Self-Compacting Sustainable Concrete using High Volume Fly Ash and Ggbs

Sushree Sangita Rautray, Manas Ranjan Das

Abstract*: *The current study focuses on behaviour of freshly hardened concrete through partial cement replacement by using fly ash and ground granulated blast furnace slag (ggbs) in different percent. The essential properties of freshly prepared concrete like flowability, passing ability, filling ability are determined by slump flow test, slump flow T50cm, V-funnel, J-ring and L-box test. The values are found to satisfy EFNARC guidelines. The tests were conducted in order to assess the concrete properties.

Index Terms*: *Fly ash; Ground granulated blast furnace slag; Self compacting concrete.

I. INTRODUCTION

Concrete is traditionally produced using ordinary Portland cement. The environment is affected by the carbon dioxide released due to lime stone calcinations and fossil fuel combustion for every tons of opc produced. Fly ash and ground granulated blast furnace slag (ggbs) are two waste products produced from thermal power plant and steel industries.180 billion metric tons of coal is reserved in India so nearly 90% of thermal power plant utilizes coal to produce electricity. At present nearly 185 million coal ash is produced in India and it will double itself in next two decade**.**

Likewise ggbs is also produced in large amount. Due to enormous production of these waste materials it needs to be used for various proposals to save the environment. It initiates opportunity to utilize these wastes as partial replacement of opc. In the presence of water and in ambient temperature fly ash react with the calcium hydroxide during the hydration process of opc to form the calcium silicate hydrate (C-S-H) gel. As a partial replacement of fly ash with opc or addition of admixture with fly ash develops pozzolanic effect in concrete.Modern application of SCC is focused on high performance and uniform quality Domone [1].

Different authors have investigated on the use of fly ash, ggbs, silica fume, red mud etc to form scc [2-3]. Khatib [5] investigated on SCC using fly ash and ggbs with partial replacement of cement. Ryan and Connor [6] concluded that the chloride resistance of conventional vibrated concrete in some cases be greater than that of equivalent self compacting concrete. Zhao *et al*. [7] concluded that the inclusion of fly ash and ggbs in HPC leads to a great decrease in total shrinkage but an increase in autogenous shrinkage. Mohan and Mini [8] got best result on strength and durability of scc by incorporating 10% silica fume. Vivek and Dhinakaran [9] studied that 50% ggbs, 10% silica fume and 20% metakaolin found to the optimum values as partially substitute the cement. In current study, a design mix was developed using eco-friendly self-compacting concrete by using fly ash and ggbs.

II. MATERIALS

OPC-43 grade cement has been used in the present work. Laboratory tests on cement have been carried out as per IS: 4031-1999. The fine aggregates were collected from the Kathjodi river, Bhubaneswar conforming to zone III. The coarse aggregates of size varying between 12.5 mm and 19 mm were collected from a crusher plant near Bhubaneswar. In scc mixes super plasticizer (master glenium sky 8630) had been used as per IS:9103-1999. The class-F fly ash and ggbs used have been collected from Jindal power plant and Maithan plant, Jajpur road, odisha. Results of laboratory tests conducted on these materials are presented in Table-1 to Table-4.

Table 1: Physical Properties of Cement

Characteristics	OPC-43 grade Test Results	IS:8112-1989 standard
Normal consistency (%)	34.5	NA
Specific gravity	3.15	3.15
Fineness (%)	1.33	10
Initial setting time	1 hours 40 minutes	30 (min)
Final setting time	5 hours	600 (max)
3days compressive strength (Mpa)	24.2	23 (min)
7days compressive strength (Mpa)	34.8	33 (min)
28days compressive strength (Mpa)	44.3	43 (min)

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		ggbs (%)

Table 2: Properties of Natural Fine aggregate and Coarse aggregate

Characteristics	Test value (as per IS: 383-1970)	
	Fine Aggregate	Coarse Aggregate
Fineness modulus	2.40, Zone III	6.8
Specific gravity	2.63	2.87
Water absorption	1.01%	0.845%
Free surface moisture	0.90%	Nil

Table 3: Chemical Composition of fly ash

Type	Fly ash (Present study) (%)	ASTM requirement C-618 Class F (%)	I.S.
SiO2	56.04	--	Specifications
Al2O3	33.85	--	(%)
Fe2O3	3.90	--	35 (minimum)
SiO2 + Al2O3 +Fe2O3	93.84	70.00 minimum	
CaO	0.73	--	
MgO	0.68	5.00 maximum	70.0 (minimum)
K2O	1.22		
Na_2O	0.19	1.50 Maximum	5.0 (maximum)
TiO_2	2.69		
MnO_2	0.31	--	1.5 (maximum)
SO_3	0.05	5.00 maximum	
L.O.I. (900ºC)	1.40	6.00 maximum	

Table 4: Chemical Composition of ggbs

Sl. no.	Parameters	Concentration in ggbs (%)
1	SiO2	40
2	Al2O3	13.5
3	CaO	39.2
4	MgO	3.6
5	Fe2O3	1.8%
6	SO3	0.3%
Sl. no.	Parameters	Concentration in

The X-ray diffraction test results of the test samples have been presented in Figs. 1 & 2.

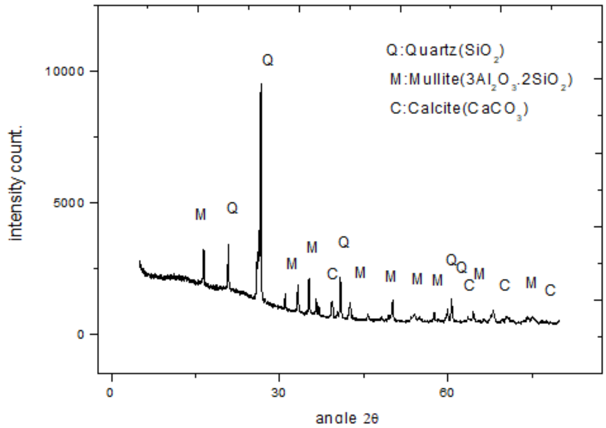

Fig. 1: X-ray diffraction of flyash

III. MIX DESIGN METHODOLOGY

Total 14 numbers of mix types have been prepared for the present investigation as given in Table 5 and mix proportions are presented in Table 6. Mix type designated as CM stands for control mixes whereas M stands for mix type with 1% superplasticizer and SM stands for mix type with 4% superplasticizer. The mass of total cementious material have been kept at 437 kg/m³.After casting specimens were cured as per requirement in water at room temperature and humidity. Then laboratory tests were conducted on the specimens to determine compressive, split tensile and flexural strengths. Tests were also conducted to determine the properties of fresh concrete.

Table 5: Mix Identification of scc mixes

Mix Designation	Proportion details
CM1	Normal SCC mix with 100% cement + 0% SP +w/b=0.45
CM2	Normal SCC mix with 100% cement + 1% SP +w/b=0.45
M1	SCC With Cement 80% + Fly Ash 20% +1% SP +w/b=0.55
M2	SCC With Cement 80% + ggbs 20 % + 1%SP+w/b=0.55
M3	SCC With Cement 60% + Fly Ash 40% + 1% SP+w/b=0.55
M4	SCC With Cement 60% + ggbs 40% +1% SP+w/b=0.55
M5	SCC With Cement 50% +Fly Ash 50% + 1% SP+w/b=0.55

Table 6: Mix Proportion of scc mixes with partial replacement of cement using fly ash and ggbs

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Mix ID	Cement Kg/m3	Fly Ash Kg/m3	Ggbs Kg/m3	FA Kg/m3	CA Kg/m3	W/B Ratio	Super Plasticizer %
CM1	437.77	0	0	756.17	893.20	0.80	0
CM2	437.77	0	0	756.17	893.20	0.45	1
M1	350	87.55	0	756.17	893.20	0.55	1
M2	350	0	87.55	756.17	893.20	0.55	1
M3	262.66	175.10	0	756.17	893.20	0.55	1
M4	262.66	0	175.55	756.17	893.20	0.55	1
M5	218.88	218.88	0	756.17	893.20	0.55	1
M6	218.88	0	218.88	756.17	893.20	0.55	1
M7	175.10	175.10	87.35	756.17	893.20	0.55	1
M8	175.10	87.35	175.10	756.17	893.20	0.55	1
SM1	218.88	218.88	0	756.17	893.20	0.45	4
SM2	218.88	0	218.88	756.17	893.20	0.45	4
SM3	175.10	175.10	87.35	756.17	893.20	0.45	4
SM4	175.10	87.10	175.10	756.17	893.20	0.45	4

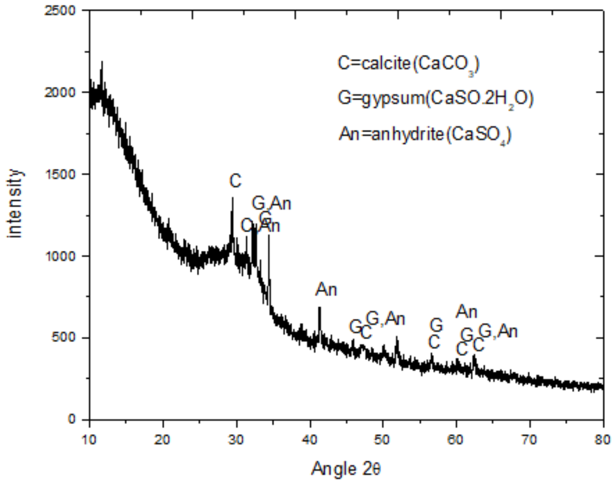

Fig. 2: XRD of ggbs

I. TESTS ON CONCRETE

A. Fresh Concrete Test

For the initial mix design of SCC all three parameters (i.e. passing ability, filling ability and segregation resistance) of fresh concrete need to be assessed to ensure that all aspects are fulfilled as per EFNARC standards as shown in Table 7.

Table 7: EFNARC Standards for fresh concrete properties

Sl. No.	Method	Property	Typical Range According to EFNARC
1	Slump-flow by Abrams Cone	Filling ability	650-800 mm
2	T50cm slump flow	Filling ability	2-5 sec
3	J-ring	Passing ability	0-10 mm
4	V-funnel	Filling ability	6-12 sec
5	L-box	Passing ability	0.8-1
6	V-funnel t5min	Segregation resistance	6-12, +3 sec

Workability

Slump flow test was implemented using 1% and 4% SP with fly ash and ggbs for partial replacement of cement in scc mixes and shown in Table 8. The maximum slump flow value was observed in control mix CM_2 [100% cement+1% SP] with 740mm. The mixes with super plasticizer content 1% gave lesser values when compared with the control mixes. But the mixes with super plasticizer 4% when compared with the control mixes gave lesser slump flow values. The mix M_1 (80% cement+20% fly ash) gave the best slump flow value of 735mm as comparison to other mixes of waste materials. The least slump flow value was obtained at mix M_6 (50% cement+50% ggbs) of 670mm. As the percentage of waste material (ggbs) increased the slump flow value decreased. All the concrete mixes gave desirable slump flow value according to the EFNARC guidelines.

Slump Flow T_{50} cm Test

The slump flow T_{50} cm test was performed using 1% and 4% SP with fly ash and ggbs for partial replacement of cement and shown in Table 8. The control mixes CM_1 and CM_2 had slump values of 3 sec . The mix SM_4 gave T_{50} CM value of 6 sec which is just higher limit according to the EFNARC standards. The best slump flow T_{50} cm values were observed in CM_1, $M_{5,}$ M_1 and M_3, i.e 3 seconds. All the values were within the range of EFNARC guidelines except SM_4.

V-Funnel Values

The V-Funnel test was performed using 1% and 4% SP with fly ash and ggbs for partial replacement of cement and shown in Table 8. From Table 8, it can be observed that the values for all mixes conducted in v-funnel test were within the range of EFNARC standards. The control mix CM1 and CM2 gave v-funnel value of 9 sec and 10 sec respectively. The maximum values of v-funnel were obtained in mixes M6, SM4 i.e. 12 seconds. The mixes of M6, SM4 contained higher level of ggbs percentage as compared to fly ash or cement in volume of concrete mixes.

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Table 8: Test results of scc fresh properties for all mixes

Mix ID	Slump Flow	Slump Flow T50 cm (Sec)	V-Funnel (Sec)	J-Ring	L-Box
CM1	(mm)	3	9	(mm)	(Ratio)
CM2	730	3.5	10	5	0.97
M1	740	3	10	4	0.96
M2	735	3.5	9	7	0.98
M3	720	3	10	9	0.96
M4	730	4	11	8	0.97
M5	705	3	9	10	0.96
M6	720	5	12	6	0.96
M7	670	3.5	10	9	0.94
M8	705	4	11	8	0.95
SM1	690	3.5	10	8	0.92
SM2	720	5	11	9	0.96
SM3	695	4	10	9	0.92
SM4	690	6	12	8	0.92

J-Ring Values

The J-Ring test was performed using 1% and 4% SP with flyash and ggbs for partial replacement of cement and shown in Table 8. The J-ring test conducted on mixes and the values were obtained within the range of EFNARC standards. The least values of J-ring were obtained from the control mixes. The CM1 and CM2 gave j-ring values of 5mm and 4mm respectively. The values of j-ring increased with the increase in percentage of fly ash and ggbs in concrete. The maximum values of J-ring were obtained from mixes M4, SM3 which consisted of greater percentage of ggbs in comparison to fly ash in volume of concrete mixes.

L-Box Values

The L-Box test was performed using 1% and 4% SP with fly ash and ggbs for partial replacement of cement in scc mixes and shown in Table 8. The best values of L-box were obtained from the mix M1 [fly ash 20%+cement 80%], i.e. 0.98. The control mixes CM1 and CM2 also gave good ratio of L-box test of 0.96 and 0.97 respectively. If the concrete flows like water then the ratio of L-box is consider as 1 and is the best flowing ability of fresh concrete properties. All the values of scc mixes satisfied the EFNARC guidelines.

A. Hardened Concrete Test

Compressive Strength

Compressive strength test was conducted for Partial Replacement of Cement with Fly Ash and ggbs using 1% and 4% SP and presented in Fig. 3. From the present study, it can be seen that the compressive strength test results of scc mixes decreased with increase in the percentage fly ash and ggbs content with partial replacement of cement for all days of water curing. The control mixes CM1 and CM2 gave compressive strength of 27.22 MPa and 48.34 MPa respectively in 28 days of water curing. The mix M1(cement 80%+fly ash 20%) gave compressive strength of 47.28 MPa in 28 days which was near to the value of control mix CM2. Compressive strength value decreased as the percentage of waste materials increased in the SCC mixes. The mixes with super plasticizer content 4% and water to binder ratio 0.55 showed very low compressive strength in 7 days (i.e. 1.41MPa, 1.24MPa, 1.62MPa and 1.57MPa for mixes SM1, SM2, SM3 and SM4 respectively) but drastic increase in percentage of compressive strength after 28 days curing. The percentage of increase in compressive strength were 887.23%, 796.77%, 716.04% and 743.31% for the mixes SM1, SM2, SM3 and SM4 respectively after 28 days of curing.

Split Tensile Strength

Split Tensile Strength test was conducted for Partial Replacement of Cement with Fly Ash and ggbs using 1% and 4% SP and presented in Fig. 4. The maximum split tensile strength was obtained in the control mix CM2 after 7 days and 28 days of water curing, (i.e. 3.51MPa and 5.53MPa). The mix M1 obtained tensile strength of 3.24MPa and 4.8MPa in 7 days and 28 days curing. The mixes with super plasticizer content 4% does not showed any Split tensile strength in 7 days of curing. The mixes SM1 and SM3 gave values of 0.90MPa and 0.60MPa after 28 days of curing.

Flexural Strength

Flexural Strength test was conducted Partial Replacement of Cement with Fly Ash and ggbs using 1% and 4% SP and presented in Fig. 5. The maximum flexural strength was obtained in the control mix CM2 after 7 days and 28 days of water curing, (i.e.

6.5MPa and 8.5MPa). The mix M1 gave flexural strength of 4.9MPa & 8.1MPa at 7 & 28 days respectively. Nearly similar strengths were obtained in mixes M1 & CM2 after 28 days of curing. As the percentage of fly ash & ggbs increased in volume of concrete, the flexural strength goes on decreasing at 7 & 28 days of water curing.

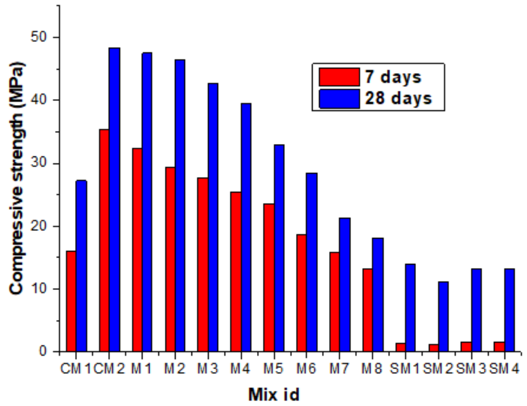

Fig. 3: 7 and 28 days compressive strength test result of control mix and partial replacement of cement with fly ash and ggbs using 1% and 4% s

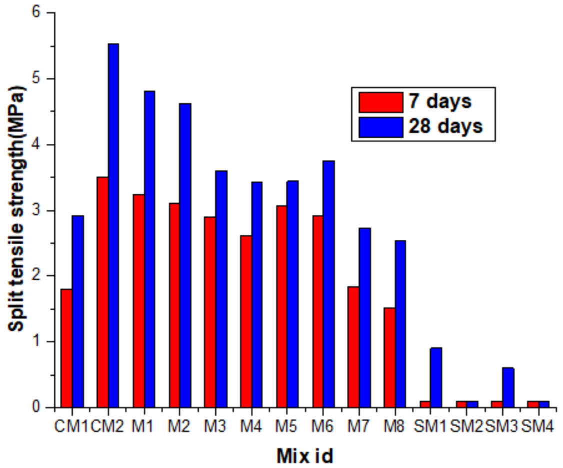

Fig. 4: 7 and 28 days split tensile strength test result of control mix and partial replacement of cement with fly ash and ggbs using 1% and 4% sp.

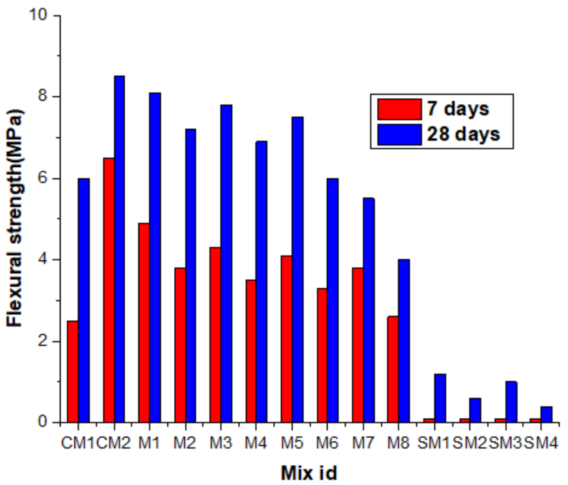

Fig. 5: 7 days and 28 days flexural strength test result of control mix and partial replacement of cement with fly ash and ggbs using 1% and 4% sp

II. CONCLUSIONS

The slump flow rate showed a reduced graph with respect to increased fly ash and ggbs percent in concrete mixes. The best slump flow value was obtained in control mix CM2. The lowest slump value was obtained in the mix SM4. In the present study, all mixes showed good slump value and are within the range of EFNARC standards.

The best slump flow T50cm was observed in 4 mixes CM1, M1, M3 and M7 which is 3 seconds. Increasing percentage of ggbs in place of cement increases the slump flow T50cm values. All mixes for slump flow T50cm values are within the range of EFNARC guidelines except SM4 (cement40%+ggbs40%+fly ash 20%) mix. The SM4 had the slump flow T50cm of 6 seconds which is just higher than maximum limit of 5 seconds recommended in EFNARC standards. The v-funnel experiments conducted on fresh concrete mixes gave desired results according to the EFNARC guidelines. The best v-funnel values were obtained in mixes of CM1, M1 and M4, i.e 9 seconds.The J-ring value was best in control mix CM1 (cement 100%+ 0% SP) with 4mm. The J-ring values increased with addition of fly ash and ggbs in volume of concrete as comparison to the control mixes. The L-box test results were performed well for all the mixes in the present study. The mix with greater slump flow value gave better results of L-box. All the mixes except SM4 satisfied the properties of fresh concrete as per EFNARC guidelines to qualify as self-compacting concrete.

There was decrease in percentage wastes in compressive strength in SCC mixes. The maximum split tensile strength was observed in control mixture CM2 mix. There was decrease in split tensile and flexural strength along with percentage increase of waste substances in the SCC mixes.

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