# STUDY OF FRESH AND MECHANICAL PROPERTIES OF SELF-COMPACTING RECYCLED COARSE AGGREGATE CONCRETE (SCRCAC)

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**Abstract -** *Self - Compacting Concrete (SCC) is one of the special concretes with excellent strength and durability properties which can be placed under its own weight without any means of vibration. Besides, it can be handled without segregation and bleeding. SCC has high binder content which is usually cement and a filler material. Partial replacement of Ordinary Portland Cement (OPC – 70 %) with Supplementary Cementitious Materials like Metakaolin (MK – 10 %) and Fly Ash (FA – 20 %) is carried out in this study. Self - Compacting Recycled Coarse Aggregate Concrete (SCRCAC) is formed by integrating the Recycled Coarse Aggregate (RCA) in SCC. This study evaluates the feasibility of producing SCRCAC by incorporating RCA in varying proportion (0, 25%, 50%, 75% and 100% RCA replacement) which was extracted from Construction and Demolition waste. In this study, admixture is used to maintain the workability and stability. Various tests were performed such as Slump flow, $T_{50cm}$ Slump flow, V-funnel, L-box and U-box as prescribed by EFNARC to check the filling and passing ability of concrete and to fall under the category of SCC. The effect of incorporation of Recycled Coarse Aggregates in SCC was carried out by performing the tests such as compressive strength and split tensile strength. The study objective is to enumerate the optimum usage of Recycled Coarse Aggregates for the SCRCAC mixes based on their performances in their fresh and hardened state.*

***Key Words***: Self - Compacting, Recycled Coarse Aggregate, Metakaolin, workability, strength.

## 1. INTRODUCTION

Concrete is a ubiquitous material that builds the majority of the world's bridges, roads, dams and buildings which makes it a highest consumed material on earth besides water. To produce a ton of OPC it requires about 4 GJ energy and cement clinker manufacture releases approximately 1 ton of carbon dioxide into the atmosphere [1]. Aggregates form the major part of concrete approximately about 80% by mass and are extracted from quarries. Stone crushing and quarrying activities have considerable effects on environmental quality and human health which leads to depletion of natural aggregates in alarming rate. Henceforth we are directed towards 'sustainable' development with ecofriendly ingredients of concrete. A building made of reinforced concrete structure is demolished at the end of its lifecycle and its residues are normally sent to the landfills. Nevertheless, all the concrete mass treated as waste can be incorporated into new concretes in the form of aggregates. Recycled aggregates from Construction and Demolition Waste (CDW) are the most promising solution for reducing the adverse environmental impacts in landfills caused by the construction industry [2].

Concrete have evolved over ages and its innovation relay on the need to serve its intended purpose. One such innovation is the Self Compacting concrete. Using SCC, the addition of supplementary materials in cement has significantly improved and has reduced cement consumption [3]. SCC proves to be a promising material for under water structures and in the fabrication of light weight and slender sections. SCC has been widely used as an alternative to normally vibrated concrete (NVC) though its application is limited. SCC specimens have on average 10% higher load carrying capacity than referenced VC specimens [4]. The improved construction practice and performance, combined with the health and safety benefits, make SCC a very attractive solution for both precast concrete and civil engineering construction. The most important properties of SCC are its flow ability and stability. This flow ability can be attained by the use of high range water reducing admixture (HRWRA), Superplasticizers (SP) and Viscosity Modifying Admixture (VMA). The stability to segregation is based on the use of a large amount of fine particles, by limiting coarse aggregate and by reducing water – to – binder ratio [16]. The workability of SCC is higher than the ordinary concrete. SCC can be characterized by the following properties such as Filling ability, Passing ability and Segregation resistance [16]. A concrete mix can only be classified as Self-compacting concrete if the requirements for all three characteristics are fulfilled. In this study, Self - Compacting Recycled Coarse Aggregate Concrete (SCRCAC) is produced by integrating the Recycled Coarse Aggregate (RCA) in SCC and its optimum replacement of RCA is determined.

## 2. MATERIALS

The materials used in this study are Cement, Fly ash, Metakaolin, Natural Fine Aggregates, Natural coarse aggregates, Recycled coarse aggregates, Superplasticizer and Water.

### 2.1 Cement

OPC of 53 grade was used and tested as per IS: 4031-1988 and found satisfied. The specific gravity of cement is obtained as 3.14.

### 2.2 Fly ash (FA)

The fly ash used is a by-product of coal fired electricity generating plants. It improves the workability of plastic concrete, strength and durability of hardened concrete thus adopted in this study. Class F fly ash is used having specific gravity of 2.2.

### 2.3 Metakaolin (MK)

Metakaolin is an artificial pozzolana admixture obtained from thermally activated ordinary clay and kaolinitic clay. The specific gravity of Metakaolin used is 2.5.

### 2.4 Natural Fine aggregate (NFA)

The locally available manufacture sand is used in the present study. The specific gravity and fineness modulus of the material are 2.7 and 2.78 respectively which is in accordance with IS: 2386-1963.

### 2.5 Natural Coarse aggregate (NCA)

The locally available crushed angular aggregate of maximum particle size ranging between 10 to 12 mm was used in present experimental study. The specific gravity of natural coarse aggregate is 2.8.

### 2.6 Recycled Coarse aggregate (RCA)

The locally available demolition and waste concrete are collected and crushed down using Jaw crusher apparatus. The crushed aggregates are then washed and sieved. The aggregate which passes 12mm and retained on 10mm sieve is adopted for this study as recycled coarse aggregate. The specific gravity of natural coarse aggregate is 2.5.

### 2.7 Superplasticizer (SP)

The super plasticizer used is Master Glenium SKY 8233, which is a polycarboxylic ether based admixture. Mostly compatible with all OPC, PPC, PSC and can be used with high pozzolanic material to produce high performance concrete. This super plasticizer has specific gravity of 1.08.

### 2.8 Water

The Available tap water in laboratory was used in mixing the ingredients and for curing purpose also. It was free from organic materials and suspended solids, which may affect the properties of fresh as well as hardened concrete.

## 3. MIX PROPORTION

In this study there are two major objectives. One is to achieve the required workability in order to make the concrete a self compacting one and the other is to achieve the stipulated strength. The proportion of 70% cement and 30% Fly Ash could give good workability based on the previous studies [3]. The incorporation of 10% Metakaolin results optimum both in strength and workability point of view [5]. Thus the mix design is calculated in the ratio of Cement: Fly Ash: Metakaolin as 7:2:1. Based on the proposed mix design, specimens like cubes and cylinders are cast for arriving out the Compressive strength and Split tension concrete respectively. The average of three specimens is considered and specimens cast for one mix shown in Fig. 1.

The mix is varied based on the percentage of Recycled Coarse Aggregate (RCA) in Self-compacting concrete (SCC). RCA is varied in percentages 0%, 25%, 50%, 75% and 100% named as CON, M1, M2, M3 and M4 respectively. The mix having the adequate strength and the desired workability is chosen as the optimum mix.

**Fig -1**: Cast specimens per mix

The mix design for SCC was based on IS 10262:2019 code [11]. In this mix design, two parameters were anticipated (i) Initial water content and (ii) Particles less than 125 micron sieve i.e. fines. For the Trail mix 1, initial water content was assumed as 190 kg/m$^3$ along with a super plasticizer at 0.6% by mass of cementitious material content and particles less than 125 micron was determined as 0.7%. This Trail mix 1 fails in both strength and workability aspects. Further Trail Mixes were carried out by varying the dosage of super plasticizer until required workability and strength was obtained. These values were incorporated in mix design to get final mix proportion and the final proportion was checked with EFNARC guidelines.

**Table -1:** Mix Notation and Description

| Mix. No | Mix Notation | Description |
|---|---|---|
| 1 | CON | 70% OPC + 20% FA + 10% MK + 100% NCA + 0% RCA |
| 2 | M1 | 70% OPC + 20% FA + 10% MK + 75% NCA + 25% RCA |
| 3 | M2 | 70% OPC + 20% FA + 10% MK + 50% NCA + 50% RCA |
| 4 | M3 | 70% OPC + 20% FA + 10% MK + 25% NCA + 75% RCA |
| 5 | M4 | 70% OPC + 20% FA + 10% MK + 0% NCA + 100% RCA |

The final mix proportion of control mix of water, cement, Fly Ash, Metakaolin, Natural Coarse Aggregate, Natural Fine Aggregate and Superplacticizer are 180.50 kg/m$^3$, 415.63 kg/m$^3$, 118.75 kg/m$^3$, 59.38 kg/m$^3$, 692.36 kg/m$^3$, 892.86 kg/m$^3$ and 9.5 kg/m$^3$ respectively. The mix notation and description of all SCRCAC mixture are tabulated in Table 1. The quantities for all the materials are calculated for the control mix containing 70% Cement, 20% Fly Ash and 10% Metakaolin with 0% Recycled Coarse Aggregate. The quantities of materials required in control mix (CON) for one cube and one cylinder which is accounted for casting purpose which is specified in Table 2. Slump flow test, $T_{50cm}$ test, V: funnel test, L: box test and U: box was performed for all SCC mixtures in their fresh state as per ENFARC guidelines [16]. After that, Compression strength test and split tensile strength were also performed in their hardened state to study hardened properties to determine the optimum replacement of RCA both in terms of workability and strength criteria.

## 4. TEST METHODS

### 4.1 Tests for SCC – Fresh state

The flow ability is the property that characterizes the ability of the SCC to flow into formwork and filling all space under its own weight, guaranteeing complete covering of the reinforcement. The filling ability is found by Slump-flow by Abrams cone, $T_{50cm}$ slump test, and V funnel. The property of passing ability is that, SCC must flow through tight openings such as spaces between steel reinforcing bars and the mix must not block during placement. The passing ability is found by L-Box test and U-Box test. The tendency to segregate can be reduced using a sufficient amount of fines [16].

### 4.2 Tests for SCC – Hardened state

Compression strength test - The Compression strength test was performed on 150 mm cube according to the provisions given in IS: 516–1959 [13] and strength value was calculated from the average of three specimens of each curing period at 7 and 28 days.

Split Tensile Strength test - This is an indirect test to determine the tensile strength of cylindrical specimens. Split tensile strength test was carried out on cylinder specimens of size 150 mm diameter and 300 mm length at the age of 28 days ambient curing, using compression testing machine as per IS: 5816 – 1999 [14].

## 5. RESULTS AND DISCUSSIONS

### 5.1 Fresh properties

The implementations of workability tests are shown in Fig. 2 and its results of all 5 mixes considered are shown in Table 3. From Table 3, it is evident that the workability results of M3 and M4 mixes are found to be deviating the EFNARC standards where it exceeds the maximum limit in few workability tests. Hence the mix M3 and M4 are to be neglected. The mixes CON, M1 and M2 lie between the minimum and the maximum range of EFNARC standard.

From this it can be observed that CON mix has higher workability and M2 has lower workability which lies between

**Table - 2:** Materials requirement for one cube and one cylinder

| Specimen | Cement (kg) | FA (kg) | MK (kg) | NFA (kg) | NCA (kg) | Water (ml) | SP (ml) |
|---|---|---|---|---|---|---|---|
| Cube | 1.54 | 0.44 | 0.22 | 3.31 | 2.57 | 670 | 40 |
| Cylinder | 3.23 | 0.92 | 0.46 | 6.94 | 5.38 | 1400 | 70 |

**Table - 3:** Workability test results for all SCRCAC mixes with EFNARC standards

| Mix | Slump diameter (mm) | $T_{50\ cm}$ Slump flow (sec) | V-funnel (sec) | L-box | U-box |
|---|---|---|---|---|---|
| ***EFNARC Standard*** | ***650 – 800*** | ***2 – 5*** | ***6 – 12*** | ***0.8 -1.0*** | ***0 - 30*** |
| CON | 790 | 2.8 | 8 | 0.8 | 10 |
| M1 | 760 | 3.1 | 10 | 0.9 | 15 |
| M2 | 700 | 4.5 | 11 | 1 | 27 |
| M3 | 650 | 5 | 12 | 1.3 | 45 |
| M4 | 620 | 6 | 18 | 1.8 | 56 |

(a) (b) (c)

**Fig - 2(a) 2(b) & 2(c):** Workability Tests for SCC

the minimum and the maximum range of EFNARC standard. As percentage of Recycled Coarse Aggregate increases, the workability decreases which is apparent to various literatures [2]. This is because Recycled Coarse Aggregate in SCC mixture increases the viscosity due to their highly porous nature and also due to presence of old ITZ in concrete matrix [6].

## 5.2 Mechanical properties

The cubes are tested for compressive strength at 7th and 28th day as shown in Fig. 3 and Fig. 4. Table 4 shows the results of Compression strength test between the control mix SCC and varied SCRCAC prepared with RCA at different curing ages, and its comparison on $7^{th}$ and $28^{th}$ day can be noticed in Fig. 5. The compressive strength of the mix CON is higher than all the other mixes. The compressive strength for the mixes M1, M2, M3 and M4 are 4.56%, 10.24%, 21.17% and 26.15% lesser than control mix CON. As the percentage of incorporation of Recycled Coarse Aggregate (RCA) increases, the compressive strength decreases gradually which is in accordance with the literature reviews [1,2,6]. The maximum substitution rate of RCA should be limited due to the inferior properties of RCA [7-10].

However, this reduction did not affect the potential use of the tested concrete as a structural concrete in terms of the required mechanical strength. Where, even with 100% RCA replacement the compressive strength is adequate to be used structurally. So with respect to the compressive strength and maximum incorporation of Recycled Coarse Aggregate (RCA), the **mix M2** is regarded as the optimum mix.


**Fig -3**: Compressive strength for cube

**Fig -4**: Tested cube specimen

**Table - 4:** Compressive Strength results

| Mix | Average compressive strength at 7 days (N/mm²) | Average compressive strength at 28 days (N/mm²) |
|---|---|---|
| CON | 28.533 | 37.9 |
| M1 | 26.76 | 36.17 |
| M2 | 25.55 | 34.02 |
| M3 | 21.489 | 29.88 |
| M4 | 19.653 | 28 |

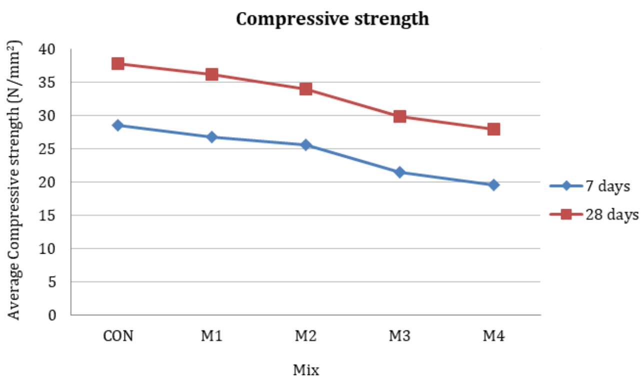


**Fig -5**: Compressive strength for all SCRCAC mixes

Table 5 and Fig. 6 depict the splitting tensile strength of all the SCRCAC mixtures relative to that of the control SCC at 28 days. The split tensile strength of the mix CON is higher than all the other mixes. As the percentage of incorporation of Recycled Coarse Aggregate (RCA) increases, the split tensile strength decreases gradually [1,2,6] which is in accordance with the literature reviews. Due to the inferior properties of RCA, the maximum substitution rate of RCA should be limited. So with respect to the split tensile strength and maximum incorporation of Recycled Coarse Aggregate (RCA), the **mix M2** is regarded as the optimum mix.

**Fig -6**: Tested cylinder specimen

**Table - 5:** Split Tensile Strength results

| Mix | Average split tensile strength at 28 days (N/mm²) |
|---|---|
| CON | 2.84 |
| M1 | 2.49 |
| M2 | 1.90 |
| M3 | 1.38 |
| M4 | 1.2 |

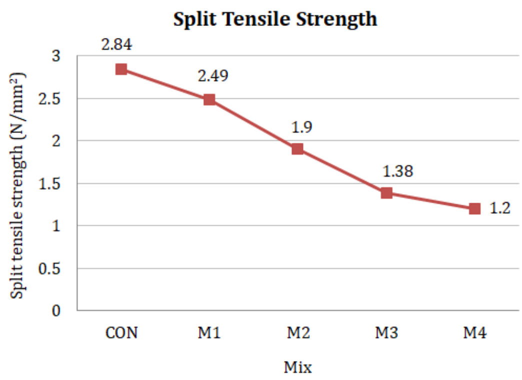


**Fig -6**: Split Tensile strength for all SCRCAC mixes

## 6. CONCLUSIONS

An experimental work is carried out in SCC to find the optimum replacement of Recycled Coarse Aggregate along with supplementary cementitious materials like Fly Ash and Metakaolin such that fair strength and workability is obtained. The following are the conclusions obtained based on this thesis work -

- Self-Compacting Recycled Coarse aggregate Concrete (SCRCAC) shows fair strength and workability with limited substitution. SCRCAC with greater substitution shows poor result in workability tests which does not fall in EFNARC standard.
- The maximum substitution rate of Recycled Coarse Aggregates is limited due to the inferior properties of Recycled Coarse Aggregates.
- It is evident that compressive strength results are higher for control mix - CON and least for 100% RCA replacement – Mix M4. The Mix M1 shows 4.6% and Mix M2 shows 10.24% reduction in compressive strength compared to Mix CON.
- Since concrete is SCC, Workability is crucial parameter than its strength. The workability values for Mix CON, M1 and M2 satisfies EFNARC standards but M3 and M4 fails in few workability tests since it does not fall under EFNARC standards.
- Hence, the Optimum Mix for incorporation of RCA with respect to workability and Strength is nominated as Mix M2 (50% replacement).

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