Performance of Self Compacting Concrete Replaced with Saturated Recycled Aggregate

Vivek K. Viswanath, Vilas Sankar K. P., Abhilasha P. S., M. Alosta

Abstract: The use of recycled aggregate in any concrete saves the virgin coarse and fine aggregates to create for the production of concrete. This concept will deliver an ecofriendly, reduced eviction of natural resources and produce a green concrete concept. Coarse aggregate consists of more than 60% of total volume in ordinary concrete but only 40% is required for Self Compacting Concrete (SCC) by weight. Demolished concrete wastes which are crushed and sieved to the size are used as substitute for natural coarse aggregates. In this paper natural coarse aggregate in self-compacting concrete is replaced with 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% & 100% recycled aggregates in mix design. Furthermore, a detailed study on workability and hardened properties of specially proportioned mixes are also carried out and satisfactory results are obtained. Thus the derived SCC can come up with reduced CO_2 emissions, economical and energy saving with all additional well-known advantages of fluid concrete.

Keywords: Recycled aggregate (RCA), Self-compacting concrete (SCC), Slump flow, Super plasticizer.

I. INTRODUCTION

Self-compacting concrete is a somewhat newly invented concrete that will have the following advantages over normally vibrated concrete. It will flow by its own weight without any compaction and completely fills the mould even in congested reinforcement joints. Its high fluidity and segregation resistance offers a very high homogeneity, less voids, superior level finishing and durability. One of the primary challenges encountered by civil engineering industry is to accomplishing the work ecofriendly aspects. In this recent era, the construction industry has grown tremendously and produce a huge amount of wastes. These wastes compose of considerably large portion of total solid waste production in the globe. Most of these are used as land fill. As a result of the lack of dumping sites and increased cost of transportation, most of the countries are encountering problems in managing and disposing of such wastes. It has been reported that the international concrete industry consumes nearly a 10 billion tonnes of coarse aggregate and produces past 1 billion tonnes of construction and demolition waste each year [1]. All these aspects promote the beneficial reuse of the produced wastes for efficient utilization and save environment. So, the utilization of demolished concrete waste and recycled aggregate crushed into the size of coarse aggregate can yield significant environmental impact [2]. Application of RCA in self-compacting concrete with varying percentages of RCA from 10% up to 100% is examined. Fresh properties are studied by conducting tests such as slump flow test, T_{500} test, V-funnel test, L-box test in laboratory according to European guidelines (EFNARC)[6]. Hardened properties of all the replaced mixes are studied and compared with control SCC specimen.

II. SCOPE OF THE WORK

Characteristic strength of concrete is 35 N/mm^2 designated as M$_{35}$ grade is designed. Cement is replaced with 30% of fly ash in all the mixes.

III. REVIEW CRITERIA

A. Cement

Ordinary Portland Cement of 53grade is adopted in this work. It is dark grey in colour and conforms to IS 12269-2013. The physical properties of the cement are presented in Table I.

B. Fly Ash

It is a material which solidifies while suspended in exhaust gases and is collected by electrostatic precipitator. They are commonly spherical in shape and range from 0.5 µm to 300 µm. Due to the unavailability of class C fly ash, class F fly ash is used. It is attained by burning of harder older, anthracite & bituminous coal. It is pozzolanic in nature and consist of less than 0.7 % lime. The properties are shown in Table I.

Table- I: Properties of Binder Materials

Properties	Cement	Fly Ash
Fineness	5%	19%
Specific gravity	3.14	2.62
Consistency	34%	29%
Initial setting time	1 hr	1.15 hrs
Final setting time	4hrs	5 hrs

C. Fine aggregate

Due to the unavailability of natural river sand, locally available rock sand conforming to grading zone II is used.

D. Coarse aggregate

Waste concrete cubes available in the material testing

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laboratory are crushed and sieved to the size of 10-12.5 mm as coarse aggregate. The properties of aggregates are shown in Table II.

E. Recycled aggregate

Waste concrete cubes available in the material testing laboratory are crushed and sieved to the size of 10-12.5 mm and are used as recycled aggregate. It is saturated and further surface-dried to compensate the strength reduction due to the higher water absorption of RCA. Fig. 1 shows the micro structure of the recycled aggregate.
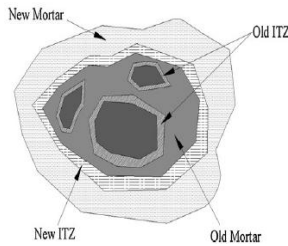

Fig. 1. Structure of recycled aggregate

Table- II: Properties of aggregates

Properties	FA	CA	RCA
Bulk density compact (kg/m^3)	1756.7	1513.5	1460
Fineness modulus	2.82	7.07	8.68
Void ratio(compact)	0.407	0.81	0.80
Specific gravity	2.5	2.82	2.61
Water absorption		0.4%	5%
Aggregate crushing value %	---	23.85	26.33

F. Super Plasticizer

High performance super plasticizer based on Poly Carboxylic Ether (PCE) having trade name Master Glenium 8233 is used as chemical admixture. It is free from chloride ion of low alkali content and is compactable with all types of cements. It is blended with Viscosity Modifying Agent (VMA) and belongs to ASTM C494 type F and IS 2645-2003. After trial and error optimum percentage is adopted as 0.9%. The chemical properties of SP is exhibited in Table III.

Table- III: Chemical properties of Super Plasticizer

Aspect	Light brown liquid
Relative density	1.08±0.01 @ 25 ^{0}c
pH	>= 6
Chloride ion	0.2%

G. Water

Ordinary fresh tap water is used in the entire work.

IV. MIX DESIGN

Mix design is carried out to have a mix of M$_{35}$ grade and a target mean strength of 43.25MPa and water binder ratio is fixed as 0.33. A microsoft spread sheet is specially prepared for the mix design with reference to Krishnamurthy et al. 2012 [4]. Steps adopted are as follows;

- Assume air content by percentage of concrete volume.
- Input coarse aggregate blending by percentage weight of total CA
- Input percentage of CA in dry state to calculate the CA volume in the concrete volume.
- Adjust percentage of FA volume in mortar volume.
- Obtain required paste volume. Adopt suitable water binder ratio by weight.
- Input percentages of fly ash by weight of cementitious material.
- Input the dosage of SP cum retarder by percentage weight of binder.
- Adjust the binder (cementitious material) content by weight to obtain the required paste.

Table- IV: Main input parameters

Dry density of CA (kg/cum)	1513.5
% of CA in dry state	50%
Dry density of sand (kg/cum)	1756.7
% of sand in mortar	43%
% of fly ash(% Wt of binder)	30%
% of RCA(% Wt of CA)	0-100%
Water binder ratio	0.33
Binder content	540
SP dosage (% Wt of binder)	0.9%

(CA- coarse aggregate, RCA- recycled coarse aggregate, SP- super plasticizer)

Table-V: Output parameters

	Lit/cum
CA Volume	268.35106
Mortar Volume	731.64894
FA Volume	314.60904
Paste Volume	394.7
Cement Volume	120
Volume of Water	178.2
Volume of Fly Ash	72
Volume of SP	4.5
Volume of VMA	0

Table- VI: Design mix obtained

C	FLA	FA	CA	Water
1	0.407	1.979	1.904	----
397.37	162	786.5	756.7	184.5

By trial and error method, the optimum dosage of superplasticizer is found out as 0.9 % with water powder ratio 0.33. The Table IV, V and VI shows the input parameters, output parameters and the final mix proportions.

V. EXPERIMENTAL PROGRAM

A. Fresh Concrete Properties

1. Slump flow test

Slump flow test combined with T_{500} time investigation helps to estimate the flow rate plus the flow-ability of self-consolidated concrete along with intrusion unavailability. The standard values of slump test results are depicted in EN 12350-2. The experiment set up is shown in Fig. 2. The end result of the experiment is a verification on the filling ability of self-compacting concrete. In order to start the above test, the steel base place is cleaned and wiped with oil, and make sure that it is free from every impurities and dust. Now hold the slump cone in inverted position, i.e. 100 mm top circle should be at the bottom of the cleaned base plate. Hold the slump cone in stable position by making it pure vertical guaranteeing that the flowing concrete will not escape through the bottom circle. Pour the flowing concrete from the top until it fill the cone without any compaction and disturbance. the excess concrete at the top of the cone can be struck off. Don't allow the filled cone to stand more than 30 secs meanwhile clear out any spillage of concrete near the base plate and confirm that there is no excess water spillage from the bottom of the cone. Drive up the cone vertically in a single movement and at the same time launch the stopwatch countdown instantly during the lifting up of the cone. Record the time taken by the flowing concrete to reach 500 mm circle diameter drawn point with an accuracy of 0.1 secs. Further, T_{500} time gives an indication of the speed of the flow and by that viscosity of the moving concrete also be monitored. Additionally, it studies the maximum flow diameter of the sample.

Fig. 2. Slump flow test and apparatus

2. V-funnel test

The viscosity and the filling ability of SCC can be investigated by V Funnel test shown in Fig. 3. Before performing the test, the interior surface of the funnel set up and its gate opening must be washed, dried and oiled properly. Later shut the gates of the funnel setup and introduce the concrete specimen into the funnel by complete avoidance external disturbance or any rodding compaction. The top excess level of concrete specimen inside the funnel can be levelled off using a trowel. Place a container to collect the flowing concrete which reach the bottom of the funnel after holding the specimen for (10 ± 2) s inside the funnel. Following that, open the gate and record the time t_v, which is the V-funnel flow time.
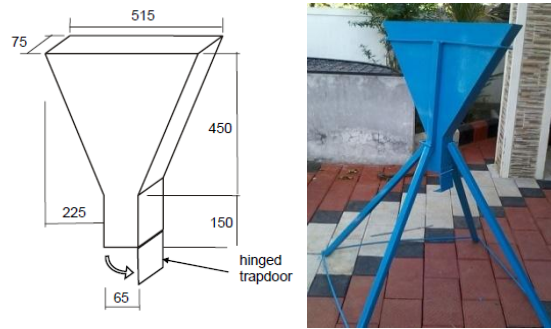

Fig. 3. V-Funnel apparatus

3. L-Box test

The intention of L-Box test is to observe the passing ability of SCC. It demonstrates the ability of the specimen to flow through narrow gap of reinforcement bars inside the structural elements. In this study, three bar test variation has been done since it gives more realistic site situation than two bar variation test inside the L-box. Place the L-box apparatus on a level surface and close the gate placed at the junction of horizontal and vertical chambers of the apparatus. Transfer the specimen concrete to the vertical section of the L-Box by allowing the specimen to stay for (60 ± 10) secs. Observe any clogging or segregation during the flow inside the chambers after the gate opening. At the end of flow movement, checkout the vertical distance from the top layer of concrete sample to the top level of the horizontal chamber section as depicted in Fig. 4 and Fig. 6. This height verification can be done in three equally apart points through the width of the L-box horizontal chamber and calculate the mean depth of the sample H_2 mm. The same method can be followed to calculate the H_1 mm at the opposite side of the L box horizontal chamber.
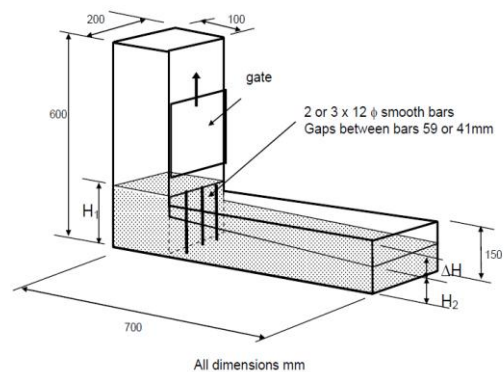

Fig. 4. L-Box apparatus

The fresh properties of the different trial and error mix design are presented in Table VII.

B. Hardened Concrete Properties

Cubes, cylinders and prisms are casted to study the strength property of each replaced mixes. All the specimens are cured by immersing in water. Cubes and cylinders are tested after 7,14 & 28 days of water curing in universal testing machine. The samples are shown in Fig. 5.

Fig. 5. Moulds and casted specimen

Table-VII: Fresh Properties of design mixes

Designation	Slump flow diameter (mm)	V- funnel time(s)	$T_{500 (s)}$	Passability (H_1/H_2)
R0	730	15	3	0.98
R10	720	18	5	0.97
R20	716	19.5	6.5	0.95
R30	712	21	7	0.94
R40	710.5	21.8	8	0.936
R50	708	22.4	9.5	0.92
R60	705.4	23.1	10.2	0.9
R70	700	24	10.7	0.89
R80	694	25.1	11	0.87
R90	690	26	11.9	0.85
R100	685	26.6	12.6	0.84

VI. RESULTS AND DISCUSSIONS

A. Fresh concrete properties

1. Slump flow diameter

Slump flow diameter variation are presented in Fig. 7. It shows an inverse relationship with percentage of RCA. It is as the result of the adhered mortar and higher water absorption of RCA. Initial stages of replacement show percentage variation are about 1.36% with R_0 and the variation increases as the replacement ratio increases. Finally, it reaches about 6.16% for 100% replacement. Angular shape and rough nature of RCA reduces the flow.

T_{500} time also shows the same behaviour as explained.

2. V-Funnel time

The variation of V-funnel time with percentage increase of RCA is shown in Fig. 8. As the percentage of replacement increases V-funnel time increases. V-funnel time is an indication of viscosity of the mix. So, the results show that increase in the RCA makes the mix more viscous. This is because of the same reason which reduces flow diameter. The roughness of RCA causes resistance to flow through v-funnel. Viscosity can be reduced by higher dosage of super plasticizer. According to EFNARC guidelines all the mixes belongs to VF-2.

3. Passability

Passing ability is the rate of height from concrete by the horizontal section from the box. Increased percentages show

an inverse relationship with passability. It goes on decreasing from 0.98 to 0.84 as the percentage of replacement increases to 100%. This indicates that as the RCA content increases flow through congested reinforcement delays. The variations are shown in Fig. 9. All the replaced mixes show reduced workability properties in all aspects. Workability properties can be improved by increasing dosage of super plasticizer. It should be checked that any kind of segregation or bleeding is happening at any time.
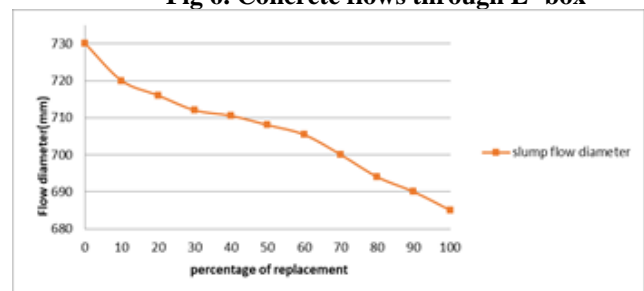

Fig 6. Concrete flows through L- box
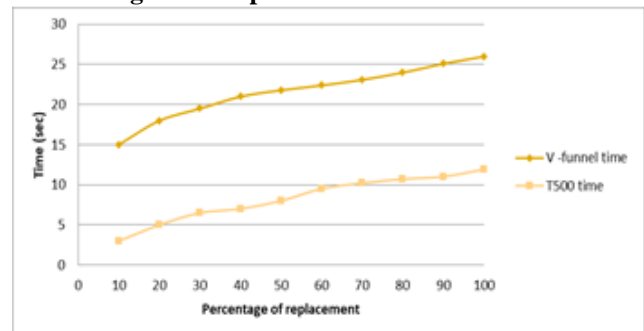

Fig. 7. Slump flow diameter variations

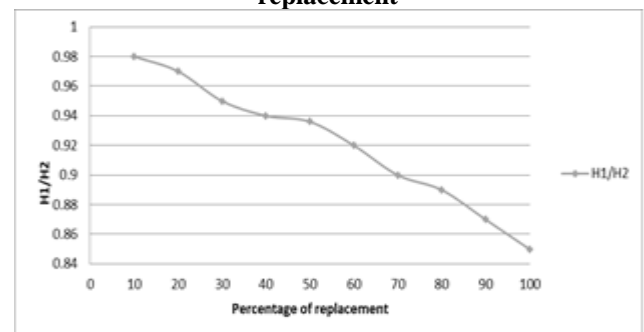**Fig. 8. Variation of V-funnel time and T_{500} time with % of replacement**

Fig. 9. Variation of the ratio H_1/H_2 with % of replacement

Table- VIII: Typical range of values of workability

No:	Method	Unit	Typical range of values	
			minimum	Maximum
1	Slump flow test	mm	550	850
2	T_{500} slump flow	mm	2	10
3	V –funnel time	sec	9	25
4	L - box test	H_2/H_1	0.8	1

B. Hardened concrete properties

1. Compressive strength

All the mixes are designed to get target strength of 43.25 MPa. Characteristic strength of the mix is 35 MPa and all the mixes achieved this value. As the percentage of RCA increases, 28-day compressive strength of mixes show declining nature. The 7- and 14-days compressive strength shows that the replaced mixes attain early strength than normal mix. This is because of the adhered cement mortar on the RCA which accelerates the hydration process. The difference in compressive strength during the replacements of RCA is depicted graphically in Fig. 10.
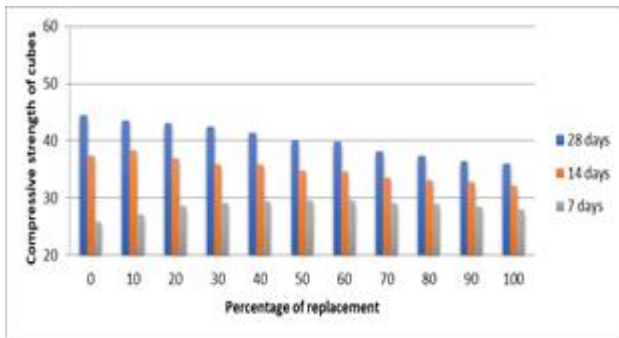

Fig. 10. Compressive strength v/s % of replacement

2. Split tensile strength

By comparing the results of 7th day strength, it is obvious that the tensile strength increases gradually as the percentage of replacement increases. This is because of the early strength gain property of RCA. The same trend can be visible in the 14 days strength results but rate of increase with percentage of replacement is less compared to 7th day results. Comparing 7th day and 28th day results of each mix about 30 % strength is only achieved on 7-day curing for control mix. But in the case of R100 mix about 76 % strength is attained in 7th day. This percentage growth of strength shows an increase for all mixes, as the % of replacement increases. The split tensile strength variation trends are shown in Fig. 11.
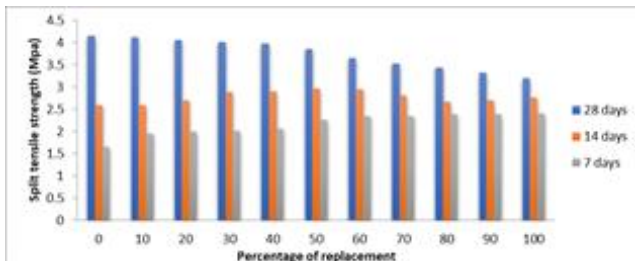

Fig. 11. Split tensile strength v/s percentage of replacement

3. Flexural strength

The flexural strength also shows the same trend as the other hardened properties. It is very evident that the adhered mortar on RCA not only reduces workability but also reduces hardened concrete properties too. The flexural strength variations are shown in Fig. 12. The hardened properties of the SCC are combined in Table IX.
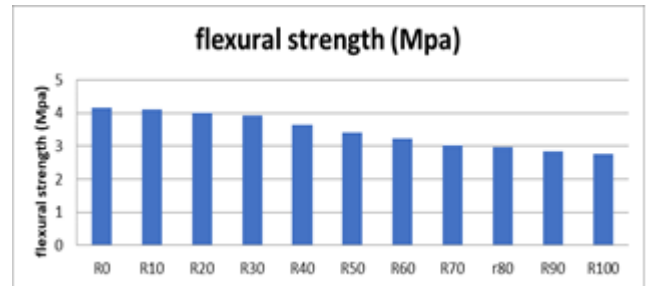

Fig. 12. Variation of flexural strength (MPa)

Table- IX: Compressive, tensile and flexural strength results

Days of curing	7 days		14 days		28 days		
	Cube	Cylinder	Cube	Cylinder	Cube	Cylinder	Prism
R0	25.77	1.65	37.3	2.59	44.49	4.15	4.16
R10	28.44	1.95	38.66	2.59	43.5	4.12	4.11
R20	28.71	1.99	36.9	2.69	43.01	4.05	4.01
R30	29.33	2.01	35.9	2.89	42.4	4.01	3.92
R40	29.35	2.05	35.87	3	41.38	3.98	3.65
R50	29.5	2.26	34.69	2.96	40.21	3.85	3.42
R60	29.53	2.33	34.83	2.95	39.8	3.65	3.24
R70	29.8	2.34	33.56	2.85	38.2	3.53	3.03
R80	30	2.38	33.05	2.55	37.35	3.43	2.98
R90	29.9	2.39	32.8	2.62	36.5	3.32	2.85
R100	29.95	2.4	32.1	2.56	36.01	3.19	2.76

VII. CONCLUSION

- Recycled aggregates can be considered as a good substitute to natural aggregates even in self-compacting concrete.
- A successful mix design for SCC with recycled aggregate was developed confirming to EFRNARC specifications by trial and error method.
- An increase of 19.70% slump variation was observed with 100% recycled aggregate replacement when compared with minimum slump requirement based on standard guidelines.
- The V-funnel test which is an indication towards viscosity necessity in SCC falls well in the range of 9-25 sec specified by the EFNARC guidelines for all percentage replacements of recycled aggregates.
- T_{500} results arrived well in the field of standard guideline proving that recycled aggregate is a substitute for natural aggregate in SCC.
- In every sets of replacement of recycled aggregate, the recommended passing ratio value of 0.80 were passed.
- The hardened properties results of every recycled aggregate SCC mixes pop up within the acceptable limits prescribed in the standard code.

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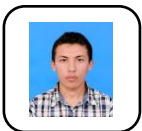
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