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Mechanical and Durability properties of Self Compacting Concrete with recycled concrete aggregates

C.Sumanth Reddy, K.V.Ratna Sai, Dr.P.Rathish Kumar

Abstract- Rapid industrialization and growing infrastructural demands have created an alarmingly high risk of exhaustion of natural resources for concrete production. The possibility of use of aggregates recovered from the disposed and demolished concrete wastes in production of new concrete serves both the purposes of sustainability and effective waste management, considering the current practice of landfill disposal. Self compacting concrete (SCC), with its unique ability to consolidate under its own weight, is the future of concrete industry with its added efficiency in terms of cost and time management. This work currently explores the possibility of using SCC produced using recycled concrete aggregates as new structural concrete. To accomplish that the mechanical and durability properties of the concrete are studied. Three concrete grades M20, M40 and M60 are prepared with recycled aggregate substitutions of 0%, 25%, 50% and 100% to test for compressive strength, acid resistance and water sorption. Results suggest that as much of 25% of aggregates can be replaced without any significant consequences on the concrete produced

Index Terms- Self Compacting Conncrete (SCC), Recycled concrete aggregates (RCA), Sustainability, Durability, Water Sorption, Commpressive strength, Structural applications.

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1 INTRODUCTION

Indian construction industry accounts to a total of 10-12 million tons of waste annually and over 50% of it being concrete and masonry waste [1]. On the other hand, housing sector projections indicate a shortage of aggregates to an extent of about 55,000 m3 along with the road development sector predicting a requirement of 750 million m3 [1]. In this scenario, disposing off potential aggregates in the form of C&D waste as landfills, with environmental and economic consequences is definitely worth a second look. Recycling of C&D waste for recovery of aggregates is definitely appreciated and pioneer approach dates back to 50's. Indian industry is also recently incorporating this thought with plans to use the aggregates in road construction, though still in an elementary stage.

Self Compacting concrete is extensively recognized by its unique ability to consolidate under its own weight. This innovation which revolutionized the construction industry in 90's by its remarkable efficiency in time and economy management is currently gaining popularity and being used in Indian market and promises to be the future of construction industry.

There is significant research previously available in respect to recycling of C&D waste but only quite a few directed at its use in structural concrete mostly because of the importance it holds. First attempt to incorporate recycled aggregates in structural concrete was given by RILEM but it included ordinary concrete. The integration of use of recycled aggregates in SCC and its use as structural concrete by studying the durability properties marks the uniqueness of this work.

- *C.Sumanth Reddy,* 3rd year Undergraduates, Dept of Civil Engineering, National Institute of Technology,Warangal, India, Ph : 91-9866906307, E-mail: sumanthreddy018@gmail.com
- *K.V.Ratna Sai*, 3rd year Undergraduates, Dept of Civil Engineering, National Institute of Technology,Warangal, India.
- *Dr.P.Rathish Kumar ,Associate Professor, Dept of Civil Engineering, National Institute of Technology, Warangal, India*

2 MATERIALS

2.1 Basic materials

Materials used in this work other than the recycled aggregates are Cement (OPC-53, Specific gravity 3.11 and conforming to IS 12269), Fine aggregate (River sand, Fineness modulus 2.6, Specific gravity , conforming to IS 383), Coarse aggregate (properties mentioned in Table 1), Fly ash was employed to function as binder (Class F, Specific gravity 2.05) and silica fume (conforming to IS 15388). Super Plasticizer used was an SNF (Sulphonated Napthalene Formaldehyde) condensate based high range water reducing admixture from Fosroc.Though some inconsistencies were observed whilst using SNF based plasticizer in terms of retention of fresh properties over very long durations, this work being presented was completed on the assumption that type of plasticizer does not significantly affect the hardened properties of consequent concrete.

2.2 Recycled aggregates

Recycled aggregates used in this work were obtained from an old concrete water tank (possibly 20-30 years old based on the recovered amount) and the aggregates were used in a raw and unprocessed stage. The aggregates were used in an air dry stage to evade any kind of inconsistencies due to initial moisture content.

The properties of aggregates were primarily ensured to satisfy all the requirements as per RILEM guidelines. The properties are given in Table 1

Since durability properties of concrete were of primary interest and it is known that composition of cement influences the consequent durability of concrete produced, certain important properties of cement are tested and mentioned in Table 2

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Table 1: Physical properties of coarse aggregates

Property	0% RCA	25% RCA	50% RCA	100% RCA
Bulk Density	1.46	1.44	1.39	1.28
Specific gravity	2.78	2.72	2.68	2.55
Angularity Index	10.31	11.35	12.09	13.99
Water absorption	1.00	2.10	3.52	5.68
Crushing Index	22.77	23.00	24.21	28.16

Table 2: Properties of cement

Property	Value	Limits (as per IS 12269)
Fineness	320 m^2/Kg	Min 225 m^2/Kg
Autoclave expansion	0.10%	Max 0.80%
Total loss on ignition (% by mass)	1.3%	4.0%
Total Chloride (% by mass)	0.011%	Max 0.1%

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3 MIX DESIGN

Nan Su method of mix design is considered as the base of desired mix throughout this work. However, small changes were adopted to the mix design based on aggregate packing as suggested by H.Bouwers. The void ratio of different proportions of coarse – fine aggregate were valued and the proportion which ensured minimum void ratio was employed. The results are presented in Fig 1.

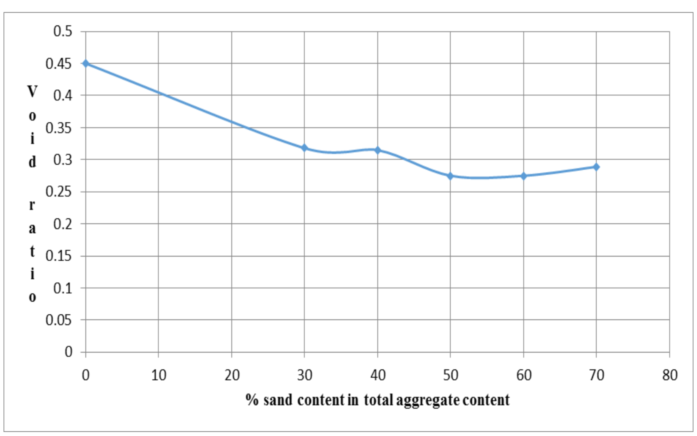

Fig 1: Void ratio variation v/s % sand content

Proportioning of other materials was made as per Nan Su method and trial mixes were prepared and tested for required fresh and compressive strength properties (with natural aggregate). The fresh properties observed for final confirmed mixes are presented in Table 3. The fresh properties were ensured to conform to EFNARC guidelines.

Table 3: Fresh properties of mixes

Mix	Slump (mm) (H flow)	T_{50} (s)	V funnel time (s)	V_5 time (s)	J ring (mm)
30MPa	680	1.58	8.28	9.26	1
50MPa	720	4	8.4	10	3
70MPa	700	3.4	8.0	10.6	4
EFNARC limitations	650-800	2-5	6-12	V+ (0-3)	10

3 grades of concrete were finalized for testing and are denoted by Mix-A (30MPa), Mix-B (50MPa) and Mix-C (70MPa). The mix designs employed for obtaining the desired properties are mentioned in Table 4.

Table 4: Mix design proportions of mixes

Mix	Cement	Fly ash	Silica fume	Sand	Coarse aggregate	Water	SP* % powder
Mix-A	1	0.543	---	3.482	2.928	0.725	1.37 %
Mix-B	1	0.335	---	2.216	1.896	0.468	1.67 %
Mix-C	1	0.166	0.111	1.662	1.519	0.357	2.41 %

Optimal percentage of aggregate as obtained from our aggregate tests (55%-45%) was used and slightly readjusted based on results obtained from trial mixes. The aggregate sizes in case of Mix – B and Mix – C are slightly varied from the common aggregate properties mentioned. The maximum sizes of aggregates in these cases are varied and readjusted as suggested by compressive packing model [7]. The maximum sizes are finalized to 16mm and 12.5mm respectively.

4 EXPERIMENTAL PROGRAM

The experimental part of this work was primarily focused on estimating the consequences of utilizing recycled concrete aggregates in SCC as a structural concrete. The most common factors influencing the performance of concrete were also to be analyzed in order to enhance them. The assumption made was that the concrete should be strong and durable to be used as structural concrete and testing was focused to this alone. To determine the compressive strength, concrete cubes of standard 15x15x15 cm were cast and cured respectively for 28, 56 and 90 days. To estimate the porosity and capillarity, viz to get an idea of crack potential, sorptivity test was conducted on concrete cube specimens by water proofing the side faces of cube and allowing only 5-10mm of the cube to be in contact with water.

5 RESULTS AND DISCUSSIONS

5.1 COMPRESSIVE STRENGTH

The results of compressive strength testing conducted after curing

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periods of 28, 56 and 90 days are depicted in Fig 2, 3 and 4. The overall performance also was above 92% and above the target strength aimed at, suggesting that as much as 100% replacement can be entertained from a strength requirement perspective. Thus we can conclude that concrete with any amount of replacement can be utilized if a structure is just needed to deliver in terms of strength.

The failure of RCA to attain compressive strength as that of natural aggregates may be ascertained to the use of aggregates in raw, unprocessed form since the investigation of failure plane suggest that it was the much weaker old mortar – new mortar inter transition zone (ITZ) that the plane traversed in most cases as shown in Fig 6. Thus we can conclude that use of recycled aggregates with any amount of processing will yield better results proving that results are consistent with previous work [8] [9].

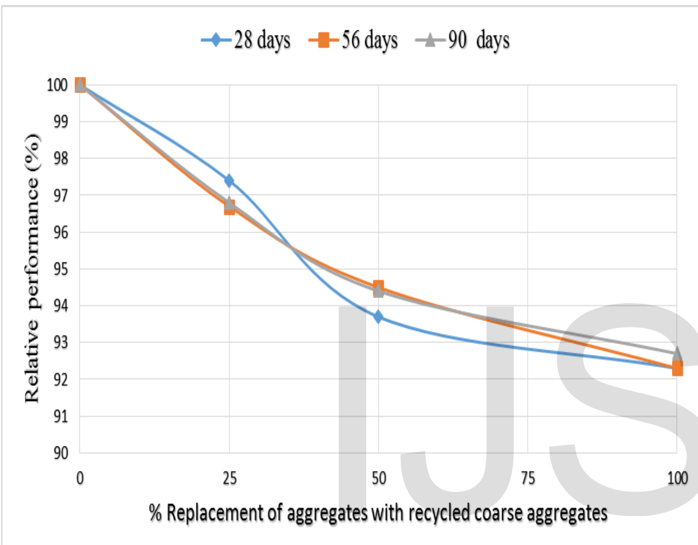

Fig 2: Relative strength performance in 30Mpa

The performance variation seems to be increasing with the grade of concrete suggesting that caution is essential when dealing with use of recycled aggregates in higher grade concretes.

Fly ash is considered responsible for the significant strength development after 28 days and since the performance of RCA based concretes is improving with age of curing, it can possibly be deduced that the performance of RCA concrete is enhance by the use of mineral admixtures, in this case, Fly ash.

The relative variation has increased as expected and conforming to previous conclusion but there has been a significant improvement in the overall performance incase of 70MPa concrete. The total % reduction in strength has reduced by a very great margin. This possibly could be considered as the influence of presence of silica fume in the mix. The density of concrete specimens in this case was higher than usually observed in case of 30MPa and 50MPa suggesting that it is might be a consequence of the micro filler effect [10] of silica fume.

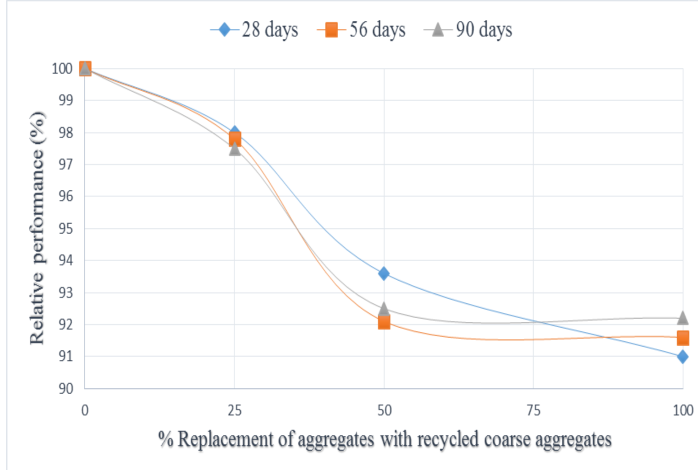

Fig 3: Relative strength performance in 50Mpa

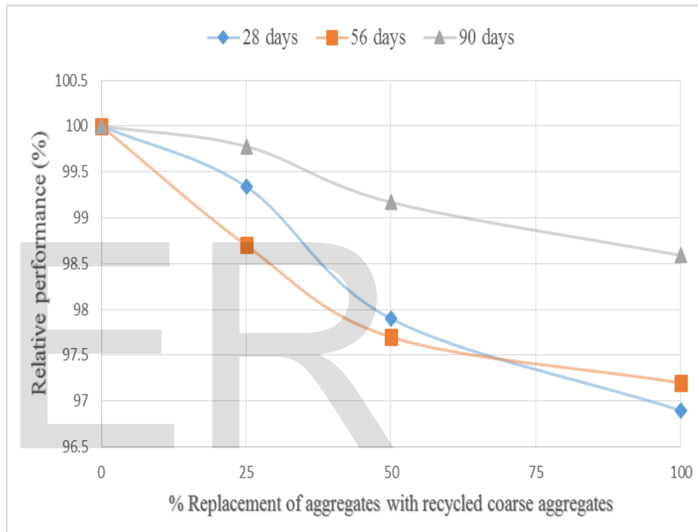

Fig 4: Relative strength performance in 70Mpa

Fig 5: Failure plane of concrete under compression

The conclusion that performance of RCA concretes is enhanced in the presence of mineral admixtures may possibly be because recycled aggregates have a higher water absorption capacity and hence in the initial mix itself, significant water is absorbed by recycled aggregates acting as water storage reservoirs and supplying the required moisture at a later stage to suffice for hydration of fly ash. However convincing this might be, it still needs to be verified and concluded.

5.2 WATER SORPTION

This test was employed with the hope of obtaining a holistic view of internal characteristics of concrete like its porosity and crack potential. The experimental setup was such that it ensured the only ingress of moisture into concrete specimen was through capillary action and measuring the increase in weight would represent the internal structure of concrete. Though several factors are believed to influence the internal character of concrete, this approach is known to give superficial information about the same and hence no sincere conclusions can be drawn from this result alone without further testing. The water sorption results after 28 days exposure are summarized in Table 5.

Table 5: Capillary water sorption results for all mixes

Mix	Age	0% RCA	25% RCA	50% RCA	100% RCA
A	7 days	100%	166.62%	190.51%	210.00%
	28 days	100%	187.35%	227.67%	229.49%
B	7 days	100%	143.79%	181.55%	204.30%
	28 days	100%	148.40%	201.94%	216.49%
C	7 days	100%	125.48%	168.33%	201.03%
	28 days	100%	126.10%	176.71%	214.21%

We can observe that the overall performance incapacity reduced as the grade of concrete increased. This might be because as the concrete grade increased, so is the denseness and compactness of inner concrete, thus suggesting a lower value of capillaries as observed. This is observed slightly in conformity to work by Khatib [11].

Performance in terms of percentage replacement of recycled aggregates suggests that the increase in recycled aggregate content leads to higher capillaries in the internal structure. Two reasons which could be possible for this are firstly, the weakened old mortar – new mortar ITZ which has led to formation of higher number of capillaries thus enabling higher water absorption and this might be significant because of use of unprocessed aggregates.

The other reason for this could be that since recycled aggregates created a moist atmosphere inside the concrete to enable reaction of fly ash, depriving themselves of their water absorption capacity initially, the availability of water through capillaries provided an external source of replenishment and hence water absorption of recycled aggregates may also be a cause for higher sorptivity value. Further analysis of these results considering the water absorption capacity and strength development due to late hydration and the relative performance and allowing a slack of about 25%, we could conclude that as much as 25% of natural aggregate could be replaced with RCA without detrimental effect however, the slack of 25% was based on an assumption. Further research is necessary to arrive at a final conclusion on this subject and also employment of effective testing procedure would ease the analysis.

6 CONCLUSIONS

- In terms of pure strength requirement alone, no stringent conditions are necessary in regard to the percentage replacement of recycled aggregates, thus making it easy in case of non-structural concretes.
- The processing of recycled aggregates play a crucial role in determining the strength and durability of consequent concrete and a direct relationship can be established between them.
- RCA concrete performance deteriorated with increase in grade of concrete suggesting that caution is to be exercised when using RCA for higher grade concretes.
- Enhancement of properties due to addition of mineral admixtures is revolutionary and can be used to optimize in order to get ideal mix at higher percentage replacement of RCA.
- Considering a cursory analysis of water sorption results, it can be concluded that it is safer to replace as much as 25% of aggregates with RCA without significant effects in developed concrete.

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