A STUDY ON PROPERTIES OF RECYCLED COARSE AGGREGATE AND IT’S CONCRETE

Harish B A¹, Dr. N Venkata Ramana², Dr. K Gnaneswar³

¹Assistant Professor, Department of Civil Engineering, GMIT, Davanagere, 577006, India.
²Associate Professor, Department of Studies in Civil Engineering, UBDTCE, Davanagere, 577004, India.
³Deputy Executive Engineer, Water Resources Department Nandyal, Kurnool (Dist.) Andhra Pradesh, India.
*E-mail: harishba129@gmail.com Contact Number: +91-8884764227.

ABSTRACT: This paper presents recycled coarse aggregate and its concrete properties. Recycled coarse aggregate exhibits lower values for loose and dry-rodded unit weight and high water absorption values than the natural coarse aggregate. Natural aggregate concrete exhibits higher mechanical strength than recycled coarse aggregate concrete. Results pronounced that the percentage increment of recycled aggregate content is inversely proportional to the strength and concluded that optimum dose of recycled aggregate is 50% and proposed a model to estimate compressive, split tensile and flexural strengths of recycled coarse aggregate concrete. The maximum replacement of RCA in concrete is 50%, and the proposed models show excellent compatibility with experimental results.

Keywords: NCA; RCA; Physical Properties; Mechanical Properties; Regression Analysis:

1. BACKGROUND

Processing of used material and using processed material in the new product is called recycling. Advancement of technology in the construction industry pushing towards sustainability. To employ recycled aggregate in a reinforced concrete structure, properties like compression, crushing resistance, the ratio of water absorption, and modulus of elasticity of concrete are to be known to understand mechanical behavior and reliability. Reused coarse total cement is another solid, which is like characteristic total cement. However, the main distinction is that the total utilized is shown up from the wrecked solid waste. Till today the examination of reused coarse total cement is, for the most part, done in nations such as the US, Japan, Europe, etc., in India; its exploration is at the starting stage. Propelled nations are utilizing reused coarse total cement for the most part for non-basic components because the exploration is likewise constrained to essential mechanical and physical properties, for more prominent uses and cook ecological characteristics in creating nations and created nations, it is necessary to research the possibility of delivering distinctive reused coarse total cement auxiliary components with locally accessible waste cement.

2. RELATED WORKS

In recycled aggregate concrete, amount of followed mortar in the first total is relative to the quality of the first concrete, low-quality cement has less developed mortar, but high-quality cement has more followed mortar [1], the undesirable surface of aggregate add to influence the holding capacity among aggregate and solid paste in concrete [2]. Recycled aggregate concrete exhibits lesser density than conventional cement concrete; its specific gravity is lower than natural aggregate [3], [4]. Water assimilation proportion is very much higher in recycled aggregate [5], [6]. From the above, it is clear that functionality of solid waste total is low and could be clarified the higher water ingestion of solid waste total hence the compressive quality of concrete made with reused total is lesser than the regular concrete [7], splitting tensile strength also decreased as recycled aggregate content increased [8]. There was no incredible contrast between the flexural quality of reused coarse total concrete and common sand with ordinary concrete [9].

From the above literature study, it is clear that in India, its research is at the initial stage, hence planned to conduct tests on natural coarse aggregate, recycled coarse aggregate, natural aggregate concrete (NAC), and recycled coarse aggregate concrete (RCAC) and to compare test results. Objectives of the proposed research are,
Viability RCAC for construction works, to examine RCAC behavior in compression, split tension and flexure to evaluate the optimal quantity of RCA in RCAC and to correlate experimental results with theory.

3. EXPERIMENTAL PROGRAM

The exploratory program was isolated into four different stages, the main stage related to the evaluation of used material's physical properties. The second stage compared to the blend plan of cement dependent on the first stage results and determination of ideal w/c proportion. Third stage connected with the throwing of cubes, cylinders, and beams that were utilized in the examination with the solid dependent on the second stage blend extents. The fourth stage related to the testing of cubes, cylinders, and beams to arrive mechanical properties of the solid utilized. An experimental program was planned and is presented in Table 1. Cubes, cylinders for compression, cylinders for split tension, and beams for flexure are cast and tested.

- RCAC indicates recycled coarse aggregate concrete, suffixed 0, 50 and 100 indicate replacement % of natural coarse aggregate (NCA) by recycled coarse aggregate (RCA)

4. MATERIALS: Materials that are used in the research area,

4.1 Cement

Ultra Tech, 43-grade cement, conforming to IS: 8112-1989 [21] standard was used in research. Tests conducted are fineness, consistency of cement, setting times, soundness, specific gravity, and compressive strength test of cement. The test results and their limiting values, as mentioned in IS: 8112-1989 [21] is reported in Table 2. From the test results, it is noticed that the obtained results are within the IS specified limits. It inferences that the cement is in good condition, and it may be used for present work.

4.2 Fine Aggregate

Sand from Bhadra River was used as fine aggregate, confirming to zone III of Table 4 of IS: 383-1970 [16]. The test results of fine aggregate are tabulated in Table 3 and Table 4.
### Sieve analysis of fine aggregate

| Sieve size (mm) | Wt. of sample retained (g) | Cumulative wt. of sample retained | Cumulative % wt. retained | Percentage finer N=100-C | IS:383-1970 Table 4 |
|----------------|---------------------------|----------------------------------|--------------------------|--------------------------|-----------------------|
| 4.75           | 49                        | 49                               | 4.9                      | 95.1                     | 90-100                |
| 2.36           | 14                        | 63                               | 6.3                      | 93.7                     | 75-100                |
| 1.18           | 96                        | 159                              | 15.9                     | 84.1                     | 55-90                 |
| 0.60           | 236                       | 395                              | 39.5                     | 60.5                     | 35-59                 |
| 0.30           | 459                       | 854                              | 85.4                     | 14.6                     | 8-30                  |
| 0.15           | 132                       | 986                              | 98.6                     | 1.4                      | 0-10                  |
| Pan            | 14                        | 1000                             | 100                      | 0                        | -                     |
| **TOTAL = 250.6** |                           |                                  |                          |                          |                       |

Fineness Modulus 2.5
Zone III

### Natural coarse aggregate (NCA)

Crushed granite of 20mm size is used as NCA. Tests are performed as per IS: 383-1970 [16], and results are tabulated in Table 5 and Table 6.

### Test results of NCA

| Test                        | Test values |
|-----------------------------|-------------|
| Specific gravity            | 2.48        |
| Fines modulus               | 7.65        |
| Water absorption            | 0.199%      |
| Bulk Density (loose)        | 1447.48 Kg/m³ |
| Bulk Density (rodded)       | 1529.92 Kg/m³|
| Impact value                | 29.76%      |
| Flakiness index             | 14.16%      |
| Elongation index            | 29.16%      |
| Percentage of voids         | 38%         |
| Void ratio                  | 15.00       |

### Sieve analysis of NCA

| IS size (mm) | Wt. of aggregates retained (g) | Cumulative wt. retained (g) | Cumulative % of wt. retained | % finer (100-c) |
|--------------|--------------------------------|-----------------------------|-----------------------------|-----------------|
| 80           | 0                              | 0                           | 0                           | 100             |
| 40           | 0                              | 0                           | 0                           | 100             |
| 20           | 1301                           | 1301                        | 26.02                       | 73.98           |
| 10           | 2913                           | 4214                        | 84.28                       | 15.72           |
| 4.75         | 671                            | 4885                        | 97.70                       | 2.30            |
| Pan          | 15                             | 5000                        | 100                         | 0               |
| **TOTAL = 292.00** |               |                             |                             |                 |

Fineness modulus = 7.92

### Recycled Coarse Aggregate (RCA)

It was acquired from demolished building waste. The concrete blocks were crushed in machine crusher and received aggregates of size 12.5mm and 20mm. Tests are similar to NCA, and results are presented in Table 7 and Table 8.

### Test results of RCA

| Tests                        | Tests value |
|------------------------------|-------------|
| Specific gravity             | 2.23        |
| Fines modulus                | 8.05        |
| Water absorption             | 4.38%       |
| Bulk Density (loose)         | 1200 Kg/m³  |
| Bulk Density (rodded)        | 1305.83 Kg/m³|
| Impact value                 | 42.65%      |
| Flakiness index              | 3.88%       |
| Elongation index             | 24.12%      |
| Percentage of voids          | 42%         |
| Void ratio                   | 15.76       |
Table 8: Sieve analysis of RCA

| IS sieve size (mm) | Wt. of aggregate retained (gm) | Cumulative Wt. retained in (gm) | Cumulative % wt. retained | % finer (100-c) |
|-------------------|---------------------------------|---------------------------------|---------------------------|----------------|
| 80                | 0                               | 0                               | 0                         | 100            |
| 40                | 0                               | 0                               | 0                         | 100            |
| 20                | 1017                            | 1017                            | 20.34                     | 79.66          |
| 10                | 2761                            | 3778                            | 75.56                     | 24.44          |
| 4.75              | 1165                            | 4943                            | 98.86                     | 1.14           |
| Pan               | 57                              | 5000                            | 100                       | 0              |

Fineness modulus = 8.05

TOTAL = 305.20

4.5 Water: Drinking water is used for mixing and curing of concrete specimens.

Table 9: Physical properties of coarse aggregate

| Property                        | RCA0 | RCA50 | RCA100 |
|---------------------------------|------|-------|--------|
| Specific gravity                | 2.48 | 2.39  | 2.23   |
| Fineness modulus                | 7.65 | 7.80  | 8.05   |
| Water absorption (%)            | 0.199| 2.26  | 4.38   |
| Loose Bulk density (Kg/m³)      | 1447.48 | 1336.80 | 1200 |
| Rodded Bulk density (Kg/m³)     | 1529.92 | 1431.86 | 1305.83 |
| Impact value (%)                | 29.76 | 39.32 | 42.65  |
| Flakiness index (%)             | 14.16 | 8.18  | 3.88   |
| Elongation index (%)            | 29.16 | 26.52 | 24.12  |
| Percentage of voids (%)         | 38    | 40    | 42     |
| Void ratio                      | 15.00 | 15.39 | 15.76  |

5. METHODOLOGY: Mix design

To achieve the desired performance of concrete, material selection and mix design are important. Grade of concrete chosen is M20, mix design procedure adopted is per IS: 10262-2009 [12], mix proportions are tabulated in table 10.

Table 10: M20 Grade concrete mix proportions as per IS: 10262-2009

| W / C Ratio | Ingredients (kg/m³) | Mix Proportion |
|-------------|---------------------|----------------|
|             | Water               | Cement         | Fine aggregate | Coarse aggregate |                     |
| 0.50        | 197                 | 394            | 634.31         | 1076.12          | 1:1.61:2.73         |
6. CASTING OF CONCRETE SPECIMENS

Ingredients except water are mixed in dry condition, for this blended water is added as per the proportion and mixed thoroughly by hand mixing. For casting, all moulds are cleaned, oiled, and secured tightly to achieve proper dimension. The mixed material is placed in the mould and is placed on a vibrating table and vibrated as per the requirement. These specimens are allowed for twenty-four hours, and after that demoulded and during demolding, care should be taken to see that no edges are harmed, and these specimens are cured in water pond for the required number of days.

7. TESTS ON FRESH CONCRETE

7.1 Slump Cone Test: It is performed per IS: 1199-1959 [14] to check the workability of freshly made concrete.

7.2 Compaction Factor Test: It is also used to examine newly formed concrete; it is carried per IS: 5515-1983 [19].

8. TESTS ON HARDEN CONCRETE

Cubes, cylinders, and beams are tested in the compression testing machine per IS: 516-1959 [18] and IS 5816-1999 [20].

8.1 SUMMARY

M20 grade concrete mix is designed per IS: 10262-2009 [12]. The distinct description of the mix proportion has been implemented. Compaction factor, slump values were found. Eventually, for right mix percentage cubes, cylinders and beams were cast and cured.
9. EXPERIMENTAL RESULTS

Experimental results of concrete at fresh and hardened state are tabulated in table 11 to table 17.

Table 11: Slump and Compaction factor values

| Mix    | Slump Value (mm) | Compaction Factor |
|--------|------------------|-------------------|
| RCAC0  | 100              | 0.91              |
| RCAC50 | 20               | 0.90              |
| RCAC100| 10               | 0.89              |

Table 12: 28 day’s Cube Compressive strength of concrete ($f_{ck}$)

| Mix     | Average Cube Compressive Strength (MPa) | % decrement when compared to RCAC0 |
|---------|----------------------------------------|-----------------------------------|
| RCAC0   | 39.70                                  | -----                             |
| RCAC50  | 36.00                                  | -9.31                             |
| RCAC100 | 22.96                                  | -42.16                            |

Table 13: 28 day’s Cylinder Compressive strength of concrete ($f_{ck}$)

| Mix     | Average Cylinder Compressive Strength (MPa) | % decrease when compared to RCAC0 |
|---------|--------------------------------------------|----------------------------------|
| RCAC0   | 14.71                                      | -----                            |
| RCAC50  | 13.39                                      | -8.97                            |
| RCAC100 | 13.01                                      | -11.55                           |

Table 14: Recommended empirical relationships between elastic modulus and compressive strength ($E$)

| Mix     | As per IS Code $E = 5000\sqrt{f_{ck}}$ (MPa) | As per EC-02 Code $E = 9500(\sqrt{f_{ck}} + 8)^0.33$ (MPa) |
|---------|-----------------------------------------------|------------------------------------------------------------|
| RCAC0   | 31503.96                                      | 37103.85                                                  |
| RCAC50  | 30000.00                                      | 36551.70                                                  |
| RCAC100 | 23958.29                                      | 36387.74                                                  |

Table 15: 28 day’s Split Tensile strength of concrete ($f_{sp}$)

| Mix     | Average Split Tensile Strength (MPa) | -10th of the ($f_{ck}$) | % Decrease when compared to RCAC0 | As per ACI Code $f_{sp} = 0.49\sqrt{f_{ck}}$ | As per GB Code $f_{sp} = 0.19f_{ck}^{0.75}$ | A.R. Santhakumar (1/10th of the $f_{ck}$) |
|---------|-------------------------------------|-------------------------|----------------------------------|-----------------------------------------------|---------------------------------------------|------------------------------------------|
| RCAC0   | 2.92                                | -----                   | 3.08                             | 3.00                                          | 3.60                                        | 3.97                                     |
| RCAC50  | 2.56                                | -12.32                  | 2.94                             | 2.79                                          | 2.60                                        | 2.82                                     |
| RCAC100 | 2.42                                | -17.12                  | 2.34                             | 1.99                                          | 2.29                                        | 2.29                                     |

Table 16: 28 day’s Flexural strength of concrete ($f_{t}$)

| Mix     | Average Flexural Strength (MPa) | % Decrement when compared to RCAC0 | As per IS Code $f_{t} = 0.7\sqrt{f_{ck}}$ | As per ACI Code $f_{t} = 0.54\sqrt{f_{ck}}$ | As per CEB-FIB Code $f_{t} = 0.81\sqrt{f_{ck}}$ | As per EC-02 Code $f_{t} = 0.3f_{ck}^{0.67}$ |
|---------|---------------------------------|-----------------------------------|-------------------------------------------|---------------------------------------------|-----------------------------------------------|-------------------------------------------|
| RCAC0   | 11.18                           | -----                             | 4.41                                      | 3.40                                        | 5.10                                         | 3.53                                      |
| RCAC50  | 8.96                            | -19.85                            | 4.20                                      | 3.24                                        | 4.86                                         | 3.31                                      |
| RCAC100 | 8.81                            | -21.19                            | 3.35                                      | 2.58                                        | 3.88                                         | 2.44                                      |

Table 17: Density of concrete ($\gamma$)

| Mix     | Average Density (kg/m³) | % decrease when compared to RCAC0 |
|---------|-------------------------|-----------------------------------|
| RCAC0   | 2401.77                 | -----                             |
| RCAC50  | 2329.77                 | -2.99                             |
| RCAC100 | 2312.88                 | -3.70                             |
10. DISCUSSION

Cube Compressive strengths (f<sub>ck</sub>) of RCAC are in the range of 36.00 to 22.96 MPa, whereas RAC0, i.e., NCAC, is having a cube CS of 39.70 MPa. By replacement of NCA with RCA in concrete, CS decreased but not less than target strength 20 MPa. Hence it can be concluded that RCAC is not inferior. RCAC50 CS was close to target mean strength.

Using BIS and EC-02 code estimated modulus of elasticity in terms of compression and are presented in table12.

Cylinder Compressive strengths (f<sub>c</sub>) of RCAC are in the range of 13.39 to 13.01 MPa, whereas RAC0, i.e., NCAC, is having a cube CCS of 14.71 MPa. By replacement of NCA with RCA in concrete, CCS decreased.

Split tensile strengths (f<sub>sp</sub>) of RCAC are in the range of 2.56 to 2.42 MPa, whereas RCAC0 or NCAC is having a STS of 2.92 MPa. The habitually tensile strength of concrete is estimated using compressive strength. ACI, Chinese codes, and equations suggested by A R Santhakuma [10] are used to determine STS in terms of compression. STS of concrete is relatively lower than corresponding compressive strength, and RCA use in concrete further decreased its STS.

Flexural strengths (f<sub>r</sub>) of RCAC are in the range of 8.96 to 8.81 MPa, but NCAC is having a flexure strength of 11.18 MPa. With the replacement of NCA with RCA in concrete, FS decreased but not less than the target strength. IS code, ACI code, CEB-FIB code, and EC-02 code is used to estimate FS in terms of compression.

The Density of RCAC is in the range of 2329.77 to 2312.88 Kg/m<sup>3</sup>, whereas RAC0, i.e., NCAC is having a density of 2401.77 Kg/m<sup>3</sup>. By replacement of NCA with RCA in concrete, Density decreased.
Regression analysis, a statistical approach, is used and proposed a model to estimate Cube CS, STS, FS, and Density of RCAC. The method of least squares says that a line can be fitted to the given data set such that the errors are minimized. This implies that one can determine $\alpha$ and $\beta$ such that the sum of the squared distances between the data points and the line $Y = \alpha + \beta X$ is minimized. ($Y = \alpha + \beta X$ where $\alpha$ is the intercept and $\beta$ is the slope).

### Table 18: Linear Regression Details for RCAC

| Cubic Strength | Split Tensile Strength | Flexural strength | Density | Regression Details |
|----------------|------------------------|-------------------|---------|-------------------|
| $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $\alpha$ = 41.25, $\beta$ = -0.1674, $R^2$ = 0.905, $r = \sqrt{R^2} = 0.95$ |
| $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $\alpha$ = 2.88, $\beta$ = -0.005, $R^2$ = 0.939, $r = \sqrt{R^2} = 0.96$ |
| $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $\alpha$ = 10.83, $\beta$ = -0.0237, $R^2$ = 0.797, $r = \sqrt{R^2} = 0.89$ |
| $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $Y = \alpha + \beta X$ | $\alpha$ = 2392.59, $\beta$ = -0.8889, $R^2$ = 0.883, $r = \sqrt{R^2} = 0.94$ |

### Table 19: Comparison of Experimental Results and Regression analysis results

| Mix  | Average CS (MPa) | Average STS (MPa) | Average FS (MPa) | Average Density (kg/m$^3$) |
|------|-----------------|------------------|-----------------|---------------------------|
| RCAC0| EXP 39.70       | RM 41.26         | EXP/RM 2.92     | EXP/RM 10.18             | EXP/RM 2401.77  |
|      | EXP 36.00       | RM 32.91         | EXP/RM 2.56     | EXP/RM 8.96              | EXP/RM 2329.77  |
|      | EXP 22.96       | RM 24.56         | EXP/RM 2.42     | EXP/RM 8.81              | EXP/RM 2312.88  |
12. CONCLUSIONS

From experimental results and discussion on a recycled coarse aggregate and its concrete, the following conclusion is drawn.

RCA obtained after crushing building demolition waste can be used for structural concrete works as its flakiness and elongation are superior to NCA, and grading limits are per BIS (USL: 383-1970). Despite lower specific gravity, lower density, and higher water absorption, higher impact value, concrete made with RCA are in no way inferior to conventional concrete. Loss of workability with time increased with an increase in RCAC. With the increment in RCA in concrete, strengths are reduced compared to NCA concrete. The maximum replacement of RCA in concrete is 50%, and the proposed models show excellent compatibility with experimental results.

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