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Self Compacting Concrete By Partial Replacement Of Cement With Fly Ash & Coarse Aggregate With Recycled Coarse Aggregate

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Abstract - **Concrete is one of the oldest and most common construction materials in the world mainly due to its availability, low cost and durability. Due to advancing technology the most revolutionary development in concrete technology was self-compacting concrete. It was first developed in Japan in the year 1980. The modern application of SCC is focused on high workability, high performance, high strength, long durability, uniform surface structure and fast construction. SCC is the high workable concrete, will flow like water, so that placing of concrete is easy than the normal concrete. The best architecture can be made by SCC. In recent years demolition of structures has led to increase in construction waste. So, in this project the properties of SCC with partial replacement of cement with fly ash and Coarse aggregate with recycled (demolished) aggregate results are compared with the normal SCC. Cement is partially replaced with Fly ash and NCA (natural coarse aggregate) is partially replaced with RCA (recycled coarse aggregate) by an amount of 20%, 25%, 30% and 35%. The effect of RCA on the properties of SCC in green state (i.e. slump flow test, T50 slump flow, L-box test, J-ring test & U-box test) and also properties of concrete in harden state (i.e, compressive strength, flexural strength and split tensile strength) are studied. The mix design was carried out for M30 grade of concrete; here fly ash (mineral admixture) is added to improve the quality & durability and the new generation super plasticizers like Polycarboxylated Ether and Master Glenium-51 are particularly used as the chemical admixtures.**

keywords - **SCC, RCA, Fly ash, Mix design, slump flow, J-ring, L-box, U-box, Compressive, Split tensile, & Flexural strength etc**

I. INTRODUCTION

Self - compacting concrete (SCC) is a fluid mixture, which is suitable for placing in difficult conditions and also in congested reinforcement, without vibration. In principle, a self - compacting or self - consolidating concrete must:

- Have a fluidity that allows self - compaction without external energy,
- Remain homogeneous in a form during and after the placing process and
- Flow easily through reinforcement.

It can also reduce viscosity for a given consistency; especially in the case of SCC made with relatively low Water – cement ratio. Reducing the free water can decrease viscosity enhancing admixtures VEA dosage necessary for stability. High binder content typically includes substitutions of cement with 20 to 40% fly ash. The cost of SCC can be reduced through the selection of adequate concrete - making materials and admixture constituents, including partial substitutions of cement and supplementary Cementatious materials by readily available fillers.

Compared with conventional concrete of similar mechanical properties, the material cost of SCC is more due to relatively high demand of cementation materials and chemical admixtures including High Range Water Reducing Admixtures (HRWRA) and Viscosity Enhancing Admixtures (VEA). Typically, the content of cementation material in SCC can vary from 450-525 kg/m$_3$.

II. MATERIALS FOR SELF COMPACTING CONCRETE

Cement

The cement used in this project was OPC of 53grade with brand NAGARJUNA. The cement is fresh and is of uniform color and consistency. It is free from lumps and foreign matters.

Fine aggregate

The F.A used in natural sand obtained from the river Godavari conforming to grading Zone-II of table 4.3 of IS: 383-1970. The sand is free from clay, silt and organic impurities. The aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity and bulk modulus accordance with IS: 2386-1963.

Natural Coarse aggregate

The well graded coarse aggregate is chosen for SCC, and smaller in size than that used for conventional concrete. Gradation is an important factor in choosing aggregate especially in typical uses of SCC where reinforcement may be highly congested or the form work has small dimensions. The maximum size of coarse aggregate used in SCC ranges from 10 mm to 16 mm.

Recycled coarse aggregate

Recycled coarse aggregate (RCA) is used as a replacement for natural aggregate to reduce the usage of natural aggregate. According to infrastructures demand, however the use of RCA as a replacement for natural aggregate is beneficial to the environment as it decreases the environmental pollution and constructional waste. RCA has a higher absorption rate than normal aggregate, needs much more water for mixing, and has a high slump loss rate depending on the elapsed time. These characteristics of RCA account for its low workability, strength, and durability. To improve the performance of RCA and to reduce its absorption chemical admixtures are added in concrete mix.

Mineral Admixture (Fly Ash)

Fly ash is one of the most extensively used by-product materials in the construction field resembling Portland cement. It is an inorganic non-combustible, finely divided residue collected or precipitated from the exhaust gases of any industrial furnace. Materials such as fly ash, blast furnace slag, etc, are commonly used as filler for producing SCC. An extremely important aspect of the durability of concrete is its permeability.

Chemical Admixture (Super Plasticizer)

In this project to produce viscosity agent type Self-Compacting Concrete, the chemical admixtures are Polycarboxylated Ether and Master Glenium-51 are using.

Master Glenium-51: (BASF)

Dosage: Master Glenium-51 is suggested to be used as 0.5-1.5 kg for 100 kg binder (cement-micro silica-fly ash). The dosage to be used must be determined before and by laboratory experiments.

Polycarboxilated ether: (Gujarat Polysol Chemicals Pvt. Ltd)

Dosage: Poly carboxilated ether is suggested to be used as 0.2 to 1.0 kilograms for 100 kg cementation material for most concrete mixes using typical concrete ingredients. The admixture should be mix with water and added to cement aggregate mixture.

Water: In this project normal tap water available in Srinivasa institute of engineering and technology is used to prepare SCC

III. Mix Design For Trail-I

A. Design stipulations data:

1. Grade designation : M_{30}
2. Type of cement : OPC 53grade
3. Maximum nominal size of aggregate : 12.5mm
4. Coarse aggregate blending : 70:30
5. Specific gravity of 12.5mm of NCA&RCA : 2.71
6. Specific gravity of F.A : 2.55
7. Cement blending : 80:20
8. Specific gravity of cement : 3.15
9. Specific gravity of fly ash : 2.2
10. Maximum water-cement ratio : 0.4
11. Workability : 650mm flow
12. Percentage of air content : 2%
13. Chemical admixtures : Master Glenium-51 & Polycarboxilated Ether
14. Specific gravity of chemicals : 1.11

B. Target strength of mix proportioning:

$$f`_{CK} = f_{CK} + 1.65\ (S)$$

Take standard deviation, S = 5 N/mm_2 (from table-1of IS: 10262-2009)

Therefore, target strength = 30 + 1.65 × (5) = 38.25N/mm_2.

C. Maximum water cement ratio: 0.40

D. Selection of water content:

From table-2 of IS:10262-2009 we have a given value for maximum water content per cubic meter of concrete for nominal maximum size of aggregates such as 10 and 20 is 186 litre. So by interpolation method we have calculated for 12.5mm. Maximum water content for 12.5mm aggregate = 202.5liter.

E. Calculation of cement content:

Water-cement ratio = 0.4

Cement content = (0.4/202.5)

= 506.25 kg/m_3

F. Proportion of volume of C.A and F.A content:

From table-3 of IS: 10262-2009 we have a given value for volume of C.A per unit volume of total aggregate for different zones of F.A. In this project the F.A utilized is of zone-II, from this table we have values for aggregate size 10 and 20, so by interpolation method we have calculated the value for 12.5mm.

Volume of C.A corresponding to 12.5mm size aggregate and F.A of zone-II = 0.5

Volume of C.A = 0.5

Volume of F.A = 1 - 0.5

= 0.5

G. Mix calculations: The mix calculations per unit volume of concrete shall be as follows

a) Volume of concrete = $1m_3$

b) Volume of cement = $\frac{\textit{Mass of cement}}{\textit{specific gravity of cement}} \times \frac{1}{1000}$ = 0.161 m_3

c) Volume of water = $\frac{\textit{Mass of water}}{\textit{specific gravity of water}} \times \frac{1}{1000}$ = $0.202m_3$

d) In this project the volume of chemical admixture considered is 0.47kgs for 100kgs of cement. The cement content obtained was 506.25kgs so the chemical admixture content obtained was 2.37kgs which was calculated by using cross-multiplication method.

e) Volume of chemical admixture =2[Mass of Admixture/specific gravity of admixture] x 1/1000 = $0.043m_3$

f) Volume of all aggregates = [a - (b + c + d)] = [1 - (0.161 + 0.202 + 0.043)]

= 0.601 m^3

g) Mass of C.A = Volume of all aggregates x volume of C.A x S.G of C.A x 1000
= 0.601 x 0.50 x 2.71 x 1000
= 814.35 kg/m^3

h) Mass of F.A = Volume of all aggregates x volume of F.A x S.G of F.A x 1000
= 0.601 x 0.50 x 2.55 x 1000
= 766.3 kg/m^3

Mix proportions for Trail-1:

Cement = 506.25 kg/m^3
Fine aggregate = 766.30 kg/m^3
Coarse aggregate = 814.35 kg/m^3
Water = 202.50 kg/m^3
Chemical admixture = 2.37 kg/m^3
Water-cement ratio = 0.40

Similarly, the mix design was calculated for the remaining trails. The amount of F.A, water content, chemical admixture and water-cement ratios are same as trail-1.

Table-1: Trail values

Trails	Blending ratios		Specific gravity of C.A	Amount of C.A (kg/m^3)
	Cement	C.A		
Trail-1	80:20	80:20	2.71	814.35
Trail-2	75:25	75:25	2.75	826.37
Trail-3	70:30	70:30	2.67	802.30
Trail-4	65:35	65:35	2.77	832.28

Table-2: Mix proportions for nominal and replaced M_{30} grade

Trails	Cement (kg/m^3)	Fly ash (kg/m^3)	F.A (kg/m^3)	C.A (kg/m^3)		Water	W/C	Chemicals (kg/m^3)	
				N.C.A	R.C.A			GE	PCE
Nominal	506.25	0	766.30	817.36	0	202.5	0.4	0.47	0.2
Trail-1	405.00	101.25	706.30	651.48	162.87	202.5	0.4	0.47	0.2
Trail-2	379.66	126.55	706.30	619.78	206.59	202.5	0.4	0.47	0.2
Trail-3	354.35	151.87	706.30	561.61	240.69	202.5	0.4	0.47	0.2
Trail-4	329.04	177.18	706.30	541.05	291.33	202.5	0.4	0.47	0.2

IV. Tests Conducted On SCC At Plastic Stage

Table-3: List of test methods & Properties of fresh SCC

Test method	Property of fresh SCC
Slump flow by Abram's cone	Filling ability
T_{50} slump flow	Filling ability
J-ring	Passing ability
L-box	Passing ability
U-box	Passing ability

Method	Property	Unit	Typical range of values	
			Minimum	Maximum
Slump-flow	Filling ability	mm	600	800
T_{50} slump flow	Filling ability	Sec	2	5
J-ring	Passing ability	mm	0	10
L-box	Passing ability	no units	0.8	1.0
U-box	Passing ability	mm	0	30

Table-4: Acceptance criteria for Self-compacting Concrete

SLUMP FLOW AND T_{50}:

About 6 liter of concrete is needed to perform the test, sampled normally. Moisten the base plate and inside of slump cone, place base plate on level stable ground and the slump cone centrally on the base plate and hold down firmly. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel. Remove any surplus concrete from around the base of the cone. Raise the cone vertically and allow the concrete to flow out freely. Simultaneously, start the stopwatch and record the time taken for the concrete to reach the 500mm spread circle. (This is the T50 time). Measure the final diameter of the concrete in two perpendicular directions. Calculate the average of the two measured diameters. (This is the slump flow in mm).



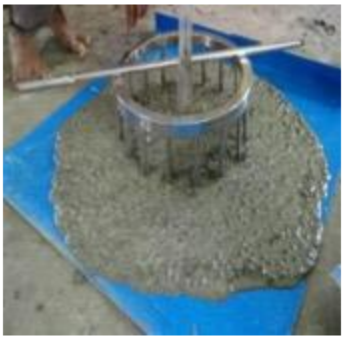
L - BOX TEST:

About 14 liter of concrete is needed to perform the test, sampled normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the vertical section of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the horizontal section. When the concrete stops flowing, the distances H_1 and $H_2$are measured. Calculate H_2/H_1, the blocking ratio. The whole test has to be performed within 5 minutes.


J-RING TEST:

About 6 liter of concrete is needed to perform the test, sampled normally. Moisten the base plate and inside of slump cone. Place base-plate on level stable ground. Place the J-ring centrally on the base plate and the slump-cone centrally inside it and hold down firmly. Fill the cone with the scoop. Do not tamp, simply strike off the concrete level with the top of the cone with the trowel. Remove any surplus concrete from around the base of the cone. Raise the cone vertically. and allow the concrete to flow through the ring. Lay the tamping rod with the flat side on the top side of the J-ring and measure the relative height differences between the lower edge of the straight rod and the concrete surface at the central position (Δh_0) and at the four positions outside the J-ring, two (Δhx_1, Δhx_2) in the x-direction and the other two (Δhy_1, Δhy_2) in the y-direction. Measure the largest diameter of the flow spread, d_{max}, and the one perpendicular to it, d_{perp}, using the ruler (reading to nearest 5 mm). Care should be taken to prevent the ruler from bending. Calculate the average of the difference in height at four locations (in mm). Clean the base plate and the cone after testing.





U-BOX TEST

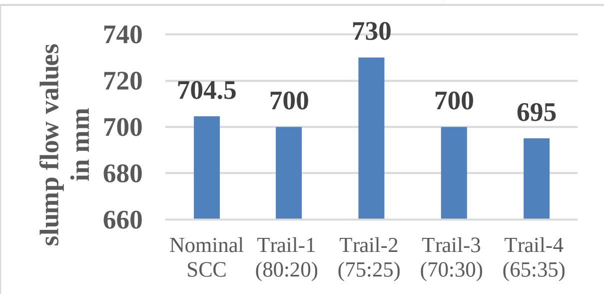
About 20 liters of concrete is needed to perform the test normally. Set the apparatus level on firm ground, ensure that the sliding gate can open freely and then close it. Moisten the inside surfaces of the apparatus, remove any surplus water. Fill the one compartment of the apparatus with the concrete sample. Leave it to stand for 1 minute. Lift the sliding gate and allow the concrete to flow out into the other compartment. After the concrete has come to rest, measure the height of the concrete in the compartment that has been filled (H_1). Measure also the height in the other compartment (H_2). Calculate H_1 - H_2, the filling height. The whole test should be performed within 5 minutes.

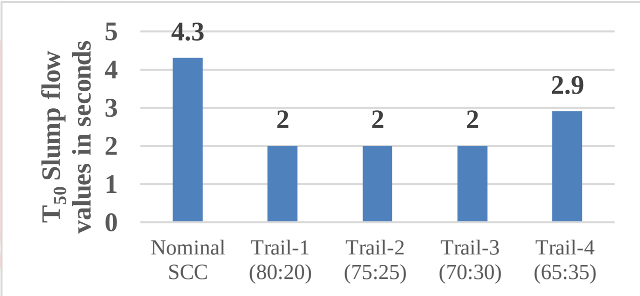


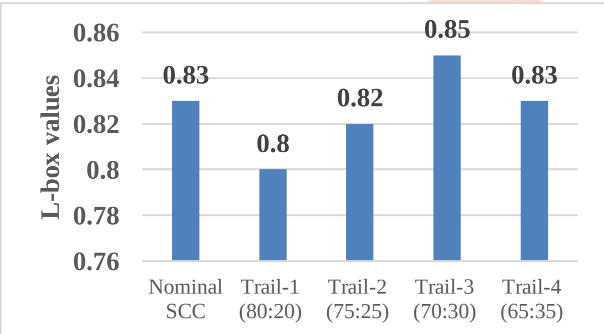
Table-5: Test Results

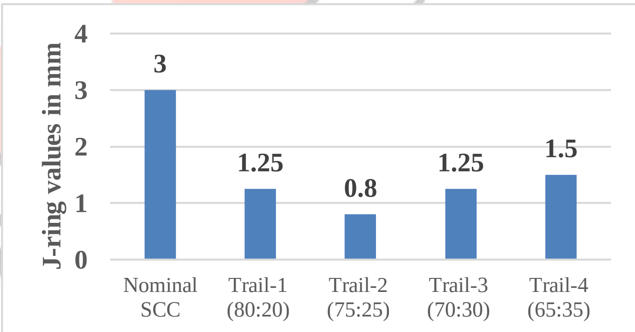
Test name	Nominal SCC	Trail-1 (80:20)	Trail-2 (75:25)	Trail-3 (70:30)	Trail-4 (65:35)
Slump flow (mm)	704.5	700	730	700	695
T_{50} slump flow (seconds)	4.3	2	2	2	2.9
L-box (no units)	0.83	0.8	0.82	0.85	0.83
J-ring (mm)	3	1.25	0.8	1.25	1.5
U-box (mm)	2	5	6	0	4

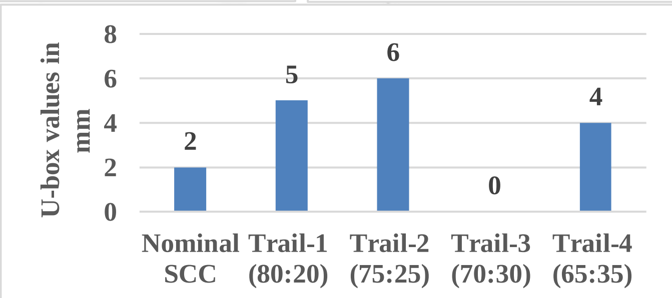
GRAPHICAL REPRESENTATION OF TEST RESULTS OF FRESH SCC:











V. TESTS CONDUCTED ON SCC AT HARDENED STATE

Compressive strength of concrete:

Place the 150mm cube in the compression-testing machine. The green button is pressed to start the electric motor. When the load is applied gradually, the piston is lifted up along with the lower plate and thus the specimen application of the load should be 300 KN per minute and can be controlled by load rate control knob. Ultimate load is noted for each specimen. The release valve is operated and the piston is allowed to go down. The values are tabulated and calculations are done.



Table-6: Compressive strength values of all mixes of M30 SCC

Trails	**Compressive strength in N/mm^2**		
	7 days	**14 days**	**28 days**
Nominal mix	26.25	40.68	43.33
Trail-1	27.26	34.75	40.94
Trail-2	21.38	32.38	38.8
Trail-3	19.15	25.79	31.59
Trail-4	19.54	18.71	22.72

Split tensile strength of concrete:

A concrete cylinder, size of diameter 150mm and 300mm height is subjected to the action of the compressive force along two opposite edges, by applying the force in this manner. The cylinder is subjected to compression near the loaded region and the length of the cylinder is subjected to uniform tensile stress.

Split tensile strength $=2P/\pi DL$


Table-7: Split tensile strength values of all mixes of M30 SCC

Trails	**Split Tensile strength in N/mm^2**		
	7 days	**14 days**	**28 days**
Nominal mix	2.78	3.15	3.48
Trail-1	2.84	2.91	3.35
Trail-2	2.02	2.32	3.10
Trail-3	1.61	1.80	2.05
Trail-4	1.78	2.15	2.01

Flexural strength of concrete:

Flexural strength or modulus of rupture carried out on the beams of size (100mm×100mm×500mm), by considering the material to be homogeneous. The beam should be tested on a span of 400 mm for 100mm specimen by applying two equal loads placed at third points. To get these loads, a central point load is applied on a beam supported on steel rollers placed at third point. The rate of loading shall be 1.8 KN/minute for 100 mm specimens the load should be increased until the beam failed. Note the type of failure, appearance of fracture and fracture load.

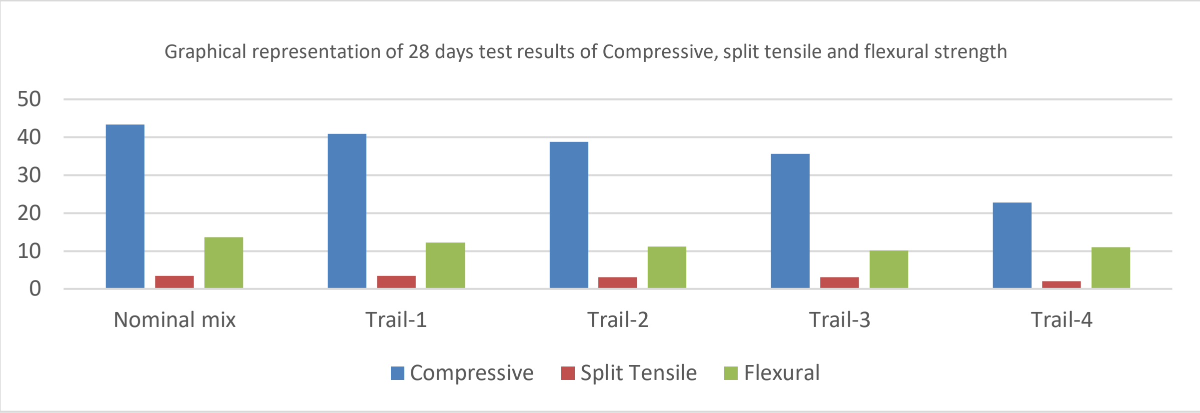
Flexural strength$=PL/bd^2$



Table-8: Flexural strength of all mixes of M30 SCC

Trails	**Flexural strength in N/mm^2**		
	7 days	**14 days**	**28 days**

Nominal mix	9.91	11.97	13.56
Trail-1	10.26	11.48	12.21
Trail-2	10.13	11.18	11.24
Trail-3	6.89	6.27	10.14
Trail-4	9.10	10.72	11.04



VI. Results And Discussions

CONCLUSION

Based on the study of behavior of self-compacting concrete the following conclusions are arrived.

- There is a significant potential for the growth of recycled aggregate as an appropriate and green solution for sustainable development in construction industry.
- Self-compacting concrete made with recycled aggregates have achieved the target strength in all the mixes and also satisfied the fresh state properties required for SCC as per EFNARC specification.
- It was observed that the concrete containing recycled aggregate gains quick early strength due to presence of partially hydrated cement adhered to aggregate which accelerates the hydration process.
- The slump flow values of all trail mixes have reached the minimum values, where as Trail-2 attained the slump flow 730mm which is the best slump of SCC at which we can pour the concrete at very congested form-works.
- T50 slump of first three trails just reached the minimum value (i.e., 2 sec) but theTtrail-4 taken 2.9 sec
- The passing ability of concrete in L-Box and J-Ring of all trails attained the minimum acceptance limits.

When the tests conducted at plastic state of SCC Including U-Box test results of all the trail mixes are showed the best results.

- The compressive strength up to Trail-2 attained the target strength of M30 and also Trail-3 attained the required strength of M30 after 28 days. Hence Trail-3 is economical than the Trail-2.
- The observed split tensile strength of Trail-3 is 3.05 N/mm2 and reached minimum value of M30 grade of concrete.
- The flexural strength of Trail-3 is 10.14 N/mm2 and reached minimum value of M30 grade of concrete.
- From the results of Compressive strength, Split tensile strength & Flexural strength of SCC the conclusion is,

An optimum percentage for the replacement of recycled coarse aggregate in place of natural coarse aggregate in the M30 grade concrete is Trail-3 of proportion 70:30.

FUTURE SCOPE

- With this type of concrete, the wastages from old demolished structures can be used up to 30% by replacing with the C.A and hence concrete wastages can be controlled and usage of natural aggregates can be minimized.
- By replacing the fly ash with cement up to 30%, the cement consumption, cost of the structure and impact on environment can be reduced.
- By using SCC we can completely avoid the usage of vibrators in construction sites.
- The duration of the project will be reduced by handling this type of concrete.
- The maximum pores will be filled and hence the durability of the structure will improve.
- For the construction of very thin concrete members like flat slabs, lift walls etc., SCC is the best concrete.
- The overall cost of the project will be optimized.

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