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Self Compacted Concrete Beams-Flexural Resistance by Partial Replacement of Cement with Ground Granulated Blast Furnace Slag

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***Abstract*— Self compacting concrete has the property of flowing and compacting due to its own weight. Since compacting of concrete in the presence of grid locked reinforcements are increasing, the need for self flowing concrete is felt very much. Meanwhile Ground Granulated Blast Furnace slag (GGBS) is an effective alternate to cement which contains cement material. In this study, self compacting concretes were considered using GGBS by replacing Portland cement with 10%, 20%, 30%, 40% and 50% by weight. The rheological and mechanical properties of SCG (GGBS incorporated SCC) were found to be increased compared to conventional concrete. Six reinforced concrete beams (SCGB) of shear span to depth ratio (a/d) 2 were tested for flexural capacity and ductile behavior. The experimental cracking moment of SCGB beams were found to be more than the theoretical cracking moment enhancing its flexural resistance. The outcomes show that the use of GGBS in SCC enables higher performance with economy and sustainability.**

Index Terms*— Self Compacting Concrete, GGBS, Flexural Resistance, Ductile Behavior.

I. INTRODUCTION

Self compacting concrete (SCC) is defined as a concrete that produce a high deformation with good segregation resistance. The SCC is distinguished by its high fluidity, passing ability and cohesiveness characteristics that eliminate or reduce to a minimum the need for mechanical compaction. The self-compacting concrete can reach self-leveling work performance in the fresh state by relying on the action of gravity, there is no need of applying external vibrations in construction sites, which improve the quality of concrete placing and can save time and labour needed in the construction sites. Hence in the last 15 years, SCC has been widely used around the world for its constructive ability and higher durability.

II. MATERIALS USED

A. Cement and Aggregates

Ordinary Portland cement of 53 grade conforming to IS 12269:1987 with specific gravity of 3.15 was used. River sand obtained from Thoothukudi and the locally available blue metal crushed stone aggregates of size 20mm were used as fine and coarse aggregates respectively. Their specific gravity, bulk density, percentage of water absorption and fineness modulus were obtained as per IS 2386:1963 and shown in Table 1.

Table 1 Properties of Aggregates

Type	Fine aggregate	Coarse aggregate
Specific gravity	2.6	2.67
Fineness modulus	2.36	4.82
Water absorption (%)	0.50	1.22
Bulk density (kg/m^3) 1629 1563		

B. Mineral Admixture

GGBS (Ground Granulated Blast furnace Slag), obtained from JSW Cement Limited, Thoothukudi and conforming to IS 12089:1987 was used as the mineral admixture. The physical and chemical properties of GGBS used for this study is given in Table 2.

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Table 2 Properties of GGBS

Chemical properties		
Parameter	JSW GGBS (%)	Codal provisions
CaO	36.34	----
Al2O3	14.43	----
Fe2O3	1.01	----
SiO2	37.75	----
MgO	8.7	Max. 17%
MnO	0.019	Max. 5.5%
Sulphide sulphur	0.38	Max. 2.0%
Loss on ignition	1.42	----
Insoluble residue	1.58	Max. 5.0%
Glass content (%)	92	Max. 85%
Physical properties		
Description		Value
Fineness of GGBS		13.1%
Specific gravity of GGBS		2.93

C. Water

Potable water with pH 7 was used.

D. Superplasticizer

The Ceraplast 300 RS(G) of sulphonated naphthalene formaldehyde condensates (SNF) type superplasticizer was used to increase the workability of self-compacting concrete at fresh state given in Table 3.

Table 3 Properties of SNF type superplasticizer

Specific gravity (30˚C)	1.234
pH (10% solution)	8.5±0.5
Solid %	43±0.5
Sodium sulphate content	< 3.9%
Viscosity (30˚C)	20±6

III.MIX DESIGN

The mix design was prepared for M30 grade SCC as per ACI guidelines based on the effect of GGBS as binary blended cement. Based on the strength obtained from trial mix given in Table 4, the actual mix was formulated. The type of mix was established by the combination of powder and Viscosity Modifying Admixture (VMA) which is prepared by increasing powder content i.e. GGBS and using VMA i.e. superplasticizer. The concrete mix proportions of GGBS incorporated SCC here after designated as SCG were as shown in Table 5. The SCG mixes with 0%, 10%, 20%, 30%, 40% and 50% GGBS were termed as SCG0, SCG10, SCG20, SCG30, SCG40 and SCG50 respectively.

Figure 5 were found to decrease by 0.003%, 2.4%, 4.9%, 5.8%, 7.5% and 27.18%, 30.23%, 35.74%, 14.25%, 16.73% with the replacement of 10%, 20%, 30%, 40%, 50% GGBS to SCC respectively. Bouzoubaa et al has reported that increase in percentage of fly ash decreases the slump flow, the same holds good for GGBS also as shown in Table 6 and Figure 2. It is clearly evident from Table 6 and Figure 3 that the time taken by the SCG mixes to flow through the V- funnel decreases by 1.7%, 0.01%, 1.7%, 0.01% with replacement of 10%, 20%, 30%, 40% GGBS and increases by 0.01% with replacement of 50% GGBS in SCC respectively which is not in good agreement with O.R.

Table 4 Trial Mix

Designation of mix	Cementitious binder by weight		FA by weight	CA by weight	Water content by weight of cement	Percentage of SP by volume of concrete	Compressive strength at the age of 28 days (N/mm^2)
	OPC	GGBS					
Trial 1	1	0	1.51	1.78	0.35	6.0	28.6
Trial 2	1	0	1.51	1.78	0.35	4.0	30.5
Trial 3	1	0	1.51	1.78	0.35	2.0	36.8

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Table 5 Validation of Mix design

Designation of mix	Cementitious binder by weight		FA by weight	CA by weight	Water content by weight of cement	Percentage of SP by volume of concrete
	OPC	GGBS				
SCG0	1	0	1.51	1.78	0.35	2
SCG10	0.9	0.1	1.51	1.78	0.35	2
SCG20	0.8	0.2	1.51	1.78	0.35	2
SCG30	0.7	0.3	1.51	1.78	0.35	2
SCG40	0.6	0.4	1.51	1.78	0.35	2
SCG50	0.5	0.5	1.51	1.78	0.35	2

IV. RHEOLOGICAL PROPERTIES

The rheological properties of SCG mixes were found using slump test, V- funnel test, L - box test and U - box test as per EFNARC[16] recommendations and seen through Figure 1.

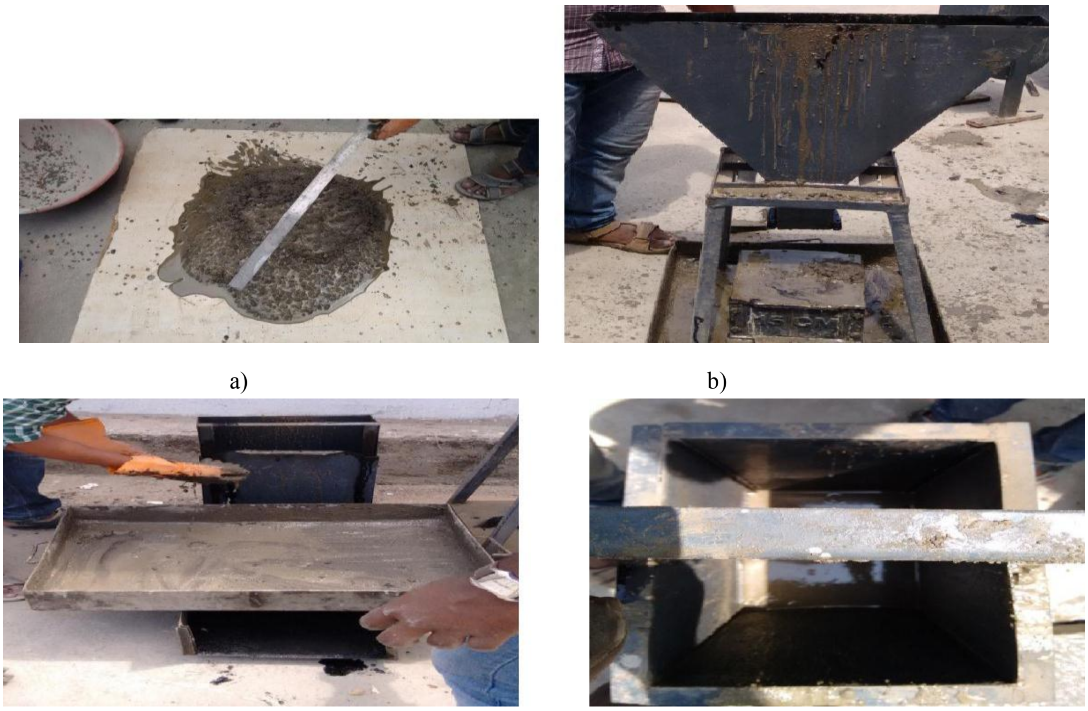
V. COMPRESSIVE STRENGTH

150 × 150 × 150 mm cubes were prepared for checking compressive strength using SCG mixes and tested in a universal testing machine at 7, 28 and 56 days respectively. The average of three specimens is the reported strengths.

VI. RESULTS AND DISCUSSION

Table 6 Fresh Concrete properties

Mix	SCG0	SCG10	SCG20	SCG30	SCG40	SCG50	EFNARC **values**
Slump flow (mm)	708	706	691	673	667	655	650 - 800
V-funnel test (sec)	11.5	11.3	11.4	11.3	11.4	11.6	6 - 12
L-box (mm)	0.876	0.968	0.973	0.984	0.832	0.829	0.8 - 1
U-box (mm)	5.26	3.83	3.67	3.38	4.51	4.38	0 - 30



a) b)

c) d)

Figure 1. a) Slump flow test b) V- Funnel test c) L-Box test d) U- Box test

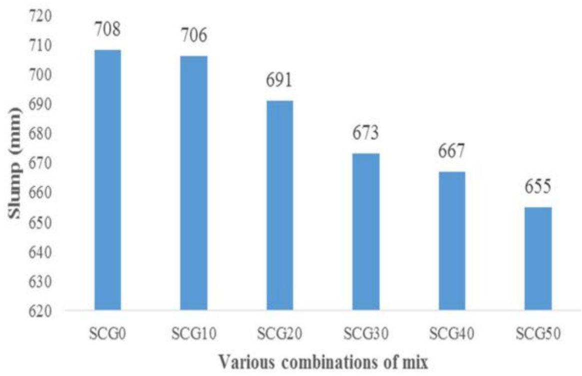


Figure 2 Slump flow of SCG mixes

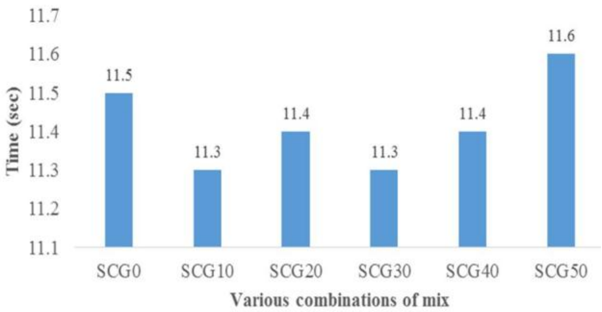


Figure 3 Filling ability of SCG mixes from V- funnel

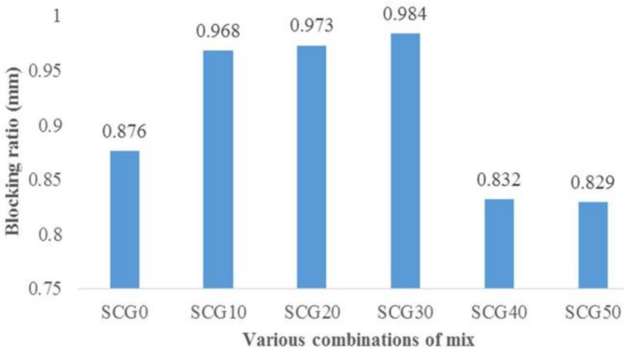


Figure 4. Passing ability of SCG mixes from L – box

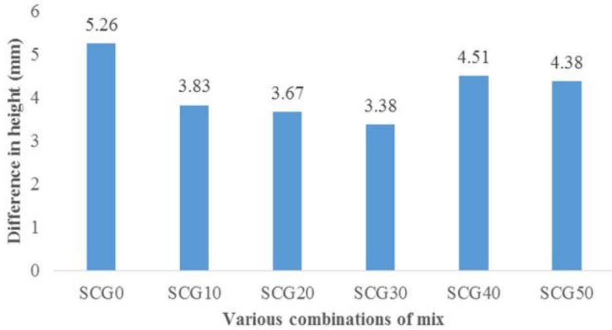


Figure 5 Passing ability of SCG mixes from U – box

VII. COMPRESSIVE STRENGTH

Table 7 Compressive strength of SCG beams

Sl.no	Specimen	Compressive strength (N/mm^2)		
		7th day	28th day	56th day
1	SCG0	27.55	36.81	39.85
2	SCG10	26.45	28.57	40.95
3	SCG20	27.15	29.37	41.15
4	SCG30	28.35	30.73	41.75
5	SCG40	29.75	32.33	42.85
6	SCG50	27.65	29.88	41.95

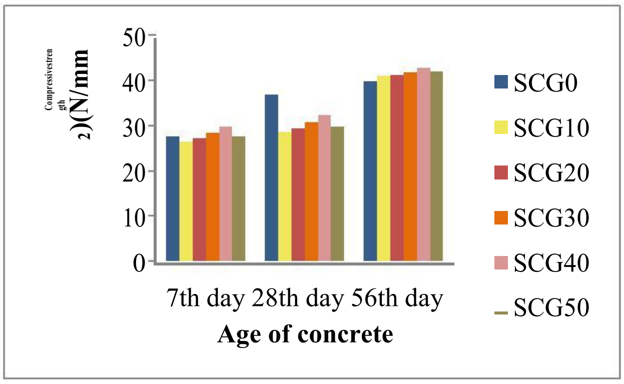


Figure 6 Compressive strength of SCG mixes

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VIII. FLEXURAL CAPACITY OF SCG BEAMS

A. Beam Geometry

Figure 7 Reinforcement cage

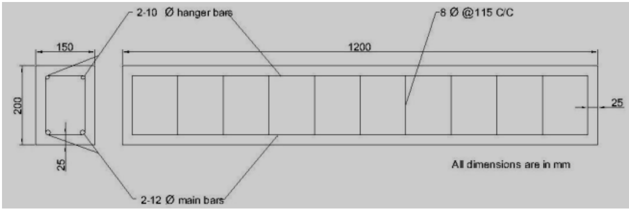

Figure 8 Beam reinforcement outline

B. Test procedure

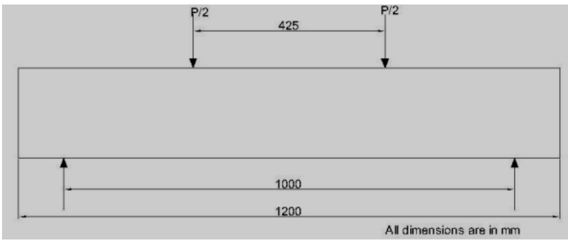

Figure 9 Test setup sketch

Figure 10 Experimental test set up

C. Crack pattern and failure mode of control beam

Figure 11 Crack pattern of control beam

The initial crack and the final crack in the control beam specimen were noticed for the loading of 3T and 11.5T respectively. The control beam is failed by developing diagonal crack in the shear region which extended up to the middle fibre as seen in Figure 11.

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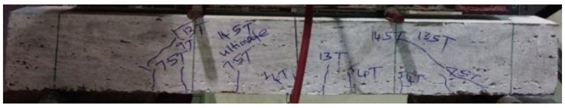
D. Crack pattern and failure mode of SCG beams

(a)

(b)



(c)

(d)

(e)

Figure 12 Crack pattern of SCG beams

Table 8 Initial and Final crack load of SCG beams

Beam ID	Initial crack load (T)	Final crack load (T)
CC	3	11.5
SCGB10	4	12
SCGB20	3.5	12.5
SCGB30	4	14.5
SCGB40	3.75	11.5
SCGB50	3.5	11

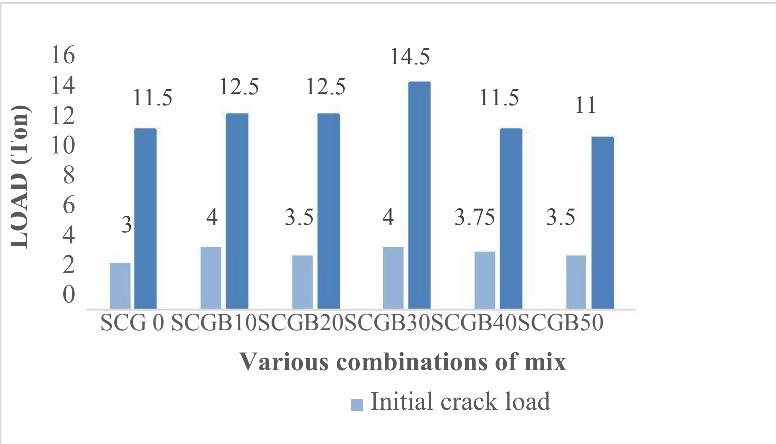


Figure 13. Initial and final crack load of SCG beams

E. Moment carrying capacity

Table 9 Theoretical and Experimental cracking moment

Specimen	Mcr (theoretical) (kNm)	Mcr (experimental) (kNm)
SCGB0	3.93	8.63
SCGB10	4.00	11.50
SCGB20	4.02	10.06
SCGB30	4.05	11.50
SCGB40	4.12	10.78
SCGB50	4.06	10.06

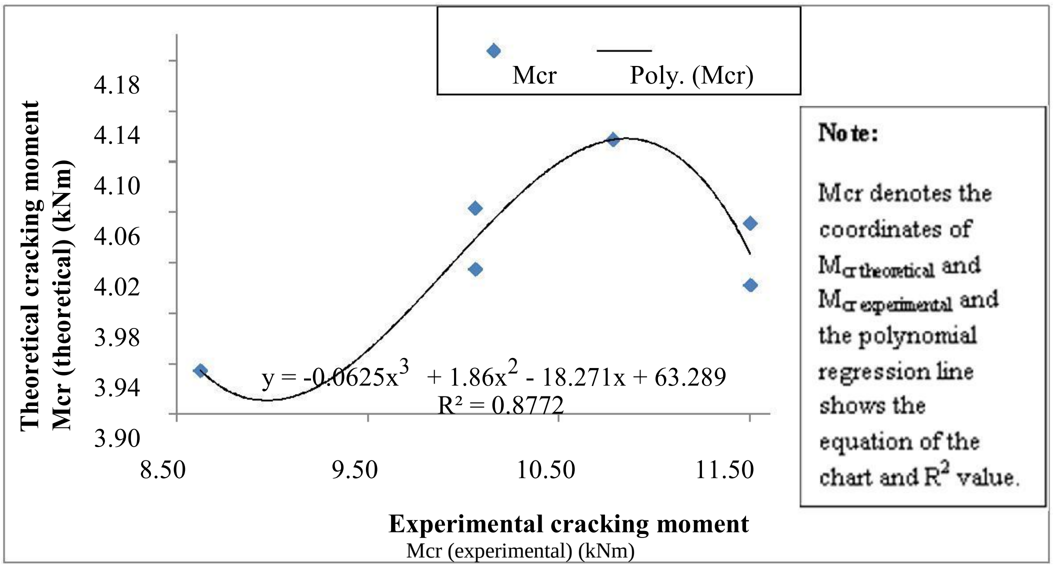


Figure 14 Cracking moment comparison

The R-squared value equals 0.8772, which is a best. Since it is closed to 1, it can be concluded that the experimental cracking moment is in depends with theoretical cracking moment.

F. Ductility factor

The ductility of SCGB beams were analyzed theoretically using ductility factor (μ) which is the ratio of ultimate deflection (δu) to yield deflection (δy) as given in (3). Ultimate deflection is defined as the deflection corresponding to the ultimate load and yield deflection is the deflection caused by the member during yielding.

Table 10 Ductility factor of SCG beams

Sl.no	Beam specimen	Ultimate deflection (δu)	Yield deflection (δy)	Ductility factor μ = δu/δy
1	SCGB0	13.7	4.3	3.19
2	SCGB10	14.6	3.7	3.94
3	SCGB20	15.2	3.8	4
4	SCGB30	15.9	4.1	3.88
5	SCGB40	14.8	4.7	3.15
6	SCGB50	13.9	4.5	3.08

It is observed from Table 9 that ductility factor of SCGB10, SCGB20, SCGB30 were 19.0%, 20.2%, 17.78% higher than conventional concrete where as SCGB40 and SCGB50 were 1.25% and 3.45% lesser than conventional concrete.

CONCLUSION

- The use of GGBS as partial replacement for OPC in SCC not only reduces the CO_2 emission from OPC but also produce the mechanical and rheological properties of SCC.
- The workability of Self Compacting Concrete found by slump decreases with increase in percentage of GGBS, the time of flow through the V- funnel test time decreased with addition of GGBS in SCC and the blocking ratio obtained from L- box was found to be satisfactory up to 30% replacement of OPC with GGBS in SCC.
- At the 7 days, the compressive strength of SCG10 and SCG20 were found to drop by 5.58% and 18.91% while compressive strength of SCG30, SCG40 and SCG50 were enhanced by 4.02%, 10.17% and 0.01% respectively from conventional mix.
- It was pointed that the compressive strength of SCG10, SCG20, SCG30, SCG40, SCG50 were reduced by 28.85%, 26.05%, 21.29%, 15.68% , 24.26% and improved by 3.39%, 3.89%, 5.67%, 8.79%, 6.25% at the age of 28 and 56 days respectively from conventional mix.
- SCGB beams with higher percentage of GGBS exhibits higher ductility.
- The experimental cracking moment of SCGB0, SCGB10, SCGB20, SCGB30, SCGB40 and SCGB50 is 54.46%, 65.21%, 60%, 64.78%, 61.78% and 59.64% higher than the theoretical cracking moment. This exhibits that the replacement of GGBS to OPC in SCC produces the flexural behavior of self compacting concrete beams.
- Ductility factor of SCGB10, SCGB20, SCGB30 were 19%, 20.2%, 17.78% higher than conventional concrete where as SCGB40 and SCGB50 were 1.25% and 3.45% lesser than conventional concrete mix. Hence, it can be concluded that upto 30% replacement of GGBS to OPC in SCC is effective.

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