EXPERIMENTAL STUDY ON SELF-COMPACTING CONCRETE CONTAINING INDUSTRIAL BY-PRODUCTS

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Abstract

Self-Compacting Concrete (SCC) is a type of concrete that has the capacity to consolidate under its own weight. The current trend all over the world is to utilize the treated and untreated industrial by-products, domestic waste etc. as a raw material in concrete, which gives an eco-friendly edge to the concrete preparation process. This practice not only helps in reuse of the waste material but also creates a cleaner and greener environment. This study aims to focus on the possibility of using industrial by-products like Ground Granulated Blast furnace Slag (GGBS) and Silica fumes (SF) in preparation of SCC. The usage of these powders is proposed as a replacement for cement in the production of SCC by adopting the much popular Nan Su et al. method of mix design. The paper deals with comparison of performances of GGBS and SF based SCC mixes.

Keywords: Self compacting concrete, blast furnace slag, silica fumes, compressive strength, split tensile strength, flexural strength

1. Introduction

Self-compacting concrete (SCC) was first developed in Japan in the late 1980's as a concrete that can flow through congested reinforcing bars with elimination of compaction, and without undergoing any significant segregation and bleeding (Melo K.A et al., 2010; Siddique R 2011; Liu M 2010). In recent times, this concrete has gained wide use in many countries for different applications and structural configurations. Adoption of SCC offers substantial benefits in enhancing construction productivity, reducing overall cost, and improving work environment. It is used when there is a shortage of labour, and also helps in achieving better surface finish (Khayat K.H 1999). Such innovative concrete requires high slump which can be achieved by the addition of super plasticizer. To avoid segregation on super plasticizer addition, the sand content is increased by 4% to 5%. When the volume of coarse aggregate in the concrete is excessive, the opportunity of contact between coarse aggregate particles increases greatly, causing interlocking and the possibility of blockage on passing through spaces between steel bars is also increased. Therefore, the first point to be considered when designing SCC is to restrict the volume of the coarse aggregate. This reduction necessitates the use of higher volume of cement which increases the cost, besides resulting in undesirable temperature rise. So cement should be replaced by other mineral admixtures like Blast Furnace Slag, Fly Ash, Silica Fumes, etc.

The usage of mineral admixtures in the production of SCC not only provides economical benefits but also reduces heat of hydration (EFNARC guidelines 2002). It is also known that some mineral admixtures may improve rheological properties and reduce thermally-induced cracking of concrete due to the reduction in the overall heat of hydration, and increase the workability and long-term properties of concrete (Recommendation for Construction of Self Compacting Concrete 1998). There is no standardized mix proportion for designing SCC, hence in this work the Nan Su et al. [Nan Su et al. 2001) method of mix design is adopted with Ground Granulated Blast furnace Slag (GGBS) and Silica fumes (SF) as powders for partial replacement of cement. Further, a comparison of the self-compatibility properties, and hardened properties like Compressive Strength, Spilt Tensile Strength and Flexural Strength for GGBS based SCC, and SF based SCC is made.

2. Materials

2.1 Cement

In this experimental study, Ordinary Portland Cement conforming to IS: 8112 -1989 (43 Grade Ordinary Portland Cement- Specification), was used. The physical and mechanical properties of the cement used are shown in Table 1.

Table 1 Properties of Cement

Physical property	Results
Fineness	2940 cm^2/gm.
Normal Consistency	29%
Vicat initial setting time (minutes)	64
Vicat final setting time (minutes)	192
Specific gravity	3.12
Compressive strength at 3-days	23.91 MPa
Compressive strength at 7-days	36.95 MPa
Compressive strength at 28-days	45.86 MPa

2.2 Ground Granulated Blast Furnace Slag (GGBS)

Ground granulated blast-furnace slag is a non-metallic powder consisting of silicates and aluminates of calcium and other bases. The molten slag is rapidly chilled by quenching in water to form glassy sand like material. The chemical composition of blast furnace slag is similar to that of cement clinker. The performance of slag depends on the chemical composition and fineness of grinding. The quality of slag is governed by IS: 12089-1987 (Specification for Granulated Slag for Manufacture of Portland Slag Cement). Table 2 shows the properties of GGBS.

2.3 Silica Fumes (SF)

Silica fumes also referred to as micro silica or condensed silica fume, is another material that is used as a pozzolonic admixture. It is a product obtained from reduction of high purity quartz with coal in an electric furnace in the manufacture of silicon or ferrosilicon alloy. Table 2 shows the properties of SF.

Table 2 Properties of GGBS and SF

Property	Test Results	
	GGBS	SF
Colour	Dull white	Light blue
Consistency, %	36.0	106.0
Specific Gravity	2.83	2.14

2.4 Aggregates

Locally available river sand of specific gravity 2.64, fineness modulus 2.91, and conforming to Zone II was used as fine aggregate. The crushed granite stone with a maximum size of 12 mm, and specific gravity 2.65 was used as coarse aggregate. Both the aggregates used conformed to IS: 383-1970 (Specification for coarse and fine aggregates from natural sources for concrete).

2.5 Super plasticizer (SP)

Super plasticizer (SP) is a chemical compound used to increase the workability, without using any additional water. The super plasticizer used in the present work is the commercially available brand, Cera Hyper plasticizer.

2.6 Water

Potable water was used for mixing and curing.

3. Mix Proportioning

The mixture proportion is a key factor to be considered to achieve SCC. Though the SCC was first developed in 1980's, there is no standard mix design adopted or developed to achieve SCC. The European Federation of Specialist Construction Chemicals and Concrete Systems (EFNARC) provide the guidelines for development of SCC. But no method of mix design specifies the grade of concrete in SCC except the Nan Su et al. method. This work mainly concentrates to achieve SCC of M25 grade by the method proposed by Nan Su et al., which specifies the usage of two powders viz., Fly Ash and GGBS as the replacement for cement in the same mix. In this work the above method is adopted to achieve SCC with GGBS and SF in two different mixes. The mix proportion obtained for the present work by adopting the said method is listed in Table 3.

Table 3 Mix proportioning (kg/m^3)

Mix Constituent	GGBS based SCC	SF based SCC
Cement (kg/m^3)	200	200
Powder	403.95	201.53
Fine Aggregate	743	743
Coarse Aggregate	961	961
Total water	224.90	295.29
Super plasticizer	10.87	7.22

4. Test on Fresh Concrete

Once a satisfactory mix is arrived at, it is tested in the lab for properties like flowing ability, passing ability and blockage by adopting T50 Slump flow, L-Box, U-Box and V-funnel tests as per EFNARC guidelines to assess the property of the mix to qualify as SCC. Table 4 gives the acceptance criteria for SCC, and Table 5 gives the results of the tests conducted for the fresh SCC mixes prepared using GGBS and SF.

Table 4: SCC - Acceptance Criteria

Test	Property	Range of values
T50 Slump flow	Filling ability	2- 5 sec
V- funnel	Viscosity	6-12 sec
L- box	Passing ability	0.8-1.0
U- box	Passing ability	0-30 mm

Table 5: Test results on fresh SCC Mixes

Test	GGBS based SCC	SF based SCC
T50 Slump flow (sec)	3	4.2
V- funnel (sec)	8	10
L- box: H_2/H_1	0.90	0.93
U- box: H_2-H_1 (mm)	25	27

5. Tests on Hardened SCC

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 provisions of IS: 516-1959 (Methods of tests for strength of concrete) and IS: 5816-1970 (Splitting tensile strength of concrete – Method of test). The test results are listed in Table 6.

Table 6 Test results on Hardened SCC (in MPa)

Property	Curing Period	GGBS based SCC	SF based SCC
Compressive Strength	7 days	21.44	9.20
	14 days	23.81	11.77
	28 days	26.23	18.32
Split Tensile Strength	7 days	1.35	0.97
	14 days	1.81	1.02
	28 days	2.03	1.63
Flexural Strength	7 days	4.41	3.66
	14 days	4.71	3.81
	28 days	4.82	3.86

6. Results and discussions

6.1 Material Property and Mix Design

In the Nan Su et al. method of mix proportioning of SCC, the quantity of the powder used in the concrete is mainly dependent on the consistency and the specific gravity of the powder itself. It can be observed from Table 2 that the consistency of SF is more than that of GGBS. Hence the quantity of GGBS required in concrete which is obtained by adopting Nan Su method is more than the quantity of SF, which may be observed from Table 3.

6.2 Compressive Strength

It may be noted from Table 6 and also Fig. 1 that the 28-days compressive strength for GGBS based SCC of M25 grade is 26.23 MPa, which is about 4.92% more than the design strength. From the test results for 7 days, 14 days and 28 days compressive strength of the SF based SCC, it may be noted that the results are not very satisfactory. This could be due to increase in the SF content which is about 50.19% of total powder content, whereas the maximum content of SF in the conventional concrete is restricted to 8% (Assem A.A.H et al. 2012). The Compressive strength of SF based SCC after 7 days, 14 days and 28 days are 9.20 MPa, 11.77 MPa and 18.32 MPa respectively. Whereas the Compressive strength of GGBS based SCC after 7 days, 14 days and 28 days are 21.44 MPa, 23.81 MPa and 26.23 MPa, which clearly indicates that the GGBS based SCC gives better strength than SF based SCC.

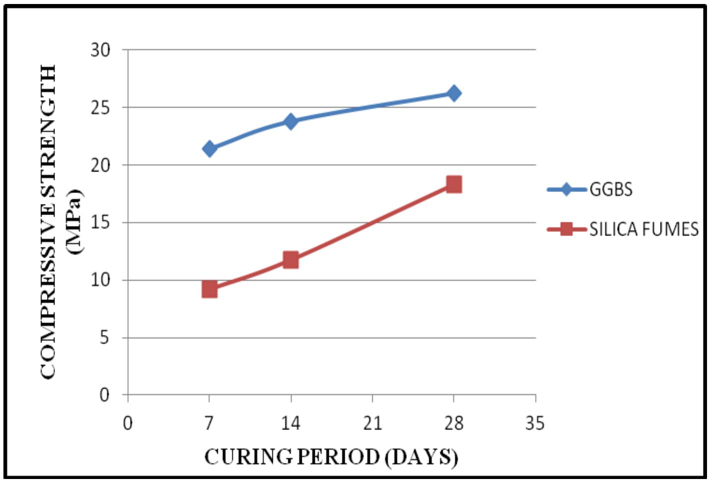

Figure 1 Variation of Compressive Strength with Curing period

6.3 Split Tensile strength

From Table 6 and also Fig. 2 it is evident that the Split tensile strength of GGBS based SCC is 39.03%, 77.45% and 24.5% more than that of SF based SCC for 7 days, 14 days and 28 days of curing period respectively.

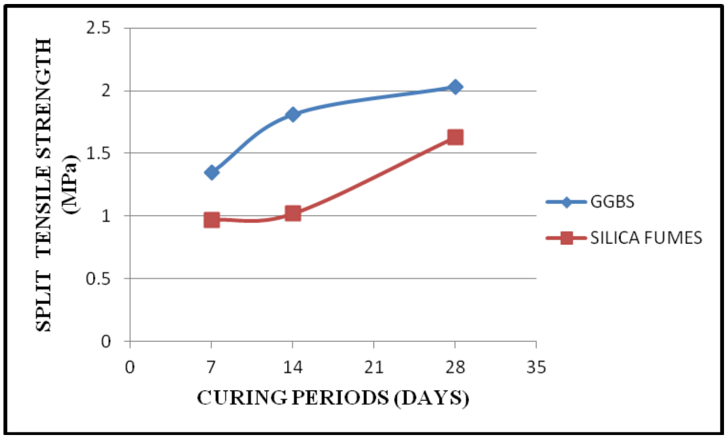

Figure 2 Variation of Split Tensile Strength with Curing period

6.4 Flexural Strength

From Table 6 and also Fig. 3, it is evident that the Flexural strength of GGBS based SCC is 20.49% , 23.62% and 24.8% more than SF based SCC for 7 days, 14 days and 28 days of curing period respectively.

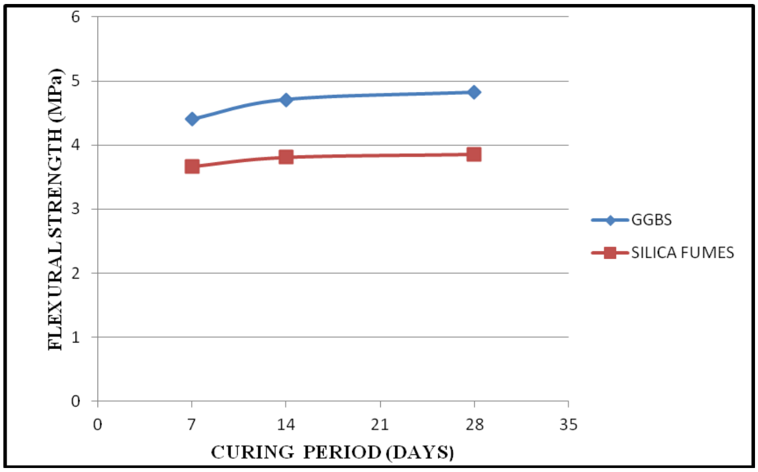

Figure 3 Variation of Flexural Strength with Curing period

7. Conclusions

The latest trend in concrete research is to use industrial by-products in preparing the concrete mixes. The addition of GGBS and SF 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 is evaluated in terms of self-compactability, compressive strength, split tensile strength and flexural strength. From the experimental investigations, the following conclusions may be drawn:

i. The SCC mixes containing GGBS and that containing SF as powder material tested for their fresh properties as per EFNARC guidelines, have satisfied the norms laid down by EFNARC. From this it can be concluded that achieving fresh SCC properties is possible by adopting the Nan Su et al. method when these industrial by-products are used as powders.

ii. The GGBS based SCC has good Compressive strength, Split tensile strength and flexural Strength when compared to the SF based SCC.

iii. The low strength of SF based SCC is possibly due to the high amount of SF (50.19%) in the mix.

iv. Though the optimum amount of GGBS content is 30% of the total powder content (Dinakar P et al. 2013), the experimental investigation proved to have satisfactory results for GGBS based SCC of grade M25 for 66.88% of total powder content. It is also seen from literature review that high volume GGBS content of 80% can be used to achieve strength of 30MPa (Dinakar P et al. 2013). The strength gain of GGBS based mix may be attributed to a higher pozzolonic activity of GGBS as compared to SF.

v. The other types of fillers, viz., fly ash, stone powder, and ground glass (as recommended by EFNARC) may be tried in different combinations and the properties of the mixes may be investigated.

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