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EXPERIMENTAL STUDY ON SELF COMPACTING CONCRETE (SSC) USING GGBS AND FLY ASH

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Abstract
Self Compacting Concrete (SSC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SSC makes it suitable for placing in difficult conditions and in section with congested reinforcement. Use of SSC can also help in minimize hearing related damage on the work site that is induced by vibration of concrete. In this paper experimental studies are carried out to understand the fresh and hardened properties of Self Compacting Concrete (SSC) in which cement is replaced by Ground Granulated Blast Furnace Slag (GGBS) and Fly Ash (FA) in various proportions for M30 grade concrete. The proportions in which cement replaced are 30% of GGBS, 20% of both GGBS and FA, 40% of GGBS, 15% of both GGBS and FA, 40% of FA and 30% of FA. The strength behaviour, Flexural behaviour and Split tensile strength behaviour of SSC are studied. The parameters are tested at different ages in accordance with Bureau of Indian Standards (BIS) for the various proportions in which cement is replaced and also the obtained parameters are compared with normal SSC (100% cement). Super plasticizer GLENIUM B233 a product from BASF is used to maintain workability with constant Water-Binder ratio.

Index Terms— ***BIS, Fly Ash, GGBS, GLENIUM B233, SSC, compressive strength, Split tensile strength and flexural strength.***

I. INTRODUCTION
For several years beginning in 1983, the problem of the durability of concrete structures was a major topic of interest in Japan. The creation of durable concrete structures requires adequate compaction by skilled workers. However, the gradual reduction in the number of skilled workers in Japan's construction industry has led to a similar reduction in the quality of construction work. One solution for the achievement of durable concrete structures independent of the quality of construction work is the employment of self-compacting concrete, which can be compacted into

every corner of a formwork, purely by means of its own weight and without the need for vibrating compaction. The necessity of this type of concrete was proposed by Okamura in 1986. A committee was formed to study the properties of SCC, inducing the fundamental investigation on the workability of concrete, which was carries out by Ozawa at the University of Tokyo. Studies to develop self-compacting concrete, including a fundamental study on the workability of concrete, have been carried out by Ozawa and Maekawa at the University of Tokyo (Ozawa 1989, Okamura 1993 & Maekawa 1999). The first use able version of SCC was completed in 1988 and was named "high performance concrete", and later proposed as "self compacting concrete".

Self compacting concrete (SCC) is a flowing concrete mixture that is able to consolidate under its own weight. The highly fluid nature of SCC makes it suitable for placing in difficult conditions and in section with congested reinforcement. Use of SCC can also help minimize hearing-related damages on the worksite that are induced by vibration of concrete. Another advantage of SCC is that the time required to place large sections is considerably reduced.

The SCC has gained wide use in many countries for different application and structural Configurations SSC require a high slump that can be achieved by incorporating several chemical admixtures. The super plasticiser influences the rheological behaviour; the viscosity and the yield value of the fresh concrete are reduced in certain concrete mix. The super plasticiser ensures high fluidity and reduces water powder ratio. Super plasticiser greatly improves pump-ability and the slump value can be greatly increased. The use of viscosity modifying admixtures increases segregation resistance of concrete and increases the deformability without segregation and then to lead high optimum self-compatibility. Self-compacting concrete plays a major role in increasing the use of industrial by products like slag, fly ash and silica fume. SSC offers possibility for utilization of dusts which are currently waste products demanding with no practical applications and which are costly to dispose off. The SCC technology is now being adopted in many countries. In the absence of suitable standardized test methods it is necessary to examine critically the existing test methods and identify or develop test methods suitable for acceptance as standards which must be capable of rapid and reliable assessment of properties of SCC on a site

II. MATERIAL

A. Cement

In the present work ordinary Portland cement of 53 Grade Birla super conforming to IS 12269:1987 has been used. The properties of the cement used are shown in TABLE 1.

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TABLE 1**: Properties of cement**

Physical Properties	Results
Fineness by dry sieve % (90 micron)	5 %
Normal Consistency	31 %
Initial setting time (min)	205
Final setting time (min)	317
Specific Gravity	3.1
Compressive strength at 3- days (N/mm^2)	35.20
Compressive strength at 7- days (N/mm^2)	47.50
Compressive strength at 28- days (N/mm^2)	54.26

B. Ground Granulated Blast Furnace Slag (GGBS)

Blast furnace slag is a by-product obtained in the manufacture of pig-iron. It is a product formed by the combination of the earthy constituents of iron-ore with the limestone flux at high temperature in the blast furnace (about 1500^0c). The molten slag is rapidly quenched by a hose of water to yield a glassy granular product called granulated blast furnace slag. Hydrated slag's, granulated or palletized, give the same hydrates as Portland cement i.e., C-S-H and AF1 phases. As they react more slowly with water than Portland cement, they can be activated by different ways: chemically in presence of lime and sulphate activators, physically by grinding or thermally. Slag, which is obtained by grinding the granulated blast furnace slag, is highly pozzolanic in nature. Cement replacement levels of slag can be much higher than that of other pozzolanic materials, such as, Fly ash and silica fume. Generally, GGBS has higher 'CaO' content than other pozzolanas. The physical and chemical properties of GGBS are given in TABLE 2 and TABLE 3.

TABLE 2**: Physical characteristics of GGBS**

Physical Properties	Values
Specific Gravity	2.62
Fineness by Blaine's air permeability (m^2/kg)	321
Wet sieve analysis % retained on (45µ)	2.9%

TABLE 3**: Chemical characteristics of GGBS**

Chemical components	Values
Silicon dioxide (SiO_2)	33.78%

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Aluminium Oxide (Al_2O_3)	17.08%
Calcium Oxide (CaO)	39.87%
Magnesium Oxide (MgO)	7.10%

C. Super Plasticiser (GLENIUM B233)

GLENIUM B233 is an admixture of a new generation based on modified polycarboxlic ether. The product has been primarily developed for application in High performance concrete where highest durability and performance is required. GLENIUM B233 is free of chlorine and low alkali. It is compatible with all types of cements. The product compile with ASTM C494 Type F. The typical properties are shown in TABLE 4.

TABLE 4**: Properties of GLENIUM B233**

Aspect	Yellowish free flowing liquid
Relative Density	1.09, 0.01 at 25°C
PH	7 ± 1
Chlorine iron content	< 0.2%

D. Aggregates

Locally available river sand of specific gravity 2.64, fineness modulus 2.8, Bulk density 15.25 KN/m^3 and conforming to zone II was used as fine aggregate. The crushed granite stone with a maximum size of 12 mm, specific gravity 2.67, bulk density 16.80 KN/m^3, flakiness particles 12.2% and well graded was used as coarse aggregate. Both the aggregate used conformed to IS: 383-1970 specification for coarse and fine aggregates from natural sources for concrete.

E. Water

Potable water was used for mixing and curing.

III. MIX PROPORTIONING

For the present work SCC of grade M30 is adopted. The mix design of SCC is obtained as per standard procedure as out lined in IS: 10262-2009 was followed. Details of mix proportions obtained are given in **Table 5** for SCC, cement is replaced by 30%, 40% of Fly ash and GGBS in four replacement levels. Fly ash is replaced by 50% GGBS in two replacement level. These six mix are compared with the Normal SCC (100% cement) Super plasticiser is used to maintain the workability with constant Water/Binder ratio as obtained from the mix design. Typical detailed calculation of mix design as per standard procedure as out lined in IS: 10262-2009.

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TABLE 5: **Details of mix proportion**

Mix-ID	GGBS30	GGBSFA20	GGBS40	GGBSFA15	FA40	FA30	GGBSFA0
W/C	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Water (litres)	180	180	180	180	180	180	180
Cementious (Kg/m^3)	450	450	450	450	450	450	450
% of replacement by Fly ash	……	20	…….	15	40	30	………
% of replacement by GGBS	30	20	40	15	…….	…….	……..
Super Plasticiser (%)	0.85	0.8	0.9	0.85	0.75	0.75	0.85
Cement (Kg/m^3)	315	270	270	315	270	315	450
Fly Ash (Kg/m^3)	…….	90	……	67.5	180	135	…….
GGBS (Kg/m^3)	135	90	180	67.5	…….	…….	…….
Fine Aggregates(Kg/m^3)	795	795	795	795	795	795	795
Coarse Aggregate (Kg/m^3)	1027	1027	1027	1027	1027	1027	1027

IV. Experimental Programme

Experimental programmes are carried out and the results are presented in this paper to study the fresh and hardened properties of SSC concrete.

A. Test on Fresh Concrete

The filling ability and stability of self-compacting concrete in the fresh state can be defined by four key characteristics. Each characteristic can be addressed by one or more test methods which are mentioned below. TABLE 6 gives the acceptance criteria.

TABLE 6: **Characteristics for fresh concrete**

Characteristics	Preferred test methods
Flow ability	Slump-flow Test

Viscosity (assessed by rate of flow)	V-funnel Test
Passing ability	L-box test
Segregation	Segregation resistance (Sieve) Test

TABLE 7: **Acceptance Criteria**

Test	Property	Ranges of values
Slump-flow	Filling ability	2 – 5 sec
V-funnel	Viscosity	6-12 sec
L-box	Passing ability	0.8-1

- **Slump-flow test for Flow ability**

The following are typical slump-flow classes for a range of application:

SF1 (550 – 650 mm) is appropriate for:

- Unreinforced or slightly reinforced concrete structures that are cast from the top with free displacement from the delivery point (e.g. housing slabs)
- casting by a pump injection system (e.g. tunnel linings)
- Sections that is small enough to prevent long horizontal flow (e.g. piles and some deep foundations).

SF2 (660 – 750 mm) is suitable for many normal applications (e.g. walls, columns)

SF3 (760 – 850 mm) is typically produced with a small maximum size of aggregates (less than 16 mm) and is used for vertical applications in very congested structures, structures with complex shapes, or for filling under formwork. SF3 will often give better surface finish than SF 2 for normal vertical applications but segregation resistance is more difficult to control. Target values higher than 850 mm may be specified in some special cases but great care should be taken regarding segregation and the maximum size of aggregate should normally be lower than 12 mm. The results of slump-flow test are shown in TABLE 8.

TABLE 8: **Slump-flow test results**

Mix-ID	GGBS30	GGBSFA20	GGBS40	GGBSFA15	FA40	FA30	GGBSFA0
Super plasticiser	0.85%	0.8%	0.9%	0.85%	0.75%	0.75%	0.85%
Slump flow (650-800)	690	685	680	690	710	700	670

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mm							
Slump-flow (2-5) sec	3.7	3.9	4.1	3.9	2.8	3.2	4.5

- V-funnel test results for Viscosity:

TABLE 9**: V-funnel test results**

Mix-ID	**GGBS30**	**GGBSFA20**	**GGBS40**	**GGBSFA15**	**FA40**	**FA30**	**GGBSFA0**
V-funnel (sec)	9.5	10.2	10.3	10.0	8.5	9.2	10.8

- L-box test results for passing ability:

TABLE 10**: L-box test results**

Mix-ID	**GGBS30**	**GGBSFA20**	**GGBS40**	**GGBSFA15**	**FA40**	**FA30**	**GGBSFA0**
L-box (Ratio)	0.94	0.92	0.92	0.91	0.97	0.96	0.9

B. Test on Hardened Concrete

The concrete is tested for the hardened properties like compressive strength, split tensile and flexural strengths each for 7 days, 14 days and 28 days. All tests were performed in accordance with the provision of IS: 516-1959 and IS: 5816-1999. The test results are tested below.

TABLE 11**: Compressive strength (in MPa) test results**

Mix-ID	**GGBS30**	**GGBSFA20**	**GGBS40**	**GGBSFA15**	**FA40**	**FA30**	**GGBSFA0**
3-days	17.9	13.7	12	13.5	12.6	18.2	13.1
7- days	24.3	21.6	20.9	22	21.1	22.8	21.4

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28-days	39	34.9	36.9	34.5	35.4	37.1	41.6

TABLE 12: **Flexural strength (in MPa) test results**

Mix-ID	**GGBS30**	**GGBSFA20**	**GGBS40**	**GGBSFA15**	**FA40**	**FA30**	**GGBSFA0**
28-days	7.2	7	7	6.5	6.6	6.7	7.5

TABLE 13: **Split tensile strength (in MPa) test results**

Mix-ID	**GGBS30**	**GGBSFA20**	**GGBS40**	**GGBSFA15**	**FA40**	**FA30**	**GGBSFA0**
28-days	4.3	3.6	3.8	3.4	3.5	4	4.3

V. RESULTS AND DISCUSSIONS

A. Fresh Concrete

- The slump flow of slag cement SSCs was in the range of 680 to 690 mm, which is less than Fly ash concrete and the V-funnel flow times were in the range of 9.5 to 10.5 sec.
- Slump flow decreases and V-funnel flow time increases with the increase of slag cement.
- It should be noted that to obtain the SCC properties , the slag mixtures requires a dosage of SP ranging from 3.6lt/m^3 to 4.05lt/m^3 , where as Fly ash concrete required a dosage 3.375 lit/m^3.The use of slag cement in SCC significantly increases the dosage of Super Plasticiser (SP). The result also shows that the dosage of SP seems to be increases with the increases of slag cement.
- The rheological tests results indicate that presence of Fly ash is necessary to achieve and improve SCC properties in the GGBS concrete. The mix containing GGBS25 shows improved in fresh concrete properties when compared to the mix containing GGBS50.

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B. Compressive Strength.

- The compressive strength at the ages of 3, 7, and 28 days for different replacement of cement with GGBS are shown in the above tables. It is observed that the compressive strength at 3 days, in which cement is replaced by 25%, 50% of GGBS were 17.9, 12.0 MPa and at the age of 7 days were 24.3, 20.9 and at the age of 28 days were 39.0, 36.9 MPa respectively. The compressive strength at the ages of 3, 7, and 28 days for the Normal SCC (100% cement) were 18.1, 29.4, 51.6 MPa.
- Tests results indicate that compressive strength at 3 days for replacement of GGBS at 25% shows an increase in strength of about 27% w.r.t normal SCC. However at 50% replacement of GGBS shows decrease in strength of about 8% w.r.t normal SCC.
- Tests results indicate that compressive strength at 7 days for replacement of GGBS at 25% shows an increase in strength of about 12% w.r.t normal SCC. However at 50% replacement of GGBS possess almost same strength as that of normal SCC.
- Test result at 28 days indicates that the incorporation of GGBS in concrete results in decrease in strength when compared to Normal SCC. But at 25% replacement of GGBS, strength at 28 days is slightly more than the target means strength of the design mix (38.25MPa). Therefore it can be concluded that the 25% GGBS can be utilized for structural concrete strength governs the design. However in situation where the transverse of full design loads in structure is likely to be delayed beyond 28 days, it is possible to use even higher replacement levels of cement with GGBS as the continued pozzolanic reaction will enable the target strength to be reached in such cases.

C. Flexural Strength.

- The Flexural strength at 28 days for different replacement of cement with GGBS is given in **Table 12**. It is observed that the Flexural strength at 28 days, in which cement is replaced by 25%, 50% of GGBS were 7.2, 7.0 MPa. The Flexural strength at 28 days for the Normal SCC (100% cement) were 7.5 MPa.
- Comparing the Flexural strength at 28 days it is seen that replacement of GGBS at 50% shows an decrease in strength of about 7% w.r.t. Normal SCC. However for 25% replacement of GGBS possess almost same strength as that of Normal SCC.

D. Split tensile Strength.

- The Split Tensile Strength at 28 days for different replacement of cement with GGBS is given in **Table 13.** It is observed that the Split Tensile Strength at 28 days, in which cement is replaced by 25%, 50% of GGBS were 4.3, 3.8 MPa. The Split tensile strength at 28 days for the Normal SCC (100% cement) were 4.3 MPa.
- Comparing the Split Tensile Strength at 28 days it is seen that replacement of GGBS at 25%

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shows same as that of Normal SCC. However at 50% replacement of GGBS shows decrease in strength of about 12% w.r.t Normal SCC.

VI. CONCLUSIONS

The latest trend in concrete research is to use industrial by-products in preparing the concrete mixes. The addition of GGBS and FA as mineral additives in SCC is a step that would gainfully employ these two otherwise waste products whose disposal is an issue in itself. In this work, SCC prepared using these industrial by-products are evaluated in terms of self compact ability, compressive strength, split tensile strength and flexural strength. From the experimental investigations, the following conclusions may be drawn:

- FA has great capability to reduce the admixture demand to achieve a desired slump flow. The demand of admixture decreases with the increases of FA content to achieve slump flow. 30% replacement of cement by FA gives slump of 710 mm, which is Maximum when it is compared to other mix proportion.
- According to our study, addition of FA to the concrete, can improve the fresh concrete properties.
- SCC mix which incorporates GGBS requires high dosage of super plasticiser to produce acceptable workability.
- Replacement up to 40% of cement with GGBS shows decrease in slump flow when compared to replacement of cement with FA.
- The results shown that the use of FA in GGBS concrete offsets the effect of GGBS has increasing the dosage of admixture in concrete to achieve fresh concrete properties.
- It is possible to produce SCC by combined replacement of FA and GGBS satisfies the criteria for fresh concrete properties such as slump flow, passing ability, filing ability.
- The results derived from compressive strength tests showed that GGBS cement are more effective than Normal concrete in terms of early strength gain beyond 28 days strength.
- The mixture of SCC contained 30% of GGBS in the total cementitious content showed adequate strength development at 28 days strength with cement content 450 kg/m^3 develop 39MPa which is nearer to Normal SCC(100% cement) 41.2Mpa.
- Replacing cement with the FA reduces the strength of SCC mix when compared with GGBS and Normal SCC mix.
- The combined replacement of FA and GGBS cement shows increases in strength by increase in percentage of replacement.
- SCC mix which incorporates of powder material comprising of 60% ordinary Portland cement, 20% FA and 20% GGBS obtains high compressive strength of 34.9 MPa.

- SCC mix which incorporates of powder material comprising of 60% ordinary Portland cement, 20% FA and 20% GGBS obtains high Flexural strength of 7.0MPa.
- The combinations of FA and GGBS could be used as partial cement replacement in SCC production.

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