Evaluation of mechanical properties of high-strength concrete with sustainable materials

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Abstract. This research deals with green concrete which is defined as environmental-friendly material that contains the waste material, and its production does not cause environmental pollution. Also, it has high performance and life sustainability. In this investigation, the effect of the curing period on the properties of green concrete made with different percentages of fly ash and recycled coarse aggregate has been studied. Nine mixtures with varying percentages of replacement of fly ash (25% and 50%) and recycled coarse aggregate (RCA) (25% and 50%) were prepared. In addition to the control mixture with 100% ordinary Portland cement and 100% normal coarse aggregate to compare the results. The standard concrete cylinders (150 x 300 mm) and cubes (150 x150 x150 mm) were prepared and tested at different ages (7, 14, 28, and 60 days) to get the compressive strength, splitting strength, and modulus of elasticity. The results showed that no noticeable effect on the cementing efficiency of fly ash if its replacement ratio has no more than 50% of cement, as well as, recycled coarse aggregate has no significant effect on concrete strengths when the replacement ratio of natural aggregate less than 50%.

1. Introduction
Achieving sustainable construction can be adopted using green concrete technology (GCT). This technology provides saving in natural materials, pollution and time through utilizing waste materials [1]. Since concrete mix production consumes about 75-80% natural aggregate, besides, 8% of CO₂ emissions of the world come from cement manufacturing [2- 4]. Thus, GCT becomes necessary to reduce or eliminate using of natural aggregate. GCT characterized by lower energy and carbon consumption comparable to conventional concrete, which contains Ordinary Portland Cement (OPC). As well as, GCT can incorporate different waste materials as recycled coarse aggregate (RCA) [5, 6].

Nowadays, fly ash used worldwide for building construction. It is a principal by-product of coal combustion. Fly ash mainly utilized for cement replacement, decreases pollution to the environment, improves durability, and decreases shrinkage and hydration [7-13].

Recently, the use of recycled aggregates locally available from war-damaged buildings in Mosul has emerged as an alternative to natural coarse aggregates in concrete. Several studies were showed successful impacts of mineral additives to improve the performance of recycled aggregate such as; silica fume, fly ash, and furnace slag [14, 15]. Guo et al. [16] reported that the pozzolanic materials that used as a surface coating or admixtures in recycled aggregate concrete can remarkably enhance the overall durability.

A lot of researchers stated that the concrete strength affects by the ratio of RCA. Higher-strength value with lower aggregate percentages was reported [17–20]. Sim and Park [21] reported that the concrete/fly ash strength is lower compared to virgin concrete. To this end, the influence of recycled
aggregate and fly ash together on GCT is not reported. However, this study focuses on the utilization of fly ash and RCA in GCT.

2. Experimental Program

2.1. Cement, fly ash, admixture, and aggregate

OPC and concentrations of 25% and 50% of fly ash were selected and tested according to Iraqi Standard Specification (ISS) [22]. Table 1 provides the physicochemical characteristics of OPC and fly ash.

Sika Viscocrete-5930 Superplasticizer, which matches the requirements of (ASTM C-494) [23], was used as a water reducer, resulting in higher concrete strengths. The water-cement ratio (W/C) was constant (0.33).

Available natural sand of (4.75 mm) maximum aggregate size with grading within the limits of (BS.882) specification [24], the grading and physical properties are listed in Tables 2 and 3, respectively.

The natural rounded gravel of maximum aggregate (NCA) size (19 mm) was used, obtained from the Tigris river (Iraq). This coarse aggregate prepared within the limits. The RCA was taken from destroyed building parts inside Mosul city of 25 years old age, after cleaning and crushing it. The grading and physical properties are listed in Table 4. Figure 1 shows a sample of fly ash and a waste of concrete.

![Figure 1](image)

**Figure 1.** The (a) A Sample of fly ash and (b) A Sample of waste concrete.

| Chemical Composition | Cement (%) | Fly Ash (%) |
|----------------------|------------|-------------|
| SiO2                 | 18.0       | 64.64       |
| AL2O3                | 4.52       | 25.72       |
| Fe2O3                | 4.27       | 5.30        |
| CaO                  | 62.7       | 0.61        |
| MgO                  | 4.24       | 0.26        |
| SO4                  | 5.62       | 0.34        |
| Loss on Ignition     | 3.56       | 2.50        |
| Fineness (m2/kg)     | 300        | 376         |
| Initial setting time (min.) | 60   | 150         |
Table 2. Sieve analysis of fine aggregate.

| Sieve Size | Percentage by mass passing BS sieves 882/1992 (%) | Specification Limits BS.882 (1992) | (%) Passing |
|------------|-------------------------------------------------|----------------------------------|-------------|
| In mm      |                                                 |                                  |             |
| 3/8        | 9.52                                            | 100                              | 100         |
| No.4       | 4.76                                            | 89-100                           | 96          |
| No.7       | 2.4                                             | 65-100                           | 87          |
| No.14      | 1.2                                             | 45-100                           | 65          |
| No.25      | 0.6                                             | 25-80                            | 40          |
| No.50      | 0.3                                             | 5-48                             | 15          |
| No.100     | 0.15                                            | -                                | 6           |

Table 3. Physical properties of fine aggregate

| Color | Specific Gravity (S.S.D) | Absorption (%) |
|-------|--------------------------|----------------|
| Brown | 2.63                     | 1.5            |

Table 4. Physical properties of NCA and RCA.

| Type of coarse aggregate | NCA | RCA | RCA25<sup>a</sup> | RCA50<sup>b</sup> |
|--------------------------|-----|-----|-------------------|-------------------|
| Maximum aggregate size (mm) | 19  | 19  | 19                | 19                |
| Specific Gravity (SSD)    | 2.72| 2.515| 2.686             | 2.642             |
| Absorption (%)            | 1.00| 4.87 | 1.92              | 2.67              |
| Unit weight (kg/m<sup>3</sup>) | 1680.35 | 1389.39 | 1525.25          | 1454.85          |

<sup>a</sup>: 25% recycled RCA + 75% NCA
<sup>b</sup>: 50% recycled RCA + 50% NCA

2.2. Specimen preparation and testing program

The tests were performed at 7, 14, 28, and 60 days. 243 specimens were cast (108 cube samples for compressive strength, 108 cylinder samples for splitting tensile strength, 27 samples for modulus of elasticity). Some trial mixes were made to choose the proportion of the concrete mix. Three samples for the prescribed age were tested and took their averages. Details of all mixtures were listed in Table 5.

A 150 x 150 x 150 mm cubes were tested as per (BS1881-Part116) [25] to find out concrete compressive strength. Whereas, 150 x 300 mm cylinders specimens as per ASTM C496 [26] was used for splitting tensile test. The modulus of elasticity was measured as ASTM C469 [27] at the ages of 28 days.

Table 5. Details of concrete mixtures.
### 3. Results

To investigate and compare the behavior of concrete using fly ash and recycle coarse aggregate, an experimental study was performed on concrete samples to find the strength and properties of it. The tests were carried out after 7, 14, 28, and 60 days. Summary of the test results for different concrete mixtures listed in the tables and figures.

#### 3.1 Workability Tests

The mix of concrete used for the test is medium workability; slump cone tests are performed in this study. The workability was enhanced by adding a superplasticizer to the mixture of concrete. All workability results were listed in Table 6.

**Table 6. Summary of workability test results.**

| Mixture       | CC  | FA0RA25 | FA0RA50 | FA25RA0 | FA25RA25 | FA25RA50 | FA50RA0 | FA50RA25 | FA50RA50 |
|---------------|-----|---------|---------|---------|----------|----------|---------|----------|----------|
| Cement (%)    | 100 | 100     | 100     | 75      | 75       | 75       | 75      | 75       | 75       |
| Fly Ash (%)   | 0   | 0       | 0       | 25      | 25       | 25       | 50      | 50       | 50       |
| NCA (%)       | 100 | 75      | 50      | 100     | 75       | 50       | 100     | 75       | 50       |
| RCA (%)       | 0   | 25      | 50      | 0       | 25       | 50       | 0       | 25       | 50       |

#### 3.2 Compressive Strength

The all compressive strength results are shown in Table 7 and Figure 2. The experimental results were compared to the results exited from the control concrete (CC), all experimental tests were conducted in 4 periods, with the age of concrete: 7, 14, 28 and 60 days. There is a slight decrease in compressive strength with the increase of cement replacement with fly ash up to 50%, also for 50% RA replacement compared with CC mix, while the reduction with 50% fly ash and 50% RA replacement was 39.8%.

The considerable variance in the obtained results occurs within 7 and 14 days of curing time. The tests have been performed to show that the compressive strength of concrete was increasing with time. It can be easily noticed by comparing the changes in compressive strength over time, which is shown in Table 7. And Figure 2. The most remarkable difference was observed at an early age.
3.3 Splitting Strength

The overall outcomes of the splitting tensile strength test are listed in Figure 3 and Table 8. Figure 3 shows that the development of splitting strength with age progress for all mixes. It can be noted that the splitting tensile strength of concrete mixes increased with the increase of the proportion of RCA up to 25% then decreased, and there is a slight decrease in splitting tensile strength with the 50% replacement of RCA comparing with NCA mix, while the reduction with 50% fly ash and 50% RA replacement was 36.7%. Optimum value can be found when fly ash=25% and RCA=25%.

Table 7. Summary of compressive strength test results.

| Mixtures     | Compressive Strength (MPa) |
|--------------|-----------------------------|
|              | 7-days | 14-days | 28-days | 60-days |
| FA0RA0 (CC)  | 37.89   | 51.98   | 56.27   | 61.16   |
| FA0RA25      | 36.20   | 48.80   | 54.72   | 58.59   |
| FA0RA50      | 34.49   | 47.50   | 51.20   | 55.89   |
| FA25RA0      | 36.73   | 47.59   | 53.90   | 59.23   |
| FA25RA25     | 35.12   | 46.29   | 51.43   | 54.14   |
| FA25RA50     | 31.66   | 41.38   | 45.57   | 49.87   |
| FA50RA0      | 27.55   | 29.94   | 41.11   | 43.74   |
| FA50RA25     | 24.91   | 26.87   | 36.28   | 39.86   |
| FA50RA50     | 23.03   | 30.82   | 33.87   | 36.27   |
Table 8. Summary of Splitting Tensile Strength Test Results.

| Mixtures       | Splitting Tensile Strength (MPa) |
|----------------|---------------------------------|
|                | 7-days | 14-days | 28-days | 60-days |
| FA0RA0 (CC)    | 3.66    | 5.90    | 6.10    | 6.13    |
| FA0RA25        | 3.81    | 6.12    | 6.35    | 6.38    |
| FA0RA50        | 3.63    | 5.95    | 6.06    | 6.10    |
| FA25RA0        | 3.18    | 4.70    | 5.3     | 5.32    |
| FA25RA25       | 3.75    | 6.06    | 6.25    | 6.41    |
| FA25RA50       | 2.79    | 3.90    | 4.65    | 4.71    |
| FA50RA0        | 2.91    | 3.20    | 4.85    | 5.92    |
| FA50RA25       | 2.37    | 3.83    | 3.95    | 3.98    |
| FA50RA50       | 2.31    | 3.62    | 3.86    | 3.90    |

3.4 Modulus of Elasticity

The moduli of elasticity values are present in Table 9 and Figure 4. The modulus of elasticity of green concrete showed a similar trend to that of the compressive strength. The increase in fly ash and RCA percentage resulted in a decrease in the moduli of elasticity. The modulus of elasticity for CC concrete samples was 40.20 GPa and 34.09 GPa for the FA50RA50 mix, respectively.

Table 9 indicates the modulus of concrete at different content of fly ash and RCA. It can be notice that the modulus of elasticity was affected considerably by the replacement level of fly ash and RCA in concrete.
Figure 4. Effect of Fly Ash and RCA on the elasticity modulus of concrete at different ages curing.

Table 9. Summary of modulus of elasticity test results.

| Mixtures          | Modulus of Elasticity (GPa) 28-days |
|-------------------|-------------------------------------|
| FA0RA0 (CC)       | 40.20                               |
| FA0RA25           | 39.65                               |
| FA0RA50           | 39.07                               |
| FA25RA0           | 39.78                               |
| FA25RA25          | 38.67                               |
| FA25RA50          | 37.69                               |
| FA50RA0           | 36.16                               |
| FA50RA25          | 35.12                               |
| FA50RA50          | 34.09                               |

4. Conclusions
In this paper, the mechanical properties of green concrete with fly ash were investigated. The following outcomes have been drawn:

1. Green concrete technology containing fly ash resulted in CO2 emissions reduced.
2. Concrete with 25% fly ash is possible in structures; but, it should be taken into account that the concrete strengths.
3. Recycled coarse aggregate can be used as replacement natural coarse aggregate with acceptable effects on concrete strengths when the replacement ratio less than 50%.
4. According to this study, the optimum percentage of fly ash and RCA was 25% to obtain good concrete strengths.
5. The recorded results led to; it is possible to produce green concrete with fly ash and recycled coarse aggregate.

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