Studies on Impact Resistance of Self-Compacting Concrete with mechanically treated Recycled Coarse Aggregate

Srikanth Nune1*, Dakshina Murthy N R2, and Seshagiri Rao M V 3

*1Research Scholar, Civil Engineering Department, JNTUH Hyderabad, Telangana, India, srikanth.6090@gmail.com
2Associate Professor, Civil Engineering Department, CBIT Hyderabad, Telangana, India, nrdmurthy@yahoo.com
3Professor, Civil Engineering Department, CVR College of Engineering, Telangana, India, rao_vs_meduri@yahoo.com

Abstract. Self-compacting concrete (SCC) is an extraordinary type of concrete that is extremely flowable and spreads into the formwork without the need of external vibration. In order to attain self-compatibility SCC obliges extensively surplus quantity of fine particles as compared to conventional concrete. Recycled Coarse Aggregate (RCA) obtained by crushing of old concrete is used in the investigational analysis. Nan-Su method is used to design the SCC mixes A and B (M35 and M45). The current experimental study aims to evaluate the impact energy of Recycled Coarse Aggregate (RCA) based self-compacting concrete by replacing with Natural Coarse Aggregate (NCA) (25%, 50%, 75%, and 100%) in unprocessed and processed states for various number of revolutions (500R, 1000R, 1500R, 2000R). Tests were carried out with a constant mass of hammer (16.38 kg). The impact energy determined for the Mixes A and B is compared with respect to replacement level and processing of RCA. The impact energy calculated is maximum for mix-A (1500 and 2000 revolutions) and mix-B (2000 revolutions) at 75% and 100% replacement of RCA respectively. From the experimental results of obtained Coefficient of Variation (CoV) with respect to processing of aggregate, in both the mixes it is observed that RCA in unprocessed state and processed state (1500R) has good Coefficient of Variation. Comparing the results of Coefficient of Variation with respect to replacement level of aggregate it has a very good CoV at 25% replacement level of RCA for both the mixes.

Keywords: Self-Compacting Concrete, Natural Coarse Aggregate, Processed recycled coarse aggregate, unprocessed recycled coarse aggregate, Impact resistance.

1. Introduction

One of the current trending challenge for a Civil engineer is to plan, design and built the construction projects with the minimal use of natural resources and also to make use of alternate construction materials to maintain ecological balance. [1] Enormous amount of demolition waste generated is creating a huge pressure on the environment thereby increasing land pollution. [2] To minimize the impact of demolition waste it can be recycled and used in construction projects. [3] There is an urgent need for improving the standards of using alternate construction materials to make a sustainable development.

A virtuous volume of research has been carried out on the static behaviour of concretes but there is a lag in the behaviour of impact resistance of special concretes using recycled materials. [4] RCC structures are subjected to dynamic loads for a very short duration. [5] The various dynamic loads coming on the structures are like machine vibration, seismic forces, wind...
forces, metro trains, medical labs etc. Impact and damage caused due to impact forces are very important in RCC structures as they adversely affect the life span and leads to deterioration of the structure. [6] The parameters like crushing shear needs to be improved in PCC and tensile fracturing needs to be improved in RCC. According to ACI committee-544 drop weight test is a very simple method to find the impact strength of the concrete. The test follows a very simple procedure to calculate impact resistance of a concrete specimen, if it is subjected to number of blows by using a drop weight of constant mass and height of hammer. The specimen fails after reaching prescribed distress.

[7] Self-consolidating concrete is a concrete that is able to flow under its own weight without the need of vibration. [8] It can able to fill the clogged reinforcement. [9] [10] SCC contains mineral admixture such as flyash as a partial replacement of cement which helps in maintaining the flow ability and adequate yield value of fresh mix. [11] Reused aggregate is called as recycled coarse aggregate which is obtained by crushing concrete of demolished concrete structures. [12] Ismail et.al, from their research stated that the increase in cement content increases the impact resistance of concrete. [13] Zhang et al., in their technical paper discussed that the impact resistance of concrete penetration depth and crater diameter reduces with a decrease in w/c ratio. [14] Chakradar rao et.al, “studied the behaviour of recycled aggregate concrete under drop weight impact load and concluded that 25% of RCA does not influence on compressive strength of concrete.” [15] Kou et.al, “evaluated the fresh and hardened properties self-compacting concrete using recycled aggregate as both fine and coarse aggregate and stated that the maximum compressive and tensile splitting strength were achieved by using 25-50% aggregates as a replacement”. [16] Ning et.al, proposed a method to “optimize the impact resistance of self-compacting concrete (SCC) by precoating coarse aggregates with an asphalt-based energy-absorbing layer and determined the impact toughness index to evaluate the performance.”

The objective of the present work is to study the impact behaviour of SCC with varying percentage (25%, 50%, 75%, and 100%) of Recycled Coarse Aggregate (RCA) by Natural Coarse Aggregate (NCA). Recycled coarse aggregate in unprocessed state contains cement paste adhered to its surface. It is removed using Deval’s abrasion test and the obtained aggregate is called processed aggregate. The removal of adhered mortar is done by subjecting the RCA to various no. of revolutions by performing abrasion test. (500R, 1000R, 1500R and 2000R).

2. Materials and Methods

2.1. Properties of Materials
Ordinary Portland cement of 53 grade having a specific gravity of 3.15 is used in current investigation. Two different grades of self-compacting concrete Mixes-A and B (M35 and M45) were designed with varying percentages of RCA as a replacement of NCA. The specific gravity of the fine and recycled coarse aggregates were found to be 2.60 and 2.84 respectively. [17] According to Nan-Su method of mix design maximum and minimum size of CA used is 16mm and 12mm. This method of mix design considers mineral admixture like flyash having specific gravity 2.25 and chemical admixture like super plasticizer at required dosage to achieve self-compactability of concrete.

| Tests Conducted | Fine Aggregate | NCA | RCA |
|-----------------|----------------|-----|-----|
| zone II         |                |     |     |
| Bulk density    | 1500 Kg/m³     | 1402Kg/m³ | 1404Kg/m³ |
| Void ratio      | 0.52           | 0.8 | 0.82|
| % voids         | 35%            | 48.6% | 44.6% |
| Fineness modulus | 2.6           | 7.2 | 6.9 |
2.2. Mix Proportions
Mix design for Mixes-A and B (M35 and M45) were prepared based on Nan-Su method which is most suitable method for SCC\[18\]. The mix proportions are shown below:

| Table-2 Design Mix of Mix-A (M35) Concrete |
|-------------------------------------------|
| Mix-A (M35) | Cementitious material | Fine aggregate | Coarse aggregate | Water & (W/C) |
| Quantity (kg/m³) | 523.61 | 924 | 680 | 195.20 |
| Proportions | 1 | 1.76 | 1.30 | 0.38 |

| Table-3 Design Mix of Mix-B (M45) Concrete |
|-------------------------------------------|
| Mix-B (M45) | Cementitious material | Fine aggregate | Coarse aggregate | Water & (W/C) |
| Quantity (kg/m³) | 554.98 | 924 | 680 | 189.58 |
| Proportions | 1 | 1.66 | 1.22 | 0.35 |

2.3. Specimen Preparation
Freshly mixed concrete is placed in the cylindrical mould of 150mm diameter and 60mm height for forming a total of 84 number of specimens of which 42 number of specimens were cast for each mix with varying percentages of RCA. These specimens were tested in concrete laboratory after 28 days of curing period under drop weight impact test machine.

2.4. Impact Test
The drop weight impact test was carried out on these specimens according to the recommendations of ACI committee 544.2R-89. The impact weight was applied repeatedly from a constant height of 600 mm onto a steel ball of 63.5mm diameter. Total of eighty four number of specimens were tested under drop weight hammer. The number of blows for initial crack IC and ultimate crack UC were noticed. The schematic diagram of drop weight test machine is shown in Figure-1 and Figure-2.

*Figure-1 Drop weight impact testing machine Figure-2 Steel ball at centre of specimen*
The impact energy for each blow is calculated using the expression shown below:

\[ I = \frac{1}{2} \times m \times (V_h)^2 \times N \]

Where, \( I \)– Impact energy (N-m)
\( m \)– Drop hammer mass
\( V_h \)– impact speed (m/s)
\( N \)– Number of blows at Ultimate failure
\( m = (W/g) \)

### 3. Discussion of Results

The average blows at initial crack (IC) and Ultimate crack (UC) for Mixes-A and B are shown in the Table-4 and Table-5 respectively. The impact energy of specimens corresponding to the average blows taken by specimen at ultimate failure of the specimen and is calculated based on the following expression: Substituting the corresponding values in the equations below, we get:

\[ H= \frac{(gt^2)}{2} \]
\[ 500 = \frac{(9810 \times t^2)}{2} \]
\[ t = 0.3192 \text{ sec}; \]

\[ V_h=gt \]
\[ V_h = 9810 \times 0.3192 = 3131.52 \text{ mm/s} \]

The Impact energy per blow can be obtained by using equation as below

\[ I = \frac{1}{2} \times m \times (V_h)^2 \times N \]
\[ = (43.6) \times (3131.52)^2 \times 1/(2 \times 9810) \]
\[ = 21.79 \text{ kN-mm} \]

| Percentage of RCA | UP | 500<sup>R</sup> | 1000<sup>R</sup> | 1500<sup>R</sup> | 2000<sup>R</sup> |
|-------------------|----|----------------|----------------|----------------|----------------|
| 0%                | 8  | 10            | 97.35          | -              | -              |
| 25%               | 7  | 9             | 96.13          | 10             | 14             |
| 50%               | 8  | 10            | 96.51          | 13             | 62.59          | 14             | 96.39          | 8              | 12             | 15             | 96.39          |
| 75%               | 9  | 12            | 96.51          | 13             | 95.13          | 5              | 8              | 64.34          | 9              | 14             | 128.43         | 17             | 22             | 128.43         |
| 100%              | 12 | 15            | 96.51          | 8              | 97.64          | 8              | 12             | 96.39          | 6              | 10             | 96.39          | 10             | 14             | 96.39          |

*Table-4 Average blows at initial crack (IC) and Ultimate crack (UC) for Mix-A*
Figure 3: Failure of specimen Mix-A

Figure 4: Failure of specimen Mix-B

Figure 5: Ultimate crack in Mix-A

Table 5: Average blows at initial crack (IC) and Ultimate crack (UC) for Mix-B

| Percentage of RCA | UP | 500R | 1000R | 1500R | 2000R |
|------------------|----|------|-------|-------|-------|
|                  | IC | UC   | IE    | IC    | UC    | IC    | UC    | IE    | IC    | UC    | IC    | UC    |
| 0%               | 16 | 20   | 99.87 | -     | -     | -     | -     | -     | -     | -     | -     | -     |
| 25%              | 15 | 19   | 96.64 | 14    | 18    | 96.39 | 10    | 14    | 96.39 | 9     | 13    | 96.39 |
| 50%              | 19 | 23   | 96.39 | 14    | 19    | 128.6 | 10    | 15    | 128.43| 8     | 12    | 96.39 |
| 75%              | 12 | 15   | 96.39 | 10    | 14    | 96.39 | 10    | 14    | 96.39 | 10    | 15    | 128.43|
| 100%             | 10 | 15   | 128.4 | 17    | 21    | 96.39 | 13    | 17    | 96.39 | 10    | 14    | 96.39 | 12    | 13    | 32.30 |
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From the results presented in Table-4 and 5, it is observed that the impact resistance of the specimens has increased with increase in the percentage replacement of NCA by RCA and also with the increase in processing revolutions of RCA.

It is also observed that the impact resistance of the specimens has decreased with increase in processing revolutions of RCA in Mixes-A and B because of the smoothening of RCA while increasing the processing revolutions and due to less strength possessed by RCA compared to NCA.

Table-6 Impact energy for Mix-A in unprocessed state.

| % RCA replacement | Number of blows at First crack (IC) | Mean Number of blows (IC) | Number of blows at Ultimate crack (UC) | Mean Number of blows (UC) | Initial potential energy $E_i$ =IC mgh | Final potential energy $E_f$ = UC mgh | Impact energy $E_p = (E_i - E_f)$ Joule or kg.m²/s² |
|-------------------|------------------------------------|--------------------------|---------------------------------------|--------------------------|--------------------------------------|---------------------------------------|---------------------------------------------|
| 25%               | 8                                  | 10                       | 12                                    | 14                       | 257.86                               | 353.00                                | 95.13                                       |
|                   | 12                                 |                          | 15                                    |                          |                                      |                                       |                                             |
| 50%               | 12                                 | 12                       | 15                                    | 15                       | 290.41                               | 385.54                                | 95.13                                       |
|                   | 12                                 |                          | 15                                    |                          |                                      |                                       |                                             |
| 75%               | 15                                 | 14                       | 19                                    | 18                       | 353.00                               | 450.63                                | 97.64                                       |
|                   | 12                                 |                          | 15                                    |                          |                                      |                                       |                                             |
| 100%              | 19                                 | 18                       | 23                                    | 22                       | 450.63                               | 545.77                                | 95.13                                       |
|                   | 15                                 |                          | 19                                    |                          |                                      |                                       |                                             |

The detailed sampling of specimens at various replacement levels of RCA were shown in Table-6 where the impact energy is calculated for Mix-A in unprocessed state.
**Figure-7** Impact Energy of Mix A and Mix B in Unprocessed state

**Figure-8** Impact Energy of Mix A and Mix B in processed state (500R)

**Figure-9** Impact Energy of Mix A and Mix B in processed state (1000R)
The Impact Energy of Mixes A and B in Unprocessed state, processed state (500R, 1000R, 1500R and 2000R) is as shown in the figures 7 to 11. It is observed that for Mix-A has highest impact energy in processed state (1500R and 2000R) at 75% RCA. In Mix-B the maximum impact energy is observed in processed state (2000R) at 100% replacement.

Table-7 Mean, SD and CoV of Impact Energy for Mixes-A and B in unprocessed and processed state

| RCA  | Mean  | Standard Deviation | Coefficient of Variation |
|------|-------|--------------------|--------------------------|
|      | Mix A | Mix B              | Mix A                    | Mix B        | Mix A    | Mix B    |
| UP   | 93.88 | 104.46             | 12.52                    | 15.98        | 13.33    | 15.30    |
| P 500| 87.62 | 104.46             | 16.73                    | 16.15        | 19.10    | 15.46    |
| P1000| 88.37 | 104.40             | 16.02                    | 16.02        | 18.13    | 15.35    |
| P1500| 104.40| 104.40             | 16.02                    | 16.02        | 15.35    | 15.35    |
| P2000| 104.40| 128.74             | 16.02                    | 37.36        | 15.35    | 29.02    |

Figure-10 Impact Energy of Mix A and Mix B in processed state (1500R)

Figure-11 Impact Energy of Mixes A and B in processed state (2000R)
The Mean, standard deviation and Coefficient of variation of Impact Energy for Mixes-A and B in unprocessed and processed state are as shown in Table-7 and a plot is shown in Figure-12 for Coefficient of Variation for Mix A and Mix B. It can be observed from the experimental results of obtained Coefficient of Variation (CoV) with respect to processing of aggregate, in both the mixes it is observed that RCA in unprocessed state and processed state (1500R) has good Coefficient of Variation. Comparing the results of Coefficient of Variation with respect to replacement level of aggregate it has a very good CoV at 25%, good CoV at 50% and acceptable CoV at 75% replacement level of RCA for both the mixes. For Mix-A and Mix-B at 100% replacement level it has a very good CoV and acceptable CoV. By comparing both the mixes it can be suggested that Mix-A shows better results at all replacement levels.

4. Conclusions

Based on the experimental results, the following conclusions are drawn:

- Mix-A has highest impact energy in processed state (1500R and 2000R) at 75% RCA. In Mix-B the maximum impact energy is observed in processed state (2000R) at 100% replacement.
- Mixes A and B have a very good CoV at 25%, good CoV at 50% and acceptable CoV at 75% replacement level of RCA.
- The impact resistance gradually improved with the increase in processing of the RCA upto 25% replacement level of RCA in Mixes-A and B.
- In both the mixes it is observed that RCA in unprocessed state and processed state (1500R) has good Coefficient of Variation.
- Impact resistance also depends on recycled aggregate parent material.

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