %, 50 %, 75 % and 100 %. RDA was a mix of pieces of brick, ceramic, tile and concrete. The used coarse RDA is illustrated in figure (2). Furthermore, the coarse RDA pass on through several stages before using are collecting, crashing and grading, then the material and sand separation and sieve analysis of particle size (5-12 mm), as figure (3) and table (8).

Silica fume (Si) utilized as replacement for further cement material. The Si was supplementary into the mix (substituting 10% of the weight of cement) to rise the attachment between RDA and the cement paste that improved the concrete strength [10-12]. Steel fibres with two bent ends were used, The steel fibres (SF) added to the concrete composition at three weight contents 0.5 %, 1 % and 1.5 % with a
diameter 0.55 mm and length 35 mm. Steel fibre conforms to ASTM-A820 TYPE-1 [16]. The properties of the SF is described in table (9).

### Table 1. Cement Chemical Characteristics.

| Configuration | Results | ASTM C150 |
|---------------|---------|------------|
| CaO           | 32      |            |
| Al₂O₃         | 3.5     | ≤ 8 %      |
| SiO₂          | 18      | ≤ 21 %     |
| Fe₂O₃         | 4       | ≤ 5 %      |
| MgO           | 3       | ≤ 5 %      |
| C₄            | 2       | ≤ 2.5 %    |
| SO₃           | 1       | ≤ 4 %      |
| L.O.I         | 0.75    | 1 ≤ 5 %    |
| Inexplicable Material | 0.85     | (0.66-1.02) |
| L.S.F         | 8.28    |            |
| C₃S           | 3.5     | < 5 %      |
| C₂S           | 11.16   |            |
| C₃A           | 73.1    |            |
| C₄AF          | 32      |            |

### Table 2. Cement Physical Characteristics.

| Physical Structures | Test Outcomes       | Limits                     |
|---------------------|---------------------|----------------------------|
| Definite surface area (m²/kg) | 289 m²/kg | (230 m²/kg) lower limit |
| Setting period       |                     |                           |
| Initial:             | 3 hrs. 15 | ≥ 45 min                 |
| Final:               | 8 hrs. 35 | ≤ 10 hrs.                |
| Compressive strength (MPa) |           |                           |
| at 3-day             | 18.32 MPa | ≥ 15 MPa                 |
| at 7-day             | 30.22 MPa | ≥ 23 MPa                 |

### Table 3. Sand results of grading test.

| Size of sieve (mm) | Passing Cumulative (%) | Requirements |
|--------------------|------------------------|--------------|
| 4.75               | 98                     | 95-100       |
| 2.36               | 83                     | 80-100       |
| 1.18               | 58                     | 50-85        |
| 600                | 52                     | 25-60        |
| 300                | 17                     | 5-30         |
| 150                | 5                      | 0-10         |

### Table 4. Features of sand.

| Features           | Results | Requirements |
|--------------------|---------|--------------|
| Gravity of Specific| 2.58    | -            |
| Moisture content   | 6.8 %   | -            |
| Absorption %       | 1.1 %   | -            |
| Unit Weight (Dry), kg/m³ | 1520 | -            |
| SO₃, %             | 0.08%   | 0.5 (max. value) |
| Solid < 0.075 mm   | 3.2%    | 5 (max. value)  |
Table 5. Coarse aggregate sieving test.

| Size of sieve | Passing Cumulative (%) | Limits |
|---------------|------------------------|--------|
| 20 mm         | 100                    | 100    |
| 14 mm         | 95                     | 90 – 100 |
| 10 mm         | 55                     | 50 – 85 |
| 5 mm          | 2                      | 0 – 15 |
| 2.36 mm       | 0                      | 0 – 5  |

Table 6. Coarse aggregates physical test.

| Features                  | Results | Requirements |
|---------------------------|---------|--------------|
| Gravity of Specific       | 2.64    | -            |
| Moisture content          | 6.3%    | -            |
| Absorption (%)            | 0.7%    | -            |
| Unit Weight (Dry), kg/m³  | 1730    | -            |
| SO₃, %                    | 0.06    | ≤ 0.1        |

Table 7. Coarse aggregates chemical test.

| Features                  | Results | Requirements |
|---------------------------|---------|--------------|
| SO₃, %                    | 0.05    | -            |
| Material < 75 µm%         | 0.04    | ≤0.1         |
| Salts                     | 0.5     | -            |

Figure 2. RDA used in concrete mixtures
Figure 3. Sieve analysis of RDA particles

| Size of sieve | Passing Cumulative (%) | Requirements |
|---------------|-------------------------|--------------|
| 20 mm         | 100                     | 100          |
| 14 mm         | 100                     | 90 – 100     |
| 12.5 mm       | 84                      | 50 – 85      |
| 5 mm          | 0                       | 0 – 15       |

Table 8. Sieving of RDA test.

Table 9. Features of steel fibre.

| Commercial name | Configuration | Property | Specifications |
|-----------------|---------------|----------|----------------|
| BUNDREX         | Hooked        | Density  | 2740 kg/m³     |
|                 |               | Colour   | Grey           |
|                 |               | Standard | ASTM           |
|                 |               | Length   | 35 mm          |
|                 |               | Nominal diameter | 0.55 mm |
|                 |               | Aspect ratio (L/Df) | 65 |

Superplasticizer used to achieving the required workability, the W/C need be certainly reduce to a minimum. A superplasticizer (SP) (MegaFlow 500) was used. It confirmed ASTM C 494, Type F & G standards [17]. SP recommended quantity is (0.5 %-2 %) of cement weight, so 1% is the used dosage herein. Typical properties for MegaFlow 500 at 25 °C is stated in table (10).

Table 10. Typical properties for MegaFlow 500 (at 25 °c).

| Feature            | Test Method | Results                          |
|--------------------|-------------|----------------------------------|
| Constituent        | -           | Single                           |
| Formula            | -           | Liquid                           |
| Colour             | -           | Whitish to light brown           |
| Specific gravity   | -           | 1.09 +/- 0.02                    |
| Air entrainment    | -           | Less than 1% over control mix    |
| Chloride content   | -           | Nil to BSEN 934-2                |
| pH                 | ASTM C494   | 5.5 - 8.0                        |
Table (11) reveals the mixture details quantities used herein. The mixtures contain replacing 0 %, 25 %, 50 %, 75 % and 100 % of the gravel weight with RDA, partial substitution 10 % Si from the cement weight, Steel fibre at three weight contents: 0.5 %, 1 % and 1.5 %. The normal concrete was arranged in the similar concrete mixture method (1: 1.39: 1.96) recommended by reference [18]. The concrete mixture density of 2321 kg/m$^3$, a (W/C = 0.39), and $f'_{c}$ = 35 MPa thru a 4.9 kg/m$^3$ superplasticizer.

| Mix designation | Cement | Si | SF | SP | Sand | Water | Coarse aggregate | RDA | % Replaced RDA |
|-----------------|--------|----|----|----|------|-------|-----------------|-----|---------------|
| NC              | 490    | 0  | 0  | 0  | 680  | 191   | 960             | 0   | 0             |
| RDA25           | 490    | 0  | 0  | 0  | 680  | 191   | 720             | 240 | 25            |
| RDA50           | 490    | 0  | 0  | 0  | 680  | 191   | 480             | 480 | 50            |
| RDA75           | 490    | 0  | 0  | 0  | 680  | 191   | 240             | 720 | 75            |
| RDA100          | 490    | 0  | 0  | 0  | 680  | 191   | 0              | 960 | 100           |
| RDA50-M         | 490    | 0  | 0  | 0  | 680  | 191   | 480             | 480 | 50            |
| RDA50-Si        | 441    | 49 | 0  | 0  | 680  | 191   | 480             | 480 | 50            |
| RDA50-SF0.5     | 490    | 0  | 39.5 | 0 | 680  | 191   | 480             | 480 | 50            |
| RDA50-SF1       | 490    | 0  | 78.5 | 0 | 680  | 191   | 480             | 480 | 50            |
| RDA50-SF1.5     | 490    | 0  | 118.6 | 0 | 680  | 191   | 480             | 480 | 50            |
| RDA50-SP        | 490    | 0  | 0  | 4.9 | 680  | 186   | 480             | 480 | 50            |
| RDA50-Si-SP     | 441    | 49 | 0  | 4.9 | 680  | 186   | 480             | 480 | 50            |
| RDA50-SP-SF1    | 490    | 0  | 78.5 | 4.9 | 680  | 186   | 480             | 480 | 50            |
| RDA50-Si-SP-SF1 | 441    | 49 | 78.5 | 4.9 | 680  | 186   | 480             | 480 | 50            |

They first weighted the gravel and sand. The mixing was carried out in mixer (0.05 m$^3$ volume). In the mixer, standard concrete was mixed by way of putting coarse and fine aggregates. Although the blender was working and the mixing sustained for one minute, the water put about one-third of the amount. Then the cement was added and, after three minutes of mixing, water was dispensed gradually into the blender. At a point that a uniform mixture had been obtained, the process was stopped and then the slump and fresh unit weights were evaluated.

In the mixing of materials, a special sequence was used for the RDA concrete mixes. First, inside the mixer, about 40 % of water was dispensed, and then dry RDA pieces were extra and mixing continuous around two minutes to guarantee complete water moistening. The solid materials are thus put into the mixer and progressively added the last 60 percent of the water whereas the mixing was in development to get a consistent mix. Three to five minutes of mixing proceeded, and then the fresh densities and slump were measured.

A slump test was performed for all types of mixes in agreement with reference [19]. Agreeing to reference [20]; 6 cubes sized (150×150×150) mm used to determine the compressive strength at 28 days of curing. The cylinder dimension was 150 mm diameter x 300 mm height to determine indirect tensile strength (ASTM C496 / C496M-17) [21]; in addition to calculate the concrete density [22]. Prism samples of sizes 100×100×500 mm were made to evaluate the modulus of rupture. The test was performed in agreement to ASTM C78-02 [23]; as displayed in figure (4).
3. Results and Discussion

Table (12) demonstrates the compressive strength results of all types of concrete mixes. A ordinary concrete mixture was utilized as a guide intended for comparison. For the other mixtures, a main variable was used, which substituted the normal coarse aggregates with the RDA material. In addition, superplasticizer and Si were utilized in these mixtures to recover a few of the workability and compressive strength lost, minimizing the loss causing from RDA usage. As the amount of RDA content in the mixes increased, the compressive strength decreased (25 %, 50 %, 75 %, and 100 %). This reduction is due to using the RDA that was utilized as a replacement for normal gravels, where the porosity of the recycled aggregate which leads to the absorption of the mixture water and thus less workability. There is an important difference in compressive strength as compared to conventional coarse gravels. Simultaneously, the unit weight of RDA is lesser than the normal gravel because of higher porosity, larger water absorption, lower abrasion resistance and greater content of layers [7-8].

For this, to decrease the opposing effects of RDA on the performance of concrete structures or materials, some technique needed to develop it. Such using of mineral additives (silica fume, steel fibre, et.) as cement replacement, which is one active method. These outcomes are alike several studies [9-11]. ACI code was implemented 17 MPa compressive strength. So, the all kinds of RDA concrete might be used for structural considerations [24]. This performance also happened in the tensile strength of concrete. The density as reduced due to higher porosity of the RDA particles more than natural aggregate. Furthermore, the modulus of rupture was increased up to 34% at (RDA50-Si-SP-SF1) when mixing additives together.
### Table 12. Concrete mixes results.

| Concrete designation | Slump (mm) | Density (kg/m³) | Tensile stress (MPa) | Compressive strength (MPa) | Modulus of rupture (MPa) |
|----------------------|------------|-----------------|----------------------|---------------------------|-------------------------|
| NC                   | 70         | 2462            | 3.39                 | 32.05                     | 6.76                    |
| RDA25                | 65         | 2387            | 3.09                 | 31.03                     | 6.72                    |
| RDA50                | 62         | 2280            | 3.08                 | 29.56                     | 5.97                    |
| RDA75                | 55         | 2311            | 3.05                 | 23.43                     | 5.81                    |
| RDA100               | 45         | 2235            | 3.02                 | 22.86                     | 5.71                    |
| RDA50-M              | 55         | 2340            | 3.97                 | 36.18                     | 6.84                    |
| RDA50-Si             | 58         | 2310            | 4.30                 | 56.87                     | 7.26                    |
| RDA50-SF0.5          | 57         | 2336            | 4.23                 | 37.17                     | 7.35                    |
| RDA50-SF1            | 60         | 2388            | 5.71                 | 46.46                     | 7.71                    |
| RDA50-SF1.5          | 65         | 2346            | 7.92                 | 50.68                     | 8.57                    |
| RDA50-SP             | 60         | 2361            | 4.84                 | 37.74                     | 6.83                    |
| RDA50-Si-SP          | 66         | 2306            | 5.13                 | 65.61                     | 7.29                    |
| RDA50-SP-SF1         | 54         | 2362            | 5.59                 | 60.96                     | 8.52                    |
| RDA50-Si-SP-SF1      | 58         | 2375            | 7.60                 | 67.94                     | 9.07                    |
| RDA50-Si-SF1         | 68         | 2309            | 5.10                 | 66.04                     | 8.88                    |

### 4. Conclusions

The experimental work has offered a test of the mechanical properties of concrete comprising RDA. This represents a recent trend of experiments using discarded waste and rubbish as substitute materials for the concrete's normal gravels. The following findings were discovered:

1. An increase in the RDA replacement ratio allows the effects of the slump to decrease. However, the results increased particularly the super-plasticizer effect when using additives, if mix time addition seven to eight minutes.
2. Up to a 9 %, concrete density reduction of the control mixture density can be accomplished by deducting considered quantities of coarse aggregate and substituting it with the RDA in the highest percentage used (RDA100).
3. RDA in the concrete mix as a partial substitute of gravel decreases the compressive strength about 27 %, 29 % at RDA75, RDA100, respectively, compared with the normal concrete. However, at (RDA50-Si-SP-SF1) (Mixing additives together), the compressive strength is increase up to 112 %.
4. RDA content has a little influence on the concrete tensile strength, displaying a reduction about 11 % at RDA100. But, when Mixing additives together (RDA50-Si-SP-SF1) displaying an increase of up to 124 %, while the modulus of rupture is increase up to 34 % under the same conditions.

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