SELF COMPACTING CONCRETE MADE WITH RECYCLED AGGREGATES

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Abstract-In the recent years, the demand for construction materials increased. So that the construction and demolition waste putting a huge pressure on the environment. This has to encourage the use of recycled aggregate in concrete which allows for an efficient life cycle of natural resources and but also contributes environmental protection. In this study, recycled coarse aggregates obtained by crushed concrete were used for concrete production at various proportions from 0% to 100% with the increase of 20%. The mix proportions of the four concretes were designed in order to achieve the same compressive strengths. Different characteristics of the Self Compacting Concrete (SCC) was find out using different test methods such as; filling ability (Slump flow test, T50 slump flow test, V-funnel test), passing ability (L-box, U-box) and segregation resistance (GTM test, V-funnel at T 5min). The results showed that concrete with acceptable strength and durability could be produced if high packing density is achieved.

I. INTRODUCTION

In recent years, there is an increase in the use of sustainable materials. Sustainability helps in the reduction of usage of non-renewable resources. Concrete has the second most consumed material in the world after water uses a significant amount of non-renewable resources [1]. Numerous types of concrete have been developed to enhance the different properties of concrete [2-4]. When a large quantity of concrete is placed in a reinforcement concrete member, it is difficult to completely fill the form work by concrete without any voids or honeycombs. It is difficult to do compaction by manual or mechanical vibrators in this situation. This problem can be solved by using self-compacting concrete.

Self-compacting concrete is an innovative concrete that does not require any vibration for placing and compaction. It can consolidate under its own weight. Even in the congested reinforcement SCC is able flow through the form work and achieving full compaction. The favorable characteristics of SCC are high fluidity, segregation resistance and self-compatibility. The unique property of SCC has rapid rate of concrete placement with very low time. By the use of SCC to minimize the voids, and have uniform concrete strength, and also provides superior quality of finishing and durability of the structure.

In a concrete mixture, aggregate represent an 80% of concrete. So that the replacement of natural coarse aggregate (NCA) with the recycled coarse aggregate (RCA) can be really helpful to made a traditional concrete as a sustainable material [5]. The use of recycled aggregates is not easy to use because their properties are different from natural coarse aggregate. So that’s why the quality of RCA can be fluctuates when collected from different sources. The characteristics of RCA should be low density, low mechanical strength, and high water absorption, greater porosity when compared to NCA [6,7]. The usage of recycled aggregates develops the reduction in the dependence on natural aggregates.

In this study, the use of Coarse Recycled Aggregate (RCA) in the production of SCC in varying replacements of natural coarse aggregates at various proportions from 0% to 100% with the increase of 20%. We have tested for the mix composition, mix design for SCC. The different characteristics of the SCC was find out using different test methods such as; filling ability (Slump flow test, T50 slump flow
test, V-funnel test), passing ability (L-box, U-box) and segregation resistance (GTM test, V-funnel at T 5min). And also 28 days compressive strength test is also done. Later durability tests on concrete is also done. Comparison between conventional concrete and self-compacting concrete was also done.

II. OBJECTIVE

The use of recycled coarse aggregates in this study for the environmental and economical consideration. By using the RCA in concrete mix we can achieving the desirable strength and workability. But still the quantity of recycled aggregate is scare. And also with the usage of RCA reduction in the increase of unwanted constructional waste. This research attempt is to provide information with the use of RCA in practical for the future use.

III. SCOPE

For the reduction of natural resources and consumption of energy. By the rapid increase in population and urbanization the use of recycled aggregates plays important role in the preservation of natural resources. Minimizing the energy, environmental impact and CO₂ intensity of concrete used for construction is increasingly important as resources are decreasing. The effect of greenhouse emissions becoming more important.

IV. MATERIALS

Ordinary Portland cement (grades 43 and or 53) was used in all compositions. Fine aggregates of size 125 micron size was used which contribute to the powder. The recycled aggregates of 20 mm used in the investigation were obtained from the demolished cubes tested in the concrete technology lab of civil engineering department of C.V.S College of engineering. All the aggregates were immersed in water up to 24 hours and surface dried before use to compensate the effect of initial higher water absorption of recycled aggregates.

The admixture of conplast SP430 was used in this study for achieving required workability. Table 1 shows the results of various physical properties of recycled aggregates.

| Characteristics               | Natural coarse aggregate | Recycled coarse aggregates |
|-------------------------------|--------------------------|---------------------------|
| Specific gravity              | 2.64                     | 2.37                      |
| Bulk density (kg/m³)          | 1514                     | 1456                      |
| Water absorption (%)          | 3.34                     | 5.23                      |
| Fineness modulus              | 6.5                      | 5.95                      |
| Impact value (%)              | 9.78                     | 17.56                     |

V. MIX DESIGN

To determine the properties SCC six types of concrete mixes were made. In each mix natural coarse aggregate was replaced by recycled coarse aggregate in the ratio of 0%, 20%, 40%, 60%, 80% and 100% by volume. The preliminary mix design was carried out using method prescribed by by Nan-Su et al, 2001 [8] for target strength of 30 MPa. After the initial mix design, the trial mixes were prepared and tested for the fresh properties of SCC as per EFNARC guidelines [9]. The quantity
of components required for making 1 m$^3$ of concrete was constant, with the exception of small variations in the quantity of super plasticizer for the purpose of achieving equal consistency for all the mixes and due to slightly higher water absorption by the recycled aggregate. To counteract the effect of higher water absorption of recycled aggregate, all the aggregates were immersed in water for 24 hours and surface dried before use. The composition of designed mixtures has been shown in table 2.

Table 2. Details of mixes for 1 m$^3$ of concrete

| Mix Type | Cement (Kg) | Coarse aggregate | Fine aggregate | Silica fume (Kg) | Water (Kg) | Dose of SP (Kg) |
|----------|-------------|------------------|----------------|-----------------|------------|-----------------|
| RC0      | 360         | 804 Normal       | 980            | 125             | 195        | 4.9             |
| RC20     | 360         | 644 Normal       | 980            | 125             | 195        | 4.9             |
| RC40     | 360         | 483 Normal       | 980            | 125             | 195        | 4.9             |
| RC60     | 360         | 322 Normal       | 980            | 125             | 195        | 4.9             |
| RC80     | 360         | 161 Normal       | 980            | 125             | 195        | 5.2             |
| RC100    | 360         | 0 Normal         | 980            | 125             | 195        | 5.2             |

5.1 Treatment process for RCA

For the improvement of quality and properties of RCA treatment process is required. The treatment process for RCA were carried out using the method prescribed by Arjun B et al., [10]. In this study the applied water pressure is 500 psi for about 20 to 30 min. After cleaning the aggregates drying under sun light about 30 min. After sun drying the RCA was kept in the oven and maintain the temperature of 150 °C about 30 min. After oven drying the dried RCA is very clean when compared to before RCA.

VI. TEST METHODS

6.1 Fresh state properties

Self-compacting concrete has following properties of filling ability, passing ability, segregation resistance. For determining these properties the following test methods were used as per EFNARC guidelines [11]. For filling ability slump flow test, V-funnel test, Orimet tests were conducted. For passing ability L-box test, U-box test, J-ring tests were used. For segregation resistance GTM screen stability test, V-funnel at T5 min tests was used, and this can also be observed in the slump flow test. Table 3 gives the recommended values for different tests of SCC by EFNARC.

Table 3. Typical range of values for SCC for the structural use

| S. No. | Method                  | Unit       | Typical range of values | Property      |
|--------|-------------------------|------------|-------------------------|---------------|
| 1      | Slump flow test         | Mm         | 650 - 800               | Filling ability|
| 2      | V-funnel                | Sec        | 8 - 12                  | Filling ability|
| 3      | Orimet                  | Sec        | 0 - 5                   | Filling ability|
| 4      | L-box                   | (h2/h1)mm  | 0.8 - 1.0              | Passing ability|
| 5      | U-box                   | (h2/h1)mm  | 0 - 30                  | Passing ability|
| 6      | J-ring                  | Mm         | 0 - 10                  | Passing ability|
| 7      | GTM screen stability test| %          | 0 - 15                  | Segregation resistance|
| 8      | V-funnel at T5 minutes  | Sec        | 0 +3 of V-funnel        | Segregation resistance|
6.2 Hardened state properties

The specimens of size 100*100*100 mm size was adopted to test the compressive strength of SCC by using compressive testing machine of 3000KN capacity. The hardened concrete was tested for 3 days, 7 days, and 28 days of specimens according to IS516-1959 [12]. The split tensile strength test was conducted same as the compressive strength test. The Split tensile strength was performed at the age of 3 days, 7 days, and 28 days of specimens according to IS516 and IS 5816-1959 [12]. The details of size, specimen, and test methods were presented in table 4.

| Property            | Age of specimen | Size of the specimen (mm) |
|---------------------|-----------------|----------------------------|
| Compressive strength| 3,7,28          | 100*100*100                |
| Split tensile strength | 7,28            | 300 diameter &150 height   |

6.3 Durability properties

The durability of a concrete structure is closely associated to the permeability of the surface layer, the one that should limit the ingress of substances (CO₂, chloride, sulphate, water, oxygen, alkalis, acids, etc.) that can initiate or propagate possible deleterious actions. For determining the durability properties the following tests were conducted.

- **Water Permeability Test**
  Water permeability test was conducted in accordance with BS EN 12390-8:2000 [13] using specimens of size 100 mm × 100 mm × 100 mm at the curing ages of 28, 56, and 120 days. The specimens were kept under water pressure of 500 ± 50 kPa for 72 ± 2 hours. After the specified interval, the specimens were removed from the apparatus and split in two halves, perpendicularly to the face on which the water pressure was applied. As soon as the split face had dried to such an extent that the water penetration front could be clearly seen, the water front was marked on the specimen. The maximum depth of water penetration was recorded to the nearest millimeter.

- **Initial Surface absorption Test**
  Initial surface absorption test determines the rate of flow of water into concrete per unit area at a stated interval from the start of the test and at a constant applied head of water. By the measurement of the length of flow along a capillary of known dimension estimation of flow volume is obtained. The Initial Surface Absorption (ISA) of the SCCs was found by testing the 100 mm sized cubes at the curing ages of 28, 56, 120 days in accordance with BS 1881-208:1996 [14]. The specimens were oven-dried to constant weight prior to the test and left to cool to the laboratory temperature in a desiccator. The water contact area is defined by a plastic cell sealed onto the concrete surface of the test specimen and is not kept less than 5000 mm². Water is introduced into the cell via a connecting point and pressure is maintained at a head of 200 mm using a funnel. A second connection point to the cap leads to a horizontal capillary tube. At the start of the test, the connection to the reservoir is closed and the absorption is measured by observing the movement of the end of the water line in the capillary tube with an affixed scale at 10 minute interval. The ISA-10 (Initial Surface absorption at 10 min) was calculated as per the procedure laid down in the aforesaid Standard.

- **Rapid Chloride Permeability Test**
  Rapid chloride penetrability test of the SCC mixes was measured at the curing ages of 28, 56, and 120 days in accordance with ASTM C1202-94 [15] using a 100 mm diameter and 50 mm thick
concrete disc cut from the cylindrical specimen. The resistance of concrete against chloride ion penetration is represented by the total charge passed in coulombs during a test period of 6 hours.

- **Capillary suction test**
  
  Capillary suction test (CST) is used to measure the rate of absorption of water by hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. In this investigation, the CST was conducted in accordance with ASTM C 1585 – 04 [15] at the curing ages of 28, 56, 120 days. Discs of 100 mm diameter and 50 mm thickness were cut from the 100 mm × 200 mm cylinders and kept for oven drying until constant mass was achieved. The specimens were then allowed to cool to room temperature and kept in a desiccator till testing. The sides of the specimens were suitably sealed. The end of the specimen, which was not in contact with water was also sealed using a loosely attached plastic sheet. The mass of the specimen was recorded with a precision balance.

VII. RESULTS AND DISCUSSION

1. **Fresh state properties**

   The results obtained from the fresh SCC are mentioned in Table 5. The result obtained for the slump flow test of all the mixes is 660-770 which ranks all the designed mixtures in SF1 & SF2. As per v-funnel test the result ranges from 8.26-10.78. It gives the flow ability of concrete even with congested reinforcement [16]. The orimet test is also gives the good flow ability in the range of 0.15-3.67.

   The L-box test gives another property passing ability. The result of L-box is 0.89-0.90. And no value is less than the 0.8 this indicates the mixture is suitable for densely reinforced structures. U-box & J-ring test shows the good passing ability in the range of 7.57-18.67 [10] and 8.45–9.56. GTM screen stability test and V-funnel test at T5 min shows the good results to the segregation resistance [17], the range of values are 5.67-9.23 and 8.67-11.67 [18].

   | S. No. | Mix   | Slump flow test | V-funnel test | Orimet test | L-box test | U-box test | J-ring test | GTM screen stability test | V-funnel at t-5 min |
   |-------|-------|-----------------|--------------|-------------|-----------|-----------|-----------|------------------------|-------------------|
   | 1     | RC0   | 660             | 8.65         | 0.15        | 0.90      | 7.57      | 8.45      | 5.67                   | 9.12              |
   | 2     | RC20  | 730             | 9.42         | 1.45        | 0.97      | 11.67     | 8.98      | 7.56                   | 10.34             |
   | 3     | RC40  | 700             | 9.98         | 2.56        | 0.94      | 15.48     | 9.00      | 8.35                   | 10.98             |
   | 4     | RC60  | 770             | 10.78        | 3.67        | 0.96      | 19.32     | 9.23      | 9.45                   | 11.67             |
   | 5     | RC80  | 720             | 9.12         | 2.89        | 0.99      | 21.78     | 9.56      | 10.56                  | 9.45              |
   | 6     | RC100 | 630             | 8.26         | 1.25        | 0.89      | 18.67     | 8.56      | 9.23                   | 8.67              |

2. **Hardened state properties**

   The results obtained from the variation of mixes in the compressive strength are shown in table 6. This specimens attains high strength of following 20%, 40%, 60%, 80%, 100% by the replacement of natural aggregates with the RCA. At the age of 28 days, the reduction of compressive strength (Figure 1 & 2) was observed to be 3.08% and 6.05% for 20% & 40% replacement of natural aggregates by RCA. This reduction in strength goes up to 6.45%, 6.89% and 7.12% for 60%, 80% and 100% mixes for the replacement of natural aggregates by RCA. Since the reduction in compressive strength is over all 7%. This is the indication for the use of RCA in structural concrete [16].
Table 6 Results for compressive strength test and tensile strength

| Mix type | 3 days Compressive strength | 7 days Compressive strength | 28 days Compressive strength | 7 days Tensile strength | 28 days Tensile strength |
|----------|-----------------------------|-----------------------------|-------------------------------|------------------------|-------------------------|
| RC0      | 24.89                       | 36.78                       | 47.56                         | 3.30                   | 4.90                    |
| RC20     | 24.36                       | 34.67                       | 45.78                         | 3.10                   | 4.60                    |
| RC40     | 24.15                       | 35.34                       | 44.34                         | 2.80                   | 4.40                    |
| RC60     | 22.67                       | 31.83                       | 43.21                         | 2.50                   | 4.00                    |
| RC80     | 22.15                       | 32.12                       | 42.56                         | 2.30                   | 3.60                    |
| RC100    | 19.45                       | 29.37                       | 40.23                         | 2.10                   | 3.30                    |

Figure 1. Mix types vs. compressive strength

Figure 2. Mix types Vs. Tensile strength
3. Durability

- Water permeability test

The results of water penetration depths of different SCC mixes with partial and full replacement of NCA with RCA are shown in figure 3. We can observe that, there was increase in the depth of water penetration in the SCC mixes with the increase in the RCA amount at all the curing ages tested. The SCC mix C-R50 made with 50% RCA shows an increase in the depth of water penetration by an amount of 7.9%, 8.7% and 22% at 28, 56 and 120 days respectively compared to the control mix C-R0 [13]. Furthermore, complete replacement of NA with RCA in SCC mix C-R100 shows a predominant rise in the water penetration depth by 31.4%, 22.6% and 35.2% at 28, 56 and 120 days respectively. Indeed, the major factor that affects the water penetration is the mortar adhered to the aggregates.

![Figure 3. Test results for water permeability](image)

- Initial surface absorption test

The ISAT results for various SCC mixes tested in this investigation are shown in figure 4. In all curing ages values increase with the increase in the RCA content at all the curing ages tested in this investigation. For 50% replacement of NCA with RCA, there was an increase in the value of ISA by the order of 13.7%, 15.6% and 16.5% at 28, 56 and 120 days of curing period respectively. This increase in the value of ISA becomes significant for the 100% replacement of NCA with RCA. In this case, an increase of the order of 32%, 33.5% and 28.5% was observed for SCC mix C-R100 compared to mix C-R50 at curing periods of 28, 56 and 120 days respectively [14]. Higher ISA values indicate higher surface porosity which suggests that with increasing content of RCA the surface porosity of the SCC mix increases.

![Figure 4. Initial surface absorption test results for SCC](image)
4. **Rapid chloride penetrability test**

Figure 5 shows the results of resistance to chloride ion penetration of the various SCC mixes made with 50% and 100% RCA at 28, 56 and 120 days. The results for control mix containing 0% RCA at different curing ages are also plotted for comparison. Figure 6 shows that the resistance to chloride ion penetration decreased with the increase in RCA content at all curing ages. From the results, it can be observed that incorporation of 50% RCA in SCC mix C-R50 shows an increase in the total charge passed by about 7.6%, 8.3% and 6.14% respectively after 28, 56, 120 days of curing. Similarly, the SCC mix C-R100 shows increment in the total charge passed relative to the control mix C-R0 [15], which is of the order of 13.9%, 12.4% and 14.8% at 28, 56 and 120 days of curing. This increase in the charge penetration is related to the presence of high volume pores within the RCA mixes and this volume is expected to increase with an increase in the content of RCA.

![Figure 5. Rapid chloride penetrability test results for SCC](image)

5. **Capillary suction test**

The results of capillary suction test conducted on SCC mixes with partial and full replacement of NCA with RCA at 28, 56 and 120 days of curing. It can be observed from figure 6 that, there has been an increase in the values of Initial Rate of Absorption (IRA) with the increase of RCA content in SCC mixes compared to control mix. At 50% replacement of NCA with RCA, the IRA marginally increases by the order 10.34%, 9.82% and 7.75% at 28, 56 and 120 days of curing respectively compared to control SCC mix C-R0. The increase in IRA becomes more pronounced with full replacement of NCA with RCA, as there was an increase 40.5%, 35% and 26.5% in the IRA values at 28, 56 and 120 days of curing respectively compared to the control SCC mix. This suggests that up to 50% replacement of NCA, the increase in absorption rate was marginal but during complete replacement IRA increases sharply [15].

![Figure 6. Test results for capillary suction test](image)
6. Comparison of SCC with RCA and NA

To determine the flowing ability and passing ability of self-compacting concrete, various tests were performed in its fresh state of mixture. The fresh state tests include slump flow test, V-funnel, L-box, U-box test [19]. Later compressive strength test was performed on the hardened concrete cubes after 7 days and 28 days. The fresh state and hardened state test results of self-compacting concrete using recycled aggregates and normal aggregates are tabulated in Table 7 & 8 [20].

Table 7. Results of SCC using recycled aggregates

| S.No. | Mix     | Slump flow (mm) | V-funnel (sec) | L-box (mm) | Avg strength @7 days | Avg strength @28 days |
|-------|---------|-----------------|----------------|------------|----------------------|-----------------------|
| 1     | SCCRA0  | 660             | 8.65           | 0.90       | 36.78                | 47.56                 |
| 2     | SCCRA20 | 730             | 9.42           | 0.97       | 34.67                | 45.78                 |
| 3     | SCCRA40 | 700             | 9.98           | 0.94       | 35.34                | 44.34                 |
| 4     | SCCRA60 | 770             | 10.78          | 0.96       | 31.83                | 43.21                 |
| 5     | SCCRA80 | 720             | 9.12           | 0.99       | 32.12                | 42.56                 |
| 6     | SCCRA100| 630             | 8.26           | 0.89       | 29.37                | 40.23                 |

Table 8. Results of SCC using normal aggregates

| S.No.  | Mix       | Slump flow (mm) | V-funnel (sec) | L-box (mm) | Avg strength @7 days | Avg strength @28 days |
|--------|-----------|-----------------|----------------|------------|----------------------|-----------------------|
| 1      | SCCNA0    | 690             | 8.50           | 0.90       | 37.67                | 49.21                 |
| 2      | SCCNA20   | 750             | 9.20           | 0.95       | 35.58                | 47.56                 |
| 3      | SCCNA40   | 710             | 9.45           | 0.94       | 36.95                | 45.78                 |
| 4      | SCCNA60   | 790             | 10.34          | 0.92       | 33.78                | 44.56                 |
| 5      | SCCNA80   | 740             | 9.00           | 0.95       | 33.67                | 43.78                 |
| 6      | SCCNA100  | 650             | 8.15           | 0.88       | 30.43                | 41.34                 |

7. Slump cone test

Because of high water absorption slump flow of RCA (self-compacting concrete containing recycled aggregates) was less than that of NCA (self-compacting concrete containing normal coarse aggregates). Experimentally it was found that water absorption of recycled aggregates (figure 7) was 4.35%, while that for normal aggregates the water absorption was found out to be 0.57%. The water absorption of recycled aggregates is increases due to coating of cement mortar over the aggregate particles.
8. V-funnel test

The values of V-funnel for RCA is more than the NCA (figure 8). This occurs because of the high water absorption, size of aggregates, specific gravity.

![V-funnel comparison](image)

Figure 8. V-funnel comparison

9. L-box test:

The L box value (Figure 9) of RCA was almost similar as that of NCA having equal mix proportions. This is preferably because of nearly same specific gravity, equal amount of coarse aggregate content and similar size of aggregate particles. The specific gravity of normal aggregates is somewhat higher than that of recycled aggregates.

![L-box comparison](image)

Figure 9. L-box comparison

10. Compressive strength test:

By decreasing the water powder ratio increase in the compressive strength of each mix. It was found that the compressive strength of RCA is 15-20% of compressive strength of NCA (figure 10 & 11). This is preferably because of higher crushing value of recycled aggregates. For replacement of fly
ash with 15% silica fume, and by reducing the water content from 0.5 to 0.42, there was sharp increase in the compressive strength.

![Bar chart showing comparison of average compressive strength at 7 days](image1)

**Figure 10. Comparison of avg. compressive strength @ 7 days**

![Bar chart showing comparison of average compressive strength at 28 days](image2)

**Figure 11. Comparison of avg. compressive strength @ 28 days**

**VIII. CONCLUSION**

From this work, the following conclusions were drawn.

1. There is a significant scope for growth of recycled aggregate as an appropriate and green solution for sustainable development in construction industry.
2. The self-compacting concrete made with RCA have achieved the required strength in all mixes and also satisfy the fresh state properties of SCC.
3. SCC made with recycled aggregates shows negligible effect on fresh state properties of SCC.
4. The strength investigation shows that, there is a decrease and increase in compressive and tensile strength with percentage of recycled coarse aggregate. This is a cover of adhered mortar attached to recycle aggregate contributing for weaker interfacial transition zone.
5. The mixes containing recycled coarse aggregate gains quick early strength due to presence of partially hydrated cement cover the aggregate which accelerates the hydration process.
6. The concrete mixes up to 40% & 60% RCA have shown good results to fresh state and hardened state properties.
7. There is a need for the research on the effect of recycled aggregates on durability properties of concrete in SCC.

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