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Use of Recycled Coarse Aggregate in Self Compacting Concrete

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Self Compacting Concrete (SCC) is gaining popularity in construction industry due to several advantages offered by it. In this study, M-30 grade referral SCC was designed using the natural aggregates, Ordinary Portland Cement (OPC), and varying levels of Fly Ash (FA) for partly replacement of OPC. The properties of fresh and compressive strength of hardened SCC made using above ingredients, and FA and Recycled Coarse Aggregates (RCA) for partly replacement of Natural Coarse Aggregate (NCA), were also evaluated. For the first part of study, the OPC was partially replaced (0-35% by weight, at an interval of 5%) by FA, and the optimum replacement level (25%) was found for referral concrete containing NCA. For the second part of study, 12 different SCC mixes were prepared at optimum level of FA content (25%), and by replacing part of NCA (0-100% by weight, at an interval of 25%) with RCA to obtain its optimum replacement level. The workability properties of SCC and Compressive strength (CS) of hardened SCC at different FA and FA+RCA content were determined. Also, the microstructures of the optimum SCC mixes containing FA and FA+ RCA were analyzed using X-Ray Diffraction (XRD) and Scanning Electron Microscopy (SEM).

Keywords: Fly Ash (FA), Fresh Properties, Hardened Properties, NCA, RCA, SCC.

Introduction

The SCC is gaining popularity in construction industry due to several advantages offered by it. Generally, it is prepared using Natural aggregates, changing the composition of fine and coarse aggregates, and by replacing a part of OPC with suitable pozzolanic materials. The use of RCA, obtained from refuse and constructions debris, in combination with cementitious materials in concrete may also be useful and may offer several advantages too, like: maintaining ecological balance; offering economical constructions; reducing carbon dioxide emissions; reducing the excessive consumption of natural resources; and producing concrete for sustainable development. For preparing SCC, self- compactability tests were carried out to propose a rational mixed design method [1]. The SCC demands a very high slump which is achieved by adding an appropriate super-plasticizer to the mix. Also, the required slump can be achieved by a different proportion of fine aggregate, satisfying the specifications [2].The viscosity modifying admixture is used to enhance the stability of mixtures for different water/binder (w/b) ratios and consistency level [3]. The SCC can be made using Low/High Volume FA and RCA, and the results indicate that the carbonation resistance of SCC decreases on increasing the RCA content [4]. The SCC made using palm kernel shell ash for part replacement of OPC, satisfied the EFNARC recommendation [5].

The effect of RCA inclusion on properties of concrete is investigated and it is reported that CS of mix after 7 days of air exposure is more than that exposed for 28 days in water [6].

Medium strength concrete made using same cement content and effective w/c ratio as conventional concrete but by replacing 25% of NCA by RCA achieved the same mechanical properties [7].

In this study the effect of FA inclusion, with or without RCA, on the properties of SCC is investigated. Different SCC mixtures with total binder content 465 kg/m^3 and w/b ratio of 0.43 were prepared. First, the SCC was prepared with NCA, and by replacing part of OPC by FA in varying proportions (0, 5, 10, 15, 20, 25, 30 and 35%, by mass) and the resulting mixes are designated as FA00, FA05, FA10, FA15, FA20, FA25, FA30 and FA35. Similarly, another set of SCC mixes was prepared by maintaining the optimum FA content obtained from the previous step, and replacing part of NCA in varying proportions by RCA (0, 25, 50, 75 and 100%, by mass), and the corresponding mixes are designated as FA25RCA00, FA25RCA25, FA25RCA50, FA25RCA75 and FA25RCA100.

Schedule of Experiments

Materials used and Mix Proportion

The 43 grade OPC (Brand-Prism) conforming to the requirements of IS: 8112-1989 was used. OPC constituents, as supplied by manufacturer, are given in Table 1. The natural river sand (NS) of rounded particle shape and smooth surface texture conforming to Zone II, IS: 383-1987 has been used. The test results of NS: Specific gavity-2.65; Bulk density-1680 kg/m^3. Fig.1. shows the grading curve of NS. The NCA and RCA of sizes 10 and 20 mm have been considered in present work. Properties of both coarse aggregates are presented in Table 2. These values conform to the requirements of IS 383-1987. Fig. 2 presents the grading curves of all coarse aggregates. The inspection/testing of RCA revealed their greater angularity, roughness, and porosity in comparison to the NCA as shown in Figs. 3 and 4. The FA used for this investigation was brought from NTPC Unchahar (UP) and it conformed to the requirements of IS: 3812-2000. FA constituent is included in Table 1. In this investigation, a super-plasticizer (Polycarboxylic-Ether based Master Rheobuild 817RL) with approximate density and pH as 1.08 and 5.0, respectively, was used. For making and curing the SCC mixes, fresh potable tap water was used.

Table 1. Constituents of OPC and FA

Chemical constituents (%)	OPC	FA
Silicon Di Oxide (SiO_2)	20.4	50.45
Alumnium Oxide (Al_2O_3)	6.20	4.5
Iron Oxide (Fe_2O_3)	3.09	2.1
Calcium Oxide (CaO)	63.90	20.6
Magnesium Oxide (MgO)	1.50	1.7
Sodium Oxide (Na_2O)	0.50	0.8
Potassium Oxide (K_2O)	0.49	0.35
Loss of ignition	3.10	2.43

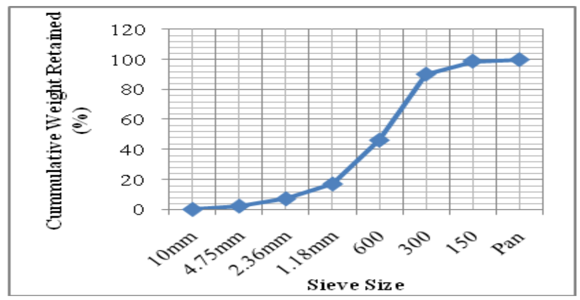

Fig. 1. Grading of fine aggregate

Table 2. Properties of NCA and RCA

Properties	NCA		RCA	
	10mm	20mm	10mm	20mm
Specific Gravity	2.66	2.7	2.6	2.5
Water Absorption(%)	1	0.9	2	1
Bulk Density(kg/m^3)	1590	1560	1600	1590
Fineness Modulus	6.7	7.2	6.5	7.0
Impact Value(%)	15	16	14	17
Crushing Value(%)	25	26	23	25

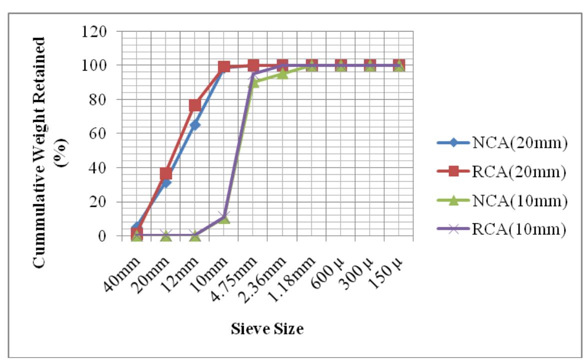

Fig.2. Grading of NCA and RCA (10 & 20mm)

Fig.3. RCA of 10mm and 20mm

Fig.4. NCA of 10mm and 20mm

Mix Proportions of SCCs

The quantities of material in different SCC mixtures are included in Table 3.

Tests of Concrete

Fresh SCCs

The different workability parameters of SCCs made with FA and FA+RCA in fresh state are determined as per EFNARC-2005 guidelines and are presented in Table 4. The Filling ability was measured with the help of Slump Flow, T-50cm Time (Sec), V-funnel and U-box. The Passing ability of different mixtures was determined using L-Box and J-Ring tests. Super-plasticizer's dose was adjusted to get the desirable workability.

Hardened SCCs

Compressive Strength

The CS of 100mm SCC cubes was found by following the provisions of IS: 516-1959.

Microstructural Analysis

The microstructures of the optimum SCC samples are analyzed by XRD and SEM.

X-ray Diffraction Analysis

The samples were prepared and the micrographs were obtained by X-Ray transmission (Xpert pro, Panalytical, USA).

Scanning Electron Microscopy Analysis

The microstructure or ITZ was analysed by using Field Emission Gun-SEM (Nove FE-SEM 450, FEI). The resolution of the machine for characterisation was 1.4 nm and 1 nm at 15kV.

Table 3. Mix Proportions of SCC mixes

Sample	OPC (kg/m^3)	FA (kg/m^3)	NCA (kg/m^3)	RCA (kg/m^3)
FA00	465.00	0	737.00	0
FA05	441.75	23.25	737.00	0
FA10	418.50	46.50	737.00	0
FA15	395.25	69.75	737.00	0
FA20	372.00	93.00	737.00	0
FA25	348.75	116.25	737.00	0
FA30	325.50	139.50	737.00	0
FA35	302.25	162.75	737.00	0
FA25 RCA00	348.75	116.25	737.00	0
FA25 RCA25	348.75	116.25	552.75	184.25
FA25 RCA50	348.75	116.25	368.50	368.50
FA25 RCA75	348.75	116.25	184.25	552.75
FA25 RCA100	348.25	116.25	0	737.00

Results and Discussion

Fresh SCCs

The workability parameters of different SCCs in fresh state are already presented in Table 4, and their variation is shown in Figs. 5-7. Fig. 5 shows that the slump values increase while T-50 time decreases on increasing the FA content. Further, the slump values decrease while T-50 time increases by increasing the RCA content in the mix. Fig. 6 indicates that both the V-Funnel time and U-box values decrease by increasing the FA content in the mixes; however, both these parameters increase with the increasing RCA in

Table 4. Workability of SSC mixes

Sample	Slump flow (mm)	T-50 Time (sec)	V-Funnel (sec)	L-Box (mm)	U-Box (mm)	J-Ring (mm)
FA00	580	5.6	12.0	0.90	20.0	7.6
FA05	600	5.4	11.9	0.89	19.0	7.4
FA10	630	5.1	11.8	0.86	18.0	7.3
FA15	640	4.8	11.7	0.85	17.0	7.0
FA20	650	4.2	11.5	0.83	16.5	6.5
FA25	670	4.0	11.3	0.81	16.0	6.3
FA30	680	3.5	11.2	0.80	15.0	6.1
FA35	710	3.0	11.0	0.78	14.0	6.0
FA25 RCA00	670	4.0	11.3	0.81	16.0	6.3
FA25 RCA25	650	4.2	11.5	0.83	16.5	6.5
FA25 RCA50	630	5.1	11.7	0.86	17.0	6.9
FA25 RCA75	610	5.5	11.9	0.89	18.0	7.0
FA25 RCA100	590	5.9	12.0	0.90	19.0	7.2

the mix. The change in the filling ability parameters may be because of spherical shape of the FA particles and greater angularity, roughness, and porosity of RCA. It is evident from Fig. 7 that the passing ability decreases on increasing the FA content in the mix; however, it increases with the RCA content in the mix. The reasons may be same as discussed in the case of filling ability.

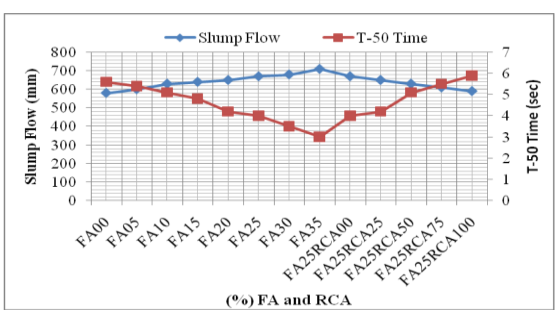

Fig. 5. Slump Flow Vs T-50 Time

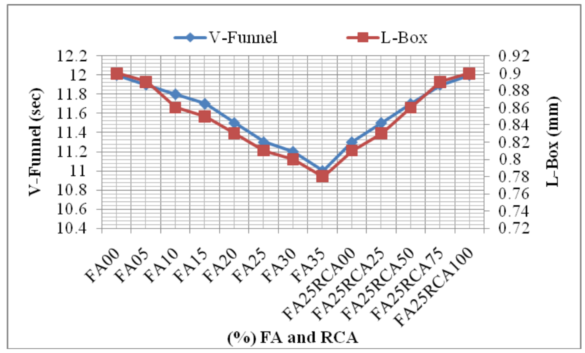

Fig. 6. V-Funnel Vs L-Box

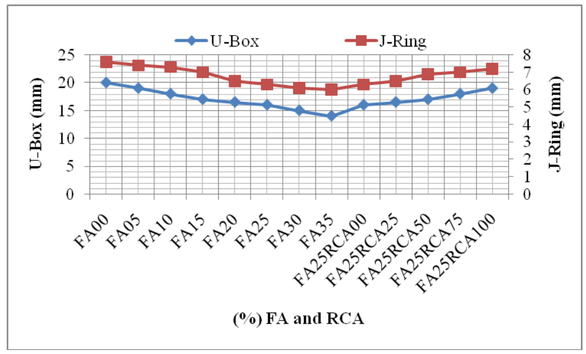

Fig. 7. U-Box Vs J-Ring

Hardened SCCs

Compressive Strength

The CS of different SCCs was determined for 100 mm cubes after 7 and 28 days of water curing and its variation is presented in Fig. 8. CS increases upto 25 % FA inclusion (optimum level) and then decreases. Further, on increasing the replacement level of NCA by RCA, at optimum FA inclusion level, the CS decreases. At optimum FA inclusion level (25%), CS of SCC made using NCA only is increased by 15.50 and 11.29% at 7 and 28 days, respectively, as compared to the control mix (FA00). When both the OPC and NCA are replaced in part/whole by FA and RCA, respectively, the maximum CS at both 7 and 28 days is obtained at FA content of 25% and RCA content of 25%. At this optimum replacement level of both OPC and NCA in combination, CS of the SCC at 7 and 28 days is increased by 3.57 and 6.93% , respectively, in comparison to the control mix (FA00), and decreased by 10.32 and 3.91%, respectively, in comparison to the referral concrete (FA25%).

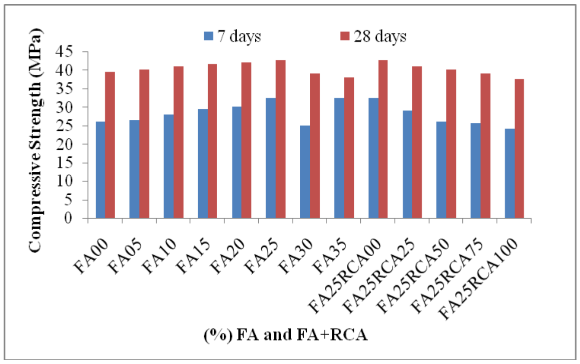

Fig. 8. Compressive Strength of SCC mixes

Microstructural Characterization

XRD

The XRD of only two optimum SCC mixes, one containing only 25% FA while the other containing FA (25%) + RCA (25%) was carried out after 28 days of water curing. The results are shown in Figs. 9-10. It is found that the amount of calcium hydroxide (CH) decreases with increase in the age of concrete and FA content. The XRD analysis of optimum FA+RCA combination shows a predominant peak of quartz and minor peaks of alkali feldspars, mica and dolomite. The CSH peaks are observed in both the XRD images.

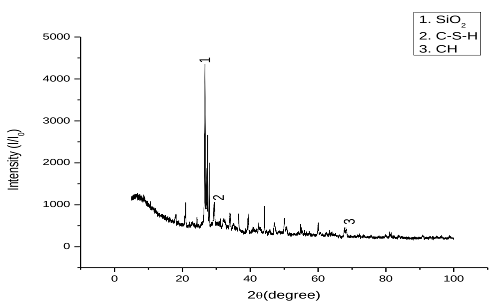

Fig. 9. XRD image of SCC with FA (25%) at 28 days

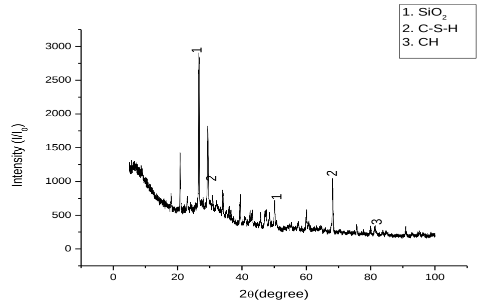

Fig. 10. XRD image of SCC with FA (25%) + RCA (25%) at 28 days

Scanning Electron Microscopy

The SEM was also conducted only for both the optimum SCC samples, as already mentioned in the XRD part, and the results are included in Figs. 11 and 12. The SEM analysis shows that the use of FA for part replacement of OPC decreases voids and increases CSH gel, which is also a product of hydration of OPC. The microstructure of concrete is improved by using FA for two reasons; one is due to filling of voids by FA, while the other is because of reduction or consumption of CH. The un-hydrated FA particles, crystals of C-S-H and ettringite are also visible in monograms (Fig. 11-12).

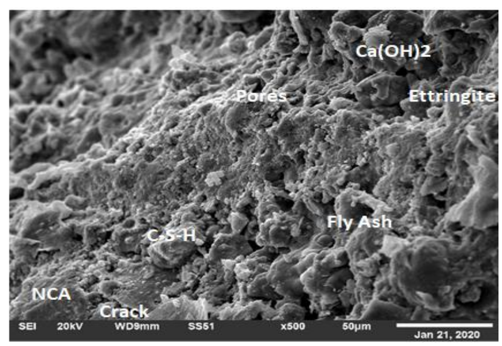

Fig. 11. SEM micrograph of FA25at 28 days

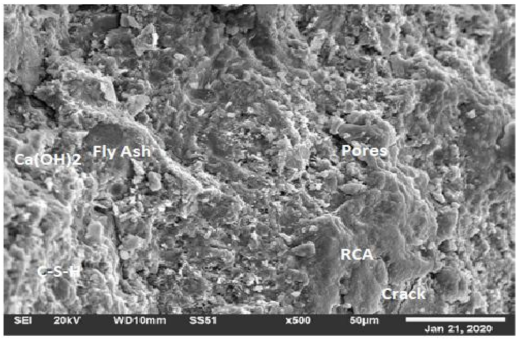

Fig. 12. SEM micrograph of FA25RCA25 at 28 days

Conclusions

It is concluded from this study that FA can be used beneficially for part replacement of OPC in SCC, the optimum level being 25%. The fresh properties of SCC also improve on replacement of OPC by FA. Further, RCA can be used successfully for part replacement of NCA in combination with the FA, the optimum replacement level being FA (25%) + RCA (25%).

The strength of SCCs made using NCA only is increased significantly at all ages, in comparison to the control mix at optimum replacement level of OPC by FA. At optimum replacement level of both the OPC and NCA in combination, the strength of SCCs is only marginally increased, in comparison to the control mix (FA00); however, it is decreased slightly in comparison to the referral concrete (FA25).

References

1. K. Ozawa, K. Maekawa, M. Kunishima, H. Okamura, Performance of concrete based on the durability design of concrete structures, Proc. Of the Second East Asia-Pacific Conference on Structural Engineering and Construction, 1989.
2. P.K. Mehta, Concrete Structure, Properties and Materials, Prentice Hall 1986; 367 -378.
3. K.H. Khayat, Z. Guizani, Use of viscosity-modifying admixture to enhance stability of fluid concrete, ACI Mater. J. 94 (4) (1997); 332-341.
4. Carbonation resistance and microstructural analysis of Low and High Volume Fly Ash Self Compacting Concrete containing Recycled Concrete Aggregates, Navdeep Singh M.E., S.P. Singh PhD. Construction and building material 127 (2016); 828-842.
5. M. Gesoglu, E. Guneyisi, E. Ozbay, Properties of self-compacting concrete made with binary, ternary and quaternary cementious blends of fly ash, blast furnace slag and silica fume, Constr. Build. Mater. 23 (2009); 1847-1854.
6. M.C. Rao, S. Bhattacharayya, S. Barai, Influence of field recycled coarse aggregate on properties of concrete, Mater. Struct. 44 (2011); 205-220.
7. M. Etxeberria, E.A. Vazquez, M. Barra, Influence of amount of recycled coarse aggregates and production progress on properties of recycled aggregate concrete, Cem. Concr. Res. 37 (2007); 735-742.