# THE EFFECT OF THE RECYCLED AGGREGATE ON THE MECHANICAL PROPERTIES OF CONCRETE

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**Abstract:** This paper investigates the mechanical behavior of concrete prepared with recycled aggregates and fly ash. The results showed that the reduction in the strength was in direct proportion with the amount of fly ash added; the average reductions in the compressive strength was 21% for the 33% fly ash replacement and 61% for the 66% fly ash replacement. And the average reductions in the flexural strength were 15% for the 33% replacement and 41% for the 66% replacement. This indicates that fly ash replacements higher than 33% are not recommended in concrete prepared with recycled aggregates in members that are structurally critical.

**Keywords**: Aluminium Fly ash, recycled concrete aggregate, mechanical properties.

## I. INTRODUCTION

Worldwide, the annual use of aggregate is about 20 billion tons, and it is expected to grow in a growth rate of 4.7% per year [1]. This great amount led to the idea of recycling construction and demolition waste two decades ago. Nowadays, extensive researches have been conducted in the field of recycling concrete to produce useable aggregates. Using recycled aggregates reduces the emission of dust in aggregate quarries, sustains the availability of natural resources of aggregates, and reduces the cost of materials transportation.

Recycled aggregates can be defined as the "*Aggregates resulting from the reprocessing of mineral construction materials (i.e. composed predominantly of crushed concrete and brick masonry), construction waste (i.e. new materials wasted on construction sites through over ordering, breakage etc.), as well as demolition waste*".

The aim of this paper is to investigate the effect on the mechanical properties resulting from introducing fly ash in concrete with recycled aggregates.
In order to achieve this aim, the following objectives were realized through:

- Design different mixes of concrete with recycled aggregates and cement replacements with fly ash at different w/c ratios.
- Conduct tensile and compressive strength tests in order to examine the effect of replacing Portland cement with fly ash in recycled concrete aggregates.
- Estimate the optimum amounts of fly ash for the targeted strength.

The paper only discusses two of the fundamental strength parameters (Compressive and Flexural Strength).

## II. BACKGROUND

Many researchers agreed that increasing the amount of recycled aggregate would lead to gradual reduction in the compressive strength of the recycled concrete [2]. However, significant reduction on strength does not take place until replacing a certain percentage of aggregate. Limbachiya et al.[3] found that, the replacement of natural aggregates by recycled aggregate up to 30% has insignificant effect on compressive strength of concrete[4].
The compressive resistance of recycled concrete aggregates is mainly maintained by adjusting water cement ratio, replacement ratio of recycled aggregate concrete, and water absorption [5].
Generally, fly ash is not a good replacement of cement in recycled aggregate concrete regarding the mechanical properties. Studies have shown that using fly ash as a replacement of cement in concrete prepared with recycled aggregate decreases the compressive resistance of the concrete up to 90 days [6]. However, it is still a good admixture that can improve the quality of recycled concrete aggregates in other different aspects.
Using recycled aggregate in concrete increases the tendency of dry shrinkage due to the higher mortar content in the concrete – unlike compressive strength. Adding fly ash to the concrete mix, either by replacing cement or as an admixture, reduces the dry shrinkage of the recycled concrete aggregates [7].
The creep of concrete shows high values when recycled aggregate content increases. Using fly ash has shown tendency to reduce the creep of concrete because of the greater long-term strength development due to the pozzolanic reaction of fly ash.
Chloride ion penetration is a total failure mood which occurs due to high permeability of concrete that leading to chloride reaction and causing corrosion in reinforcement bars. It has been found that the increase of recycled aggregate causes decrease of chloride ion resistance. However, the presence of fly

ash in the concrete mix improves its resistance against chloride ion action, especially when used as addition to cement.

Using fly ash in recycled concrete aggregates has an environmental impact; which is reflected in reduction of the emission of carbon dioxide resulting from producing high performance recycled concrete aggregates [8].

However, in order to obtain a balance between recycled concrete with reasonable performance and its environmental impact, sometimes a combination of low grade recycled aggregate with mineral admixtures such as fly ash is used, and these combinations show comparable performance when compared with a controlled mix.

## III. EXPERIMENTAL PROGRAM

### 3.1. Materials Properties and Concrete Mix Design

**Natural coarse and Fine Aggregate: Sieve Analysis**

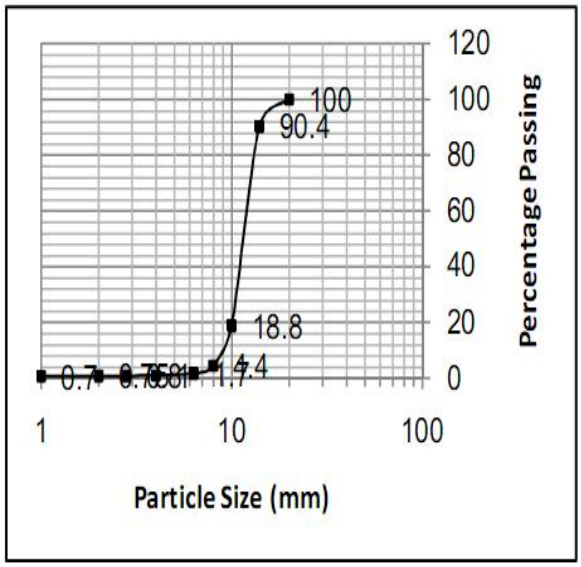



**Fig. 1 Coarse aggregate distribution**

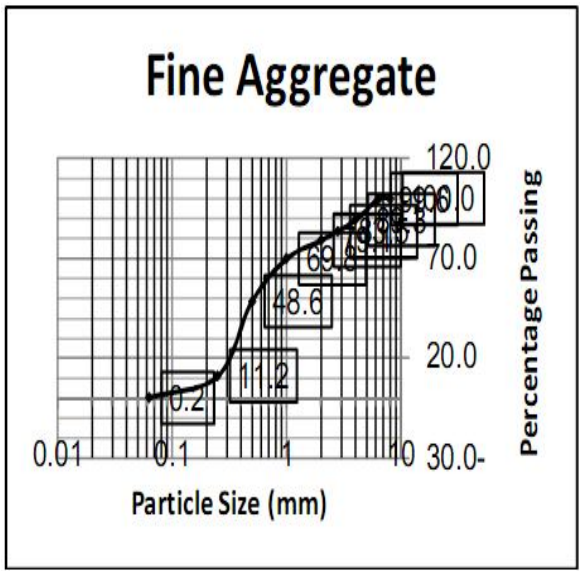



**Fig. 2 Fine aggregates distribution**

**Table 1 Water absorption and particle density for coarse and fine aggregate**

| Property | Coarse aggregate | | | Fine aggregate | | |
|---|---|---|---|---|---|---|
| | Sample A | Sample B | Avg. | Sample A | Sample B | Avg. |
| Mass in air of sample SSD (g) | 1053 | 1035.9 | | 909.1 | 906.7 | |
| Mass of Container + Water + Sample (g) | 2842.2 | 2883.9 | | 2858 | 2754 | |
| Mass of Container filled with water (g) | 2194.3 | 2194.3 | | 2296 | 2195 | |
| Mass in air of sample oven dried (g) | 1044.1 | 1028.4 | | 894.7 | 890.9 | |
| Apparent Particle Density | 2.63 | 2.64 | 2.64 | 2.68 | 2.68 | 2.68 |
| Oven Dried Particle Density | 2.58 | 2.6 | 2.59 | 2.58 | 2.56 | 2.57 |
| SSD Particle Density | 2.61 | 2.6 | 2.61 | 2.62 | 2.61 | 2.62 |
| Water Absorption | 0.85% | 0.73% | 0.79 % | 1.61% | 1.77% | 1.69 % |

**Recycled aggregate**

Recycled aggregate was provided by the University of Sheffield as a product of a concrete test conducted there.

The recycled aggregates partially replaced the 5 to 20 mm coarse aggregate fractions in the concrete mixes, and it was not sieved due to poor gradient. However, a rough gradient was conducted and comparison with the natural aggregate is as follows:

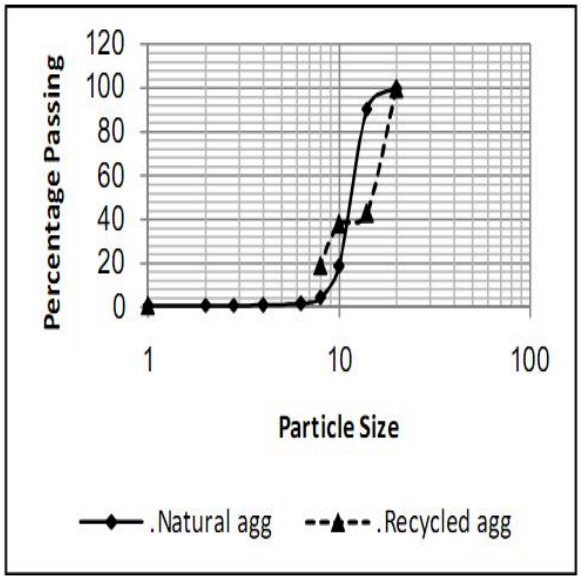



**Fig. 1 Grading for Recycled aggregates**

These quantities were not ideal because they did not meet the coarse aggregate gradient for the concrete mix but they were accepted in the current situation. Yet, in order to mitigate the effect of poor gradient; the recycled aggregate replacement were made – if possible – with the same sizes of the natural aggregate.

The main advantages of this aggregate are that it was prepared and crushed for academic and research purposes, so it does not contain bricks, glass or organic impurities.

**Cement and Fly ash**

Portland Cement Type 1-class 52.2 (supplier: Rugby Portland Cement Co.) was used for all mixes.

Fly ash with the following properties was used for cement replacement:

- Supplier: CEMEX. Product name: Fly ash 450-S.
- Fineness category S.
- Loss on ignition category B.
- BS EN 450-1.
-

Chemical compositions and specific gravity for fly ash are presented in the table below:

**Table 2 Chemical Composition (weight %) and Specific Gravity (g/cm3) for OPC and FA**

| Contents | Cement | Fly Ash |
|---|---|---|
| $SiO_2$ | 21 | 56.79 |
| $Al2O_3$ | 5.9 | 28.21 |
| $Fe2O_3$ | 3.4 | 5.31 |
| CaO | 64.7 | <3 |
| MgO | 0.9 | 5.21 |
| SO3 | 2.6 | 0.68 |
| Loss on ignition (%) | 1 | 3.9 |
| Specific Gravity (g/cm3) | 3.15 | 2.31 |

### 3.2. Mixing and Casting Procedures

Recycled aggregates were used to replace the natural coarse aggregates by 0%, 33%, 66 %, and 100%. In each mix of the above mentioned; fly ash replaced the ordinary cement by 0%, 33% and 66%.

The following notations were used; the controlled mix is always referred to as C20/25-CONTROL, where FA stands for fly ash replacement, RA for recycled aggregate replacement and NA for Natural Aggregate. Hence; the following concrete mixes were prepared in accordance with BS 5328:1997 Part 2: Methods for specifying concrete mixes

**Table 3 Ingredients proportions and quantities per mix.**

| MIX ID (Units) | Total Agg. Kg/m3 | Coarse RA Kg/m3 | Coarse NA Kg/m3 | Fine Agg. Kg/m3 | OPC Kg/m3 | FA Kg/m3 | H2O Kg/m3 |
|---|---|---|---|---|---|---|---|
| 20/25-CONTROL | 1110.78 | 0.00 | 1110.78 | 740.52 | 338.70 | 0.00 | 176.12 |
| C20/25-RA0FA33 | 1110.78 | 0.00 | 1110.78 | 740.52 | 226.93 | 111.77 | 176.12 |
| C20/25-RA0FA66 | 1110.78 | 0.00 | 1110.78 | 740.52 | 115.16 | 223.54 | 176.12 |
| C20/25-RA33FA0 | 1110.78 | 366.56 | 744.22 | 740.52 | 338.70 | 0.00 | 199.58 |
| C20/25-RA33FA33 | 1110.78 | 366.56 | 744.22 | 740.52 | 226.93 | 111.77 | 199.58 |
| C20/25-RA33FA66 | 1110.78 | 366.56 | 744.22 | 740.52 | 115.16 | 223.54 | 199.58 |
| C20/25-RA66FA0 | 1110.78 | 733.11 | 377.67 | 740.52 | 338.70 | 0.00 | 223.04 |
| C20/25-RA66FA33 | 1110.78 | 733.11 | 377.67 | 740.52 | 226.93 | 111.77 | 223.04 |
| C20/25-RA66FA66 | 1110.78 | 733.11 | 377.67 | 740.52 | 115.16 | 223.54 | 223.04 |
| C20/25-RA100FA0 | 1110.78 | 1110.78 | 0.00 | 740.52 | 338.70 | 0.00 | 247.21 |
| C20/25-RA100FA33 | 1110.78 | 1110.78 | 0.00 | 740.52 | 226.93 | 111.77 | 247.21 |
| C20/25-RA100FA66 | 1110.78 | 1110.78 | 0.00 | 740.52 | 115.16 | 223.54 | 247.21 |

### 3.3. Mechanical Properties

The mechanical properties of the concrete that were investigated included compressive and tensile flexural strengths. The development of compressive strength in the concrete mixes was investigated. Concrete cubes of 150 mm were used for the compressive strength tests.

The specimens were cured for periods of 7, 14 and 28 days in water tank in room temperature. After curing, the specimens were tested in accordance with BS EN 12390-3; three specimens per mix were tested at each age.

Flexural test prisms (500x100x100 mm) were also prepared and tested in accordance with the BS EN 12390-3 [9].

In the flexural test there have been shortage in the prisms which was out of the control of the study team; this led to the use of single curing time (28 days).

## IV. RESULTS AND DISCUSSION

### 4.1. Results for the Compressive Strength Test

The results for the compressive strength tests are presented in figures 5 below.

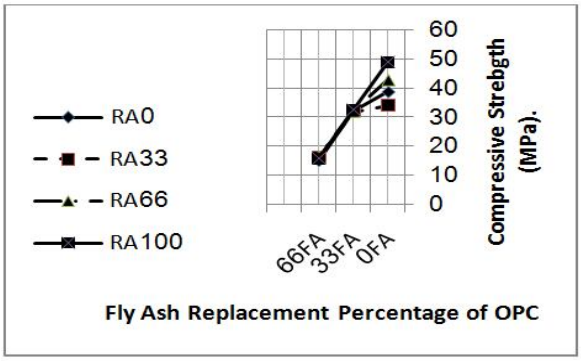



**Fig. 4 Compressive Strength For Recycled Aggregate Replacements**

The results show that fly ash content has a significant effect on the compressive strength. As the percentage of fly ash increases, the compressive strength rapidly decreases.

The pattern of recycled aggregate replacements was not in complete agreement with the literature review; as the controlled mix gave lower readings than some of other mixes, the suggested reason for this behavior was the difference in the types of coarse aggregate; the coarse aggregate was uncrushed for the NA and crushed in the AA which increase the compressive strength as the content of the RA increase in the mix. However, Fig. 5 can still describe the significant reduction in the compressive strength due to the replacement of OPC with fly ash.

The replacement of the Ordinary Portland Cement with the fly ash has reduced the compressive strength; 66% replacement led to reduction on strength by over 50%.

**Table 4 Reduction in the strength compared to the controlled mix (regarding FA contents)**

| RA replacement | Deference in strength compared to 0% FA | | | |
|---|---|---|---|---|
| FA content | 33%FA | | 66%FA | |
| Difference | MPa. | % | MPa. | % |
| 0%RA | 6.8 | 17.60% | 23.8 | 61.40% |
| 33%RA | 2.1 | 6.20% | 18.1 | 53.00% |
| 66%RA | 10.9 | 25.40% | 26.5 | 61.80% |
| 100%RA | 16.5 | 33.60% | 33.3 | 68.00% |

**Results for the Flexural Strength Test**

The effect of the recycled aggregate on the flexural strength was predictable, as the percentage of the recycled aggregate increases the flexural strength decreases. Although the 100% RA replacement recorded a lower reading than the controlled mix and the 33% RA replacement, but the reading was slightly higher than the 66% RA replacement. Results for the recycled aggregate effect are presented in Fig. 6 below:

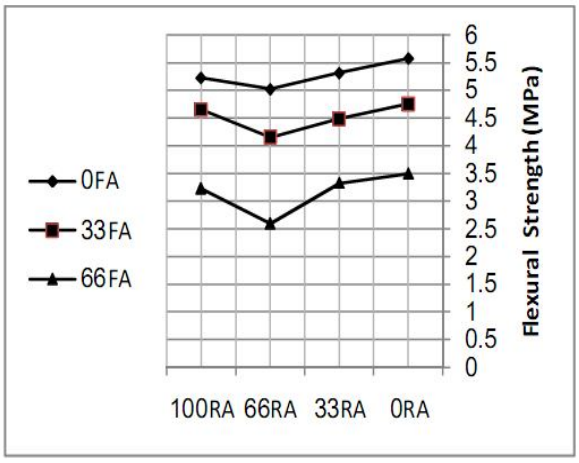



**Fig. 5 The effect of the recycled aggregates in the flexural strength**

The Results from the flexural strength showed a significant reduction when fly ash content increases. A maximum reduction of 39% in the flexural strength due to fly ash replacement was recorded in the 33% RA replacement mixes. The effect of the fly ash is described in figure 7.

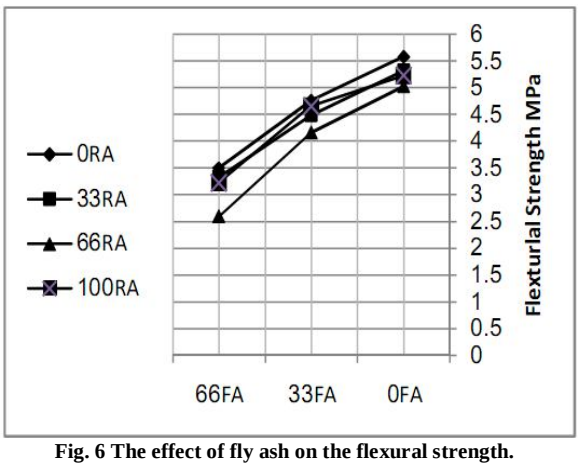



**Fig. 6 The effect of fly ash on the flexural strength.**

The relation between the cube compressive strength results and the flexural strength results is not direct in the Euro-code 2. Firstly, the compressive strength results should be linked to mean tensile strength of concrete and then the tensile strength should be linked to the flexural strength. Figure 8 below shows a comparison between the measured and calculated flexural strength

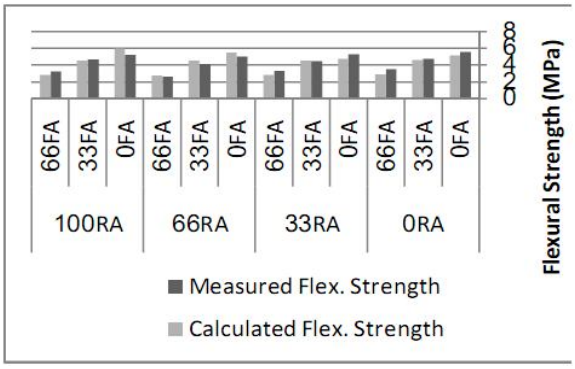



**Fig. 7 Comparison between the measured and calculated flexural strength**

## CONCLUSIONS

The aim of this paper was to investigate the effect on the mechanical properties resulting from introducing fly in concrete with recycled aggregates.

- In the compressive strength test; it was found that using recycled aggregates and fly ash directly influence the compressive strength of the concrete. Using recycled aggregate up to 100 % replacement reduces the compressive strength slightly but it is still within the limit of 20% reduction stated by the Euro-code.
- The existence of the fly ash as a partial replacement of the ordinary Portland cement decreases the compressive strength significantly. If high replacement of fly ash was applied (66%), the compressive strength dropped below half of the targeted strength defined in the mix design. While all the values for the 66FA were far below the target strength, the values for the recycled aggregate - for all replacements- were above the target strength.
- Regarding Flexural Strength test; the recycled aggregate had the same effect as in the compressive strength test. As the recycled aggregate content increases the flexural strength decreases. However, the reduction in the flexural strength due to recycled aggregate replacements was much lower when compared to the reduction of the compressive strength test.
- The effect of the fly ash replacements in the flexural strength was negative; as the fly ash content increases the flexural strength decreases. However, this reduction was still lower than the reduction in the compressive strength test recorded in this research when replacing the OPC with fly ash.
- Generally for structural use; the concrete with up to 33% recycled aggregate replacement could be used without significant effects on the mechanical properties of the concrete.

**Recommendations, Further Work and Improvement of the Current Research**

- Fly ash replacements higher than 33% are not recommended in concrete with recycled aggregates for the construction of primary members or in any other members that are structurally critical.
- Conducting the mechanical tests (Compressive strength, direct tensile splitting test, and Modulus of elasticity of concrete cylinders), and relate the results of the compressive and flexural strength tests to the durability results for the same mixes.

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