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High strength concrete using ground granulated blast-furnace slag with Alccofine and with silica fume

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Alccofine

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Concrete

ABSTRACT

High strength concrete (HSC) is highly promising building material widely used in large scale concrete constructions that require high strength, high flow ability and high durability. Several studies have been carried out in past decades to identify the use of supplementary cementitious material in concrete. To increase the durability along with strength of concrete leads to the use of high-strength concrete which is more beneficial for environmental attacks on the structure. Various studies are performed on HSC with respect to workability, strength and durability. The addition of different mineral and chemical admixtures increases the strength and durability of HSC. The effect of SCM on strength and durability of High Strength Concrete (HPC) using ground granulated blast-furnace slag (GGBS) with Alccofine and GGBS with silica fume is studied.

1. Introduction

1.1 General

Nowadays huge quantity of concrete is consumed in construction industry to meet the increasing demand of infrastructure due to increase in population and urbanization. The continuous global demand for concrete indicates that, more aggregate and cement is required in the production of concrete, thereby leading to more extraction and depletion of deposits of natural gravel, and increased CO_2 emission [1]. The conventional concrete is designed on the basis of compressive strength does not meet durability requirements. High strength concrete (HSC) aims to enhance strength and consequent advantages owing to improved strength, is used in the majority of construction applications. HSC is a concrete that possesses high strength, workability, density and durability [1-2].

The concrete is generally classified according to strength as (a) conventional concrete, up to grade 60 MPa, (b) HSC, grades 60 – 90 MPa, (c) very high-strength concrete (VHSC), grades 90 – 130 MPa (d) reactive powder concrete (RPC), grades 200 – 800 MPa; (e) high performance lightweight concrete (HPLC) greater than 55 MPa. The use of high strength concrete in the construction industry has increased over the past years. This experimental study involves the use of mineral admixture such as Alccofine 1203 and ground granulated blast-furnace slag (GGBS) in enhancing the mechanical properties of high strength concrete [3-4]. Silica fume is a by-product of the silicon smelting process which is a pozzolanic material. Silica fume is used in high-strength concrete in two different ways, as replacement for cement, and as an additive to improve properties of concrete. The main advantage of mineral admixtures in high-strength concrete is to reduce the cement content, which results in economic and environmental benefits but also increases the compressive strength and durability [5].

High Strength Concrete is required in engineering projects which has to resist high compressive loads. It is typically used in the construction of high rise structures for components such as columns, shear walls and foundations and also used in the construction of highway bridges [6]. HSC also permits reinforced or prestressed concrete girders to span greater lengths than the normal concrete girders. It also enables to build the super structures of long span bridges and to enhance the durability of bridge decks. The use of high strength concrete offers numerous advantages in the sustainable and economical design of structures.

1.2 Mineral Admixture – Supplementary cementitious materials (SCMs)

High strength and high-performance concrete required for different applications cannot be achieved with Ordinary Portland cement (OPC) alone. Mixes containing high volume of cement results in high heat of hydration, shrinkage cracks and also affects the workability. Too much cement volume also contributes to increase in the carbon footprint of the resulting concrete. To overcome the problems associated with higher cement content, mineral admixtures are introduced by fixing minimum and maximum cement content for different environmental condition and application. Mineral admixtures obtained from different sources are finely divided natural pozzolanic materials. They can be used in range of 20%-70% by volume of cement. Such Mineral admixtures are economical and environmentally friendly as well. Mineral admixtures may be pozzolanic (fly ash), cementitious (GGBS) or both (high calcium fly ash) which are obtained naturally as by products from industry [8]. Different mineral admixtures available are fly ash, GGBS, silica fume, rice husk ash, Alccofine, Metakaolin, etc. [10-11].

These mineral admixtures improve concrete parameters in terms of workability, strength, durability, shrinkage reduction and reduction in heat of hydration. Following characteristics define the concrete as high performance concrete with the incorporation of mineral admixtures.

1. High consistency (no segregation)
2. High durability
3. High early strength
4. High ultimate strength
5. Sustainable and Cost effectiveness (use of industrial by products)

1.3 Cement

Cement, being the key binder material, contributes to the strength of concrete. For achieving high strength concrete, high grade cement is necessary, 53-grade Ordinary Portland cement which confirms to IS 12269-2013 is used. Properties of cement are listed in Table 1.

Table 1

Properties of Cement

Grade	53
Specific gravity	3.15
Fineness (m^2/Kg)	276
Colour	Dark grey, No lumps

Fig. 1 shows the SEM image of cement particle surface morphology showing its flaky angular structure.

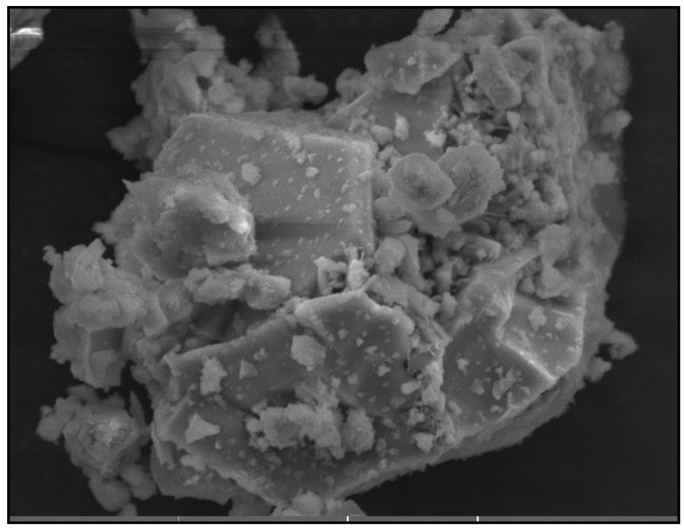

Fig. 1. SEM of Cement

1.4 Ground Granulated Blast-furnace Slag (GGBS)

Higher cement content in high strength concrete induces more heat of hydration. To reduce this and to increase durability, industrial by-product such as GGBS is used, replacing the percent cement volume. GGBS is obtained as a byproduct from blast-furnace of iron-ore. Slag contains silicate, alumina silicates and calcium silicates [9,12]. To activate slag, Portland cement is good catalyst, GGBS results in better flow than any other mineral admixture. For present work, GGBS is procured from JSW and properties are given in Table 2.

Table 2

Properties of GGBS

Specific gravity	2.8
Fineness (Blaine’s air)	385 m^2/kg

Fig. 2 gives the SEM image of GGBS sample. It has similar morphological surface as of cement showing finer angular and flaky particles.

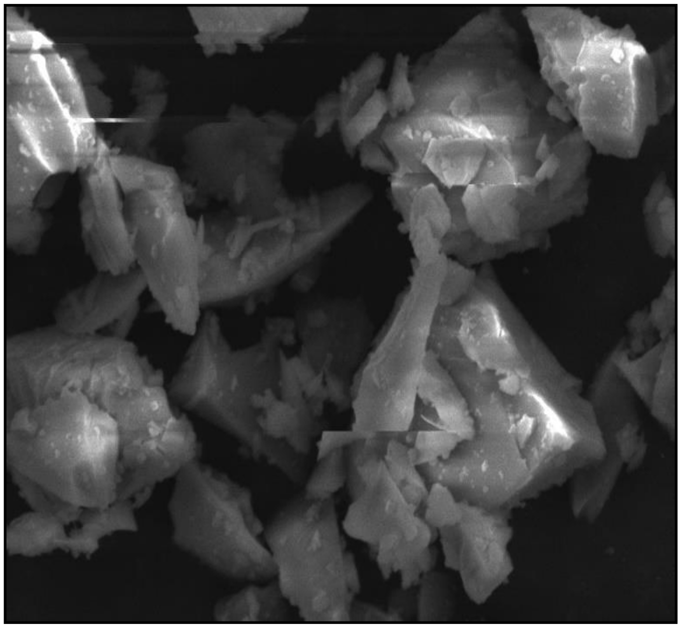

Fig. 2. SEM of GGBS

1.5 Alccofine

Mineral additive and its low calcium-based slag. It improves the hydration process as well increases the fast-early-strength [4]. Alccofine is procured from Alccofine division of Ambuja Cement. Particle size is very small and can fill up the pores left by cement and GGBS, properties tabulated in Table 3. Fig. 3 gives the SEM image of Alccofine which exhibits finer flaky particles than GGBS.

Table 3

Properties of Alccofine

Specific gravity	2.61
Avg. particle size (μ)	4-6
Fineness (m^2/Kg)	1000

1.6 Silica fume

Silica fume is a by-product of the manufacturing process of silicon and ferrosilicon alloys and is in a form of glass which is highly reactive [7]. The small size of particles will accelerate the reactions with calcium hydroxide which enables silica fume to replace Portland cement for a small proportion. The major purpose of introducing silica fume to the concrete mix is to achieve high strength and durability [13]. The presence of silica fume also enhances the effectiveness of super plasticizer, which consequently reduces w/b ratio required to achieve a certain level of workability [14-15]. Normally, 3 to 10% of silica fume is used for high performance concrete.

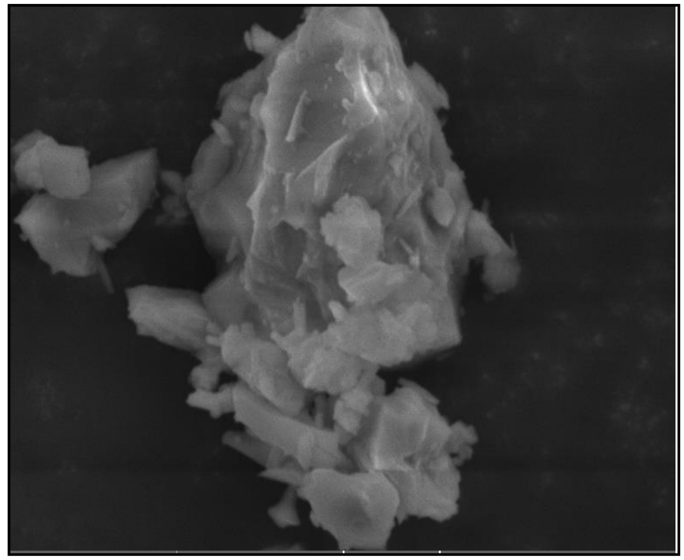

Fig. 3. SEM of Alccofine

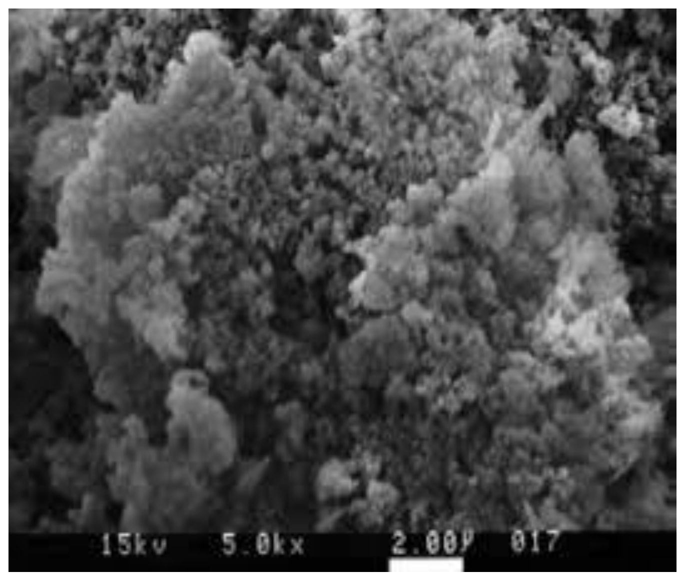

Fig. 4. SEM of Silica Fume

1.7 Aggregates

In concrete, aggregate volume acts as structural filler, which binds together with the cement to form a strong composite. Any given concrete mix generally contains 60-70% of aggregate volume. Its volume is huge compared to other constituents of concrete. The parameters such as shape, gradation, origin/parent rock characteristics contributes significantly on the workability, strength, durability and shrinkage properties of resulting concrete. In the present research, natural river sand is used as fine aggregate and a coarse aggregate of granite origin is used which are purchased from a local source. The physical characteristics of the aggregates are tested and are enlisted in the following tables. Sieve analysis of aggregates was carried out as per IS: 2386 (Part 1) and tabulated in Tables 4, 5, 6 and 7.

Table 4

Sieve analysis of coarse aggregate (20 mm down)

Sieve Size (mm)	Weight Retained (g)	% Retained	Cumulative % Retained	% Passing	% Passing as per IS:383-1970
40	0	0	0	100	100
20	740	14.7	14.7	85.3	85-100
10	4200	82	98.2	1.25	0-20
4.75	40	0.9	99.7	0.45	0-5

Table 5

Sieve analysis of coarse aggregate (12.5 mm down)

Sieve Size mm)	Weight Retained (g)	% Retained	Cumulative % Retained	% Passing	% Passing as per IS:383-1970
1	0	0	0	100	100
12.5	215	4.32	4.32	95.7	85-100
10	491	9.8	14.11	85.9	0-45
4.75	4130	82.6	96.7	3.3	0-10

Table 6

Sieve analysis of fine aggregate

Sieve size (mm)	Weight of sand retained (g)	% of sand retained	Cumulative % retained	% Passing
4.75	10	1	-	99
2.36	16	1.6	2.6	97.4
1.18	158	15.8	18.4	81.6
0.6	260	26	44.4	55.6
0.3	332	33.2	77.6	22.4
0.15	204	20.4	98	2

Table 7

Specific gravity and water absorption values of aggregates

Parameter	Coarse Aggregate	Fine Aggregate
Specific gravity	2.67	2.63
Water Absorption (%)	0.3	3.2

1.8 Water

Water is also an important constituent of concrete needed during the fresh and hardened state to attain the required strength. Potable water which is available in the institution premises is used for the mixing purpose throughout the experimental work.

1.9 Super Plasticizer

Usually in high strength concrete, volume of water is less compared to paste volume, i.e. water/concrete (W/C) ratio. Super plasticizers are of key importance in maintaining the workability of concrete at low W/C ratio. Poly Carboxylic Ether (PCE) based ‘Master-Sky Glinum JP 30 supplied by BASF Chemicals is used in the concrete preparation.

2. Experimental investigation

In this section, a detailed explanation of the methods used in mix proportioning, procedure adopted in testing the resulting concrete are explained.

2.1 Approaching to Mix Proportions

2.1.1 Least void of aggregates–control mixes

Least void of coarse aggregate and fine aggregate is calculated so that the paste will fill up these voids and gets adhered to surface of aggregates and make concrete dense. Initially void ration of 20 mm down and 12.5 mm down coarse aggregates is calculated. The least void obtained for coarse aggregate proportion is 40% (20 mm) : 60% (12.5 mm). Further least void is calculated for coarse aggregate and fine aggregate as in Tables 8 and 9 and Figs. 5 and 6.

Table 8

Percentage void observation for coarse aggregates

Minimum Void Calculation of CA				
20 mm	12.5 mm	Weight	Density	% voids
100%	0	4323	1.54	41.68
90%	10%	4387	1.56	40.81
80%	20%	4466	1.61	39.75
70%	30%	4524	1.60	38.96
60%	40%	4567	1.63	38.38
50%	50%	4596	1.63	37.99
40%	60%	4605	1.65	37.87
30%	70%	4542	1.62	38.72
20%	80%	4477	1.60	39.60
0%	100%	4223	1.51	43.03

Table 9

Percentage void for coarse and fine Aggregate

Minimum void calculations for CA and FA				
10 mm	4.75 mm	Weight	Density	% voids
100%	0%	4194	1.51	43.00
90%	10%	4545	1.62	38.20
80%	20%	4874	1.73	33.76
70%	30%	5129	1.84	30.29
60%	40%	5339	1.92	27.43
50%	50%	5304	1.91	27.88
40%	60%	5264	1.89	28.43
30%	70%	5204	1.86	29.27
20%	80%	5065	1.81	31.16
0%	100%	4581	1.64	37.74

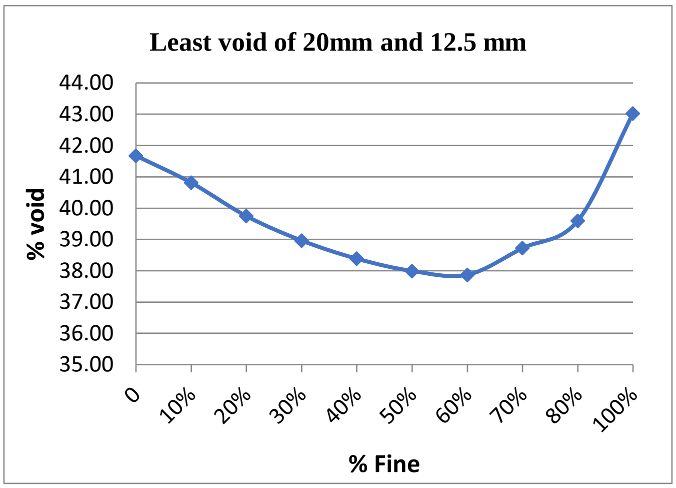

Fig. 5. Graph for Least void Proportion

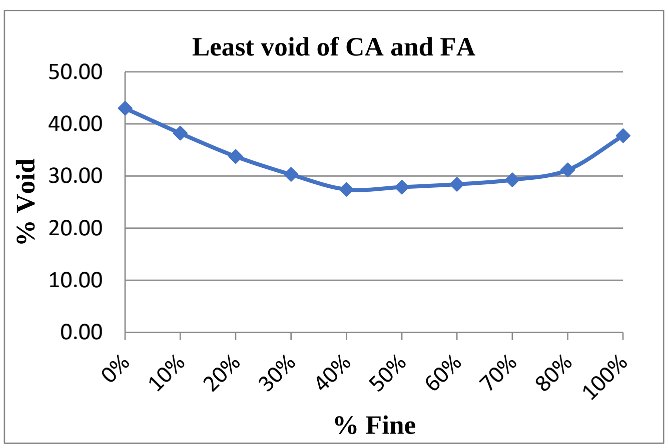

Fig. 6. Graph for Least void Proportion for CA and FA

Least void of 0.27 for coarse aggregate and fine aggregate blend is obtained for the proportion of 60%:40%. Volume of paste method is used for the initial mix calculation. On the basis of least void of aggregates obtained, volume of paste (V_P) is decided to be 0.27 and the next mixes are calculated by increasing the V_P by 10% and are listed in table below. Water to cement ratio of 0.32 is fixed and maintained same for all other mixes. For V_P = 0.27, cement content of 424 kg/m^3 is used. Since because of less volume of paste and aggregate volume of 0.73 mix became dry even though super plasticizer volume is increased. For further increments in V_P cement content is fixed to 450 kg/m^3 as per IS 456:2000 guidelines. To maintain the water to cement ratio of 0.32, water of about 144 litres is adopted. Further to maintain powder ratio proportion to volume of paste, GGBS is introduced into mix as supplementary cementations material instead of increasing Cement. Table 10 gives the mix proportioning of initial control mixes. The so prepared mixes are assessed for fresh and hardened properties to derive an optimum mix. The observations are tabulated and based on compressive strength results obtained V_P = 0.38 is considered as the control mix for further enhancements.

Table 10

Mix proportioning of Control mixes

Mix	Paste volume	Cement (Kg/m^3)	GGBS (Kg/m^3)	Water (Kg/m^3)	CA, 20 mm (Kg/m^3)	CA, 12.5 mm (Kg/m^3)	FA (Kg/m^3)
CM 1	0.27	424	-	135.5	467.5	696.5	765.0
CM 2	0.29	450	-	144	454.8	677.4	744.0
CM 3	0.3	450	29	144	450.5	670.6	735.8
CM 4	0.32	450	107.3	144	433.2	645.3	709.4
CM 5	0.35	450	185.6	144	415.9	619.1	680.2
CM 6	0.38	450	264	144	399.6	593.4	652
CM 7	0.4	450	327.7	144	384.5	572.4	628.8
CM 8	0.42	450	385.7	144	373.1	553.4	608.8

2.2 Alccofine Mixes

For the hitherto fixed control mix (CM-6) of V_P = 0.38, Alccofine is introduced. The aggregate volume part is replaced by 2%, 4% and 6% of Alccofine in trial samples so as to maintain density of control mix. Mix proportioning of different Alccofine mixes is given in Table 11.

As Alccofine volume increased, the mix became very sticky at 6% replacement and which proved very difficult to handle and place. To overcome this problem water quantity is increased to 150 litres without changing the water to cementitious ratio 0.202 for 6% replacement. This increased water mix was better flowing and easy to handle. The prepared mixes are observed for their fresh and hardened properties to derive an optimum mix

Table 11

Mix proportioning of Alccofine mixes

Mix	Cement (Kg/m^3)	GGBS (Kg/m^3)	Alccofine (Kg/m^3)	Water (Kg/m^3)	CA, 20 mm (Kg/m^3)	CA, 12.5 mm (Kg/m^3)	FA (Kg/m^3)
AL1 (2%)	450	264	9	144	395.31	588.4	646.6
AL2 (4%)	450	264	18	144	394.31	586.6	644.6
AL3 (6%)	450	264	27	144	392.12	583.4	641.1
AL4 (6%)	450	264	27	150	392.1	583.8	641.1

Based on the compressive strength results of all Alccofine mixes, Alccofine mix with 6% replacement and 150 litres of water showed better results. Hencemix AL-4 is used for further enhancement with the introduction of Nano materials in concrete.

2.3 Silica fume Mixes

For the hitherto fixed control mix (CM-6) of V_P = 0.38, Silica fume is introduced. The aggregate volume part is replaced by 2%, 4%, and 6% of Silica fume in trial samples so as to maintain density of control mix tabulated in Table 12.

Table 12

Mix proportioning of Silica mixes

MIX	Cement (Kg/m^3)	GGBS Kg/m^3	Silica fume (Kg/m^3)	Water (Kg/m^3)	CA, 20 mm (Kg/m^3)	CA, 12.5 mm (Kg/m^3)	FA (Kg/m^3)
SF1 (2%)	450	264	9	144	395.3	588.5	646.6
SF2 (4%)	450	264	18	144	394.3	586.9	644.6
SF3 (6%)	450	264	27	144	392.1	583.7	641.1
SF4 (6%)	450	264	27	150	392.1	583.7	641.1

As Silica fume volume increased, the mix became very sticky at 6% replacement and which proved very difficult to handle and place. To overcome this problem water quantity is increased to 150 litres without changing the water to cementitious ratio 0.202 for 6% replacement. This increased water mix was better flowing and easy to handle. Thus prepared mixes are observed for their fresh and hardened properties to derive an optimum mix. Based on the compressive strength results of all silica fume mixes, silica fume mix with 6% replacement and 150 litres of water showed better results. Hence mix AL-4 is used for further enhancement with the introduction of nano materials in concrete.

2.4 Specimen Preparation

2.4.1 Mixing

The mixing of concrete ingredients is done in the laboratory pan mixer having capacity of 50 Kg and speed of 30 revolutions per minute. To have homogeneous and uniform mix throughout the work, systematic mixing sequence is followed.

Mixing sequence is as follows.

1. Pre-wetting of internal surface of mixer to avoid possible moisture absorption
2. All powder contents such as cement, GGBS, Alccofine were added and mixed thoroughly for 2-3 minutes. Measured water and small quantity of super plasticizer were added.
3. After uniform formation of paste, coarse and fine aggregates were added.
4. To obtain required workability, SP was added by visible observation.
5. Because of the finer particles like GGBS and Alccofine are present in the mix, it was observed that flow increased as time of mixing is increased.
6. Once a proper cohesion was attained, mix was taken out for further tests and casting.

2.4.2 Casting

After mixing, for advanced studies on concrete such as harden properties, required number of cubes, cylinders, and beams specimens casted for different days of testing. Three 100 mm cubes, three 100 mm diameter, 200mm height cylinder, 3 500 mm x 100 mm x 100 mm beam are casted for each test. To obtain uniform quality of packing, specimens are vibrated on table vibrating machine for minimal time.

2.4.3 De-Moulding and Curing

Specimens are de-moulded from their moulds after 24 hours of setting period. Specimens are named with respect to mix and days of testing and kept for curing. Curing is a process to maintain sufficient moisture for hydration process and to get strength over time. After de-moulding, specimens are kept for curing in water at ambient temperature for 3, 7 and 28 days.

2.5 Testing Methods

To study the fresh and hardened properties of concrete specimens, different tests were conducted. For fresh property slump test was carried out, for hardened properties compressive strength tests, split tensile strength test, flexural strength test, Modulus of elasticity and water permeability tests are done.

2.5.1 Fresh Property of concrete

This test gives workability parameter of concrete. Which is carried out according to IS 1199:1959. Slump test is carried out for every mix after proper mixing. Measured slump or flow values in mm are noted down.

2.5.2 Harden properties of concrete

Different tests conducted on concrete specimens are explained below. Apart from compressive strength test, optimum concrete mixes are further tested for split tensile strength test, flexural strength test and water permeability test

2.5.2.1 Compressive strength test: Strength / grade of concrete is always assessed by the cube compressive strength, tested after different curing days. Test is conducted as per IS 516:1959. 100 mm cube specimens are tested under compressive testing machine having capacity of 3000KN

2.5.2.2. Split tensile strength test: Considered as an indirect tensile strength test, Split tensile test is carried out as per IS 5816-1989 using Cylinder specimen of 100 mm diameter and 200 mm height. They are tested in compression testing machine for splitting.

2.5.2.3. Flexural strength test: Test was conducted on beam specimen of dimension 500 mm x 100 mm x 100 mm under strain controlled flexure testing machine.

2.5.2.4. Water permeability test: It is one of the durability test performed on cylinder specimens to find out ingress of water in the specimen under certain uniform pressure of 5 bar. Testing is done as per DIN-1048 (Part 5). The cylinder specimens of 100 mm diameter, 200 mm height are subjected to test.

3. Results and Discussion

3.1 Fresh Properties of concrete

Slump test was carried out to measure the slump or slump flow of each mixes.

3.1.1 Control mixes

The slump or slump flow values of different mixes are represented in Table 13. Fig. 7 shows the slump loss of CM 1 whereas Fig. 8 depicts the slump loss of CM 6.

Table 13

Fresh properties of control mix

Mixes	V_P	GGBS addition (kg/m^3)	Slump (mm)	SP dosage (%)
CM 1	0.27	-	25	0.3
CM 2	0.29	-	60	0.25
CM 3	0.30	29.0	65	0.35
CM 4	0.32	107.3	200	0.4
CM 5	0.35	185.6	550	0.5
CM 6	0.38	264	650	0.67
CM 7	0.40	327.7	770	0.75
CM 8	0.42	385.7	765	0.8

Fig. 7. Slump loss of CM 1

Mix 1 and Mix 2 contains only cement as powder content and having more aggregate volume resulted in low slump. As GGBS volume is increased adjusting it to the paste volume from Mix 3 to Mix 8, fixing the cement content as 450 Kg/m^3, improved slump was obsereved.It could be because of the surface property of GGBS particlesand influence of super plasticizer which improves the flow as observed and also reported from various researchs. Mix 5 and Mix 6 showed minor traces of seggregation. Mix 7 and 8 were very difficult to handle with trowel even though they had a flow of 750+ mm, due to the presence of large amount of GGBS. Observing the workability and strength variation as discussed out of the control set of concrete mixes, Mix CM- 6 was considered as control for next variations in material composition.

Fig. 8. Slump loss of CM 6

3.1.2 Alccofine mixes

The slump flow value and SP dosage value of different mixes are given in Table 14. To the control mix CM-6, Alccofine was added in increments of 2%, 4% and 6%. The slump was maintained for a flow value of 700+ by adjusting the dosage of super plasticizer as the powder content of the mix is increased. For mix AL-1 and AL-2 satisfactory slump flow was observed with ease in handling. But for Mix AL-3 with 6% Alccofine addition, slump flow however was crossing 700 mm the problem of handling and placing of concrete mix was observed to be very cohesive, as shown in Fig. 9. This may be due to high powder content and less water in those mixes. To overcome this problem, water quantity for mix AL-4 was increased from 144 to 150 litres/m^3 and SP dosage was reduced to 0.54%, Fig. 10. Handling of concrete was now made easy by this adjustment. Seeing the workability, ease of handling and compressive strength, Mix AL-4 was fixed as control for further comparison.

Table 14

Slump results and SP dosage of Alccofine mixes

Mixes	Alccofine (%)	Water (Litre)	Slump flow (mm)	SP dosage (%)
AL-1	2	144	740	0.8
AL-2	4	144	700	0.8
AL-3	6	144	730	1.1
AL-4	6	150	725	0.54

Fig. 9. Mix AL-3

Fig. 10. Flow of mix AL-4

3.1.3 Silica fume mixes

To the control mix CM-6, silica fume was added in increments of 2%, 4% and 6%. The slump was maintained for a flow value of 700+ by adjusting the dosage of super plasticizer as the powder content of the mix is increased. For mix SF-1 and SF-2 satisfactory slump flow was observed with ease in handling. But for Mix SF-3 with 6% Silica fume addition, slump flow however was crossing 700 mm the problem of handling and placing of concrete mix was observed to be very cohesive, as shown in Fig. 11. This may be due to high powder content and less water in those mixes. To overcome this problem, water quantity for mix SF-4 was increased from 144 to 150 litres/m^3 and SP dosage was reduced to 0.54%. Handling of concrete was now made easy by this adjustment. Considering the workability, ease of handling and compressive strength, Mix SF-4 was fixed as control for comparison. Slump flow resuts of Alccofine mixes are in Table 15.

Table 15

Slump results and SP dosage of SF mixes

Mixes	Alccofine (%)	Water (Litre)	Slump flow (mm)	SP dosage (%)
SF-1	2	144	740	0.8
SF-2	4	144	700	0.8
SF-3	6	144	730	1.1
SF-4	6	150	725	0.54

Fig. 11. Flow of Silica fume mix

3.2 Hardened Properties of Concrete

3.2.1 Compressive strength

Average Strength of three 150 mm cube of different mixes for 3, 7 and 28 days are recorded for every trial mix and are presented below.

3.2.1.1. Control mixes: Table 16 and Fig. 12 give the compressive strength test results of control mix with only GGBS addition. Graph represents the variation of compressive strength at different ages with respect to volume of paste (V_P). 0.27 being the least volume of paste resulted in 65 MPa concrete and there is no much improvement from 7 to 28 days. As volume of paste is increased with addition of GGBS keeping maximum cement content of 450 Kg/m^3, an increase in compressive strength was observed up to V_P = 0.38 and reduced for further mixes. Increase in strength values at different ages is observed much significant for CM-6 which shows 17% increase with a maximum of 110 MPa by 28 days. Decrease in strength beyond 0.38 paste volume could be due to higher powder content and difficulty in handling and compacting.

Table 16

Compressive strength of Control mixes

Mix	Volume of Paste	Compressive strength		
		3 day	7 days	28 days
CM 1	0.27	47.2	63.4	65.2
CM 2	0.29	44.6	63.1	85.5
CM 3	0.30	46.5	69.2	86.1
CM 4	0.32	56.7	66.9	98.3
CM 5	0.35	61.5	86.3	94.8
CM6	0.38	60.0	89.4	110.8
CM 7	0.40	59.5	84.2	105.4
CM 8	0.42	62.5	90.8	107.2

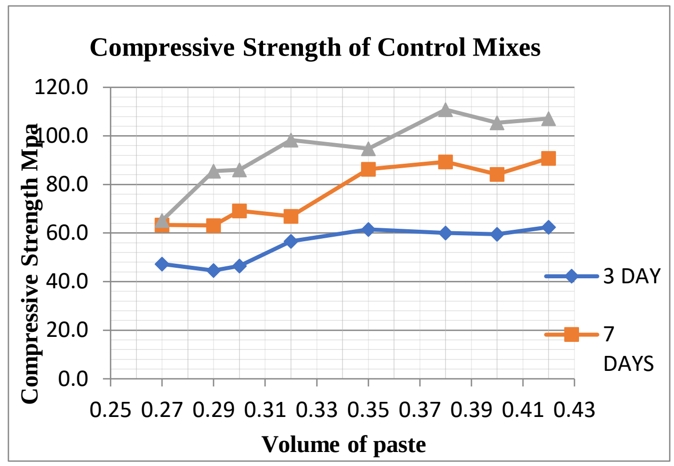

Fig. 12. Compressive strength of control mixes.

Based on the results of compressive strength mix 6 with paste volume of 0.38 was considered as the optimum mix for further material content modification.

3.2.1.2. Alccofine mixes: Table 17 gives the results of compressive strength obtained for Alccofine added mixes. Fig. 13 represents the variations of compressive strength with Alccofine mixes. Addition of Alccofine to control mix-6, have not shown any improvements in concrete for mixes AL-1, AL-2 and AL-3 compared to control and mixes are very sticky in nature and cannot be handled. For Al-4 mix water was increased as discussed in fresh property and maintained Alccofine percentage to 6%. Mix AL-4 showed an increase in early strength by 15% at 3 days of curing. However the strength increment is observed to be in the range of 2.5 to 5 % by the end of 28 days. The contribution of Alccofine to the strength is more during the initial stages than the later period of curing. This can be attributed to the fineness of Alccofine with much finer particle size than GGBS, resulting in better particle packing.

Table 17

Compressive strength of Alccofine mixes

Mix Designation	Alccofine (%)	Compressive strength		
		3 days	7 days	28 days
Control (Mix 6)	-	60.0	89.4	110.8
AL-1	2	56.7	82.5	96.20
AL-2	4	62.8	85.7	96.70
AL-3	6	64.3	87.3	110.90
AL-4	6	68.8	94.2	118.7

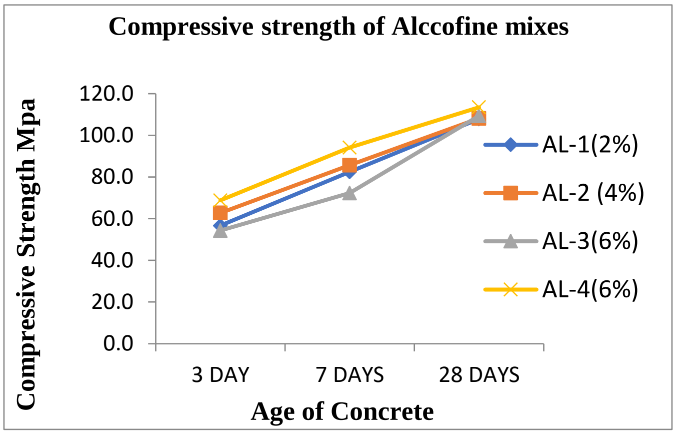

Fig. 13. Compressive strength of Alccofine mixes.

3.2.1.3. Silica fume mixes: Table 18 shows strength variation to percentage of Silica fume (SF) in concrete. Similar trends were observed in all the four mixes for 3, 7 and 28 days. Maximum strength improvement is seen in mix SF-4, But compared to Controlled mix strength was observed high.

Table 18

Compressive strength of Silica Fume mixes

Mix Designation	Silica fume (%)	Compressive strength		
		3 days	7 days	28 days
Control (Mix 6)	-	60.0	89.4	110.8
SF-1	2	46.7	72.5	75.6
SF-2	4	52.8	76.7	80.5
SF-3	6	53.3	72.3	86.4
SF-4	6	60.8	80.2	96.5

3.2.1.4. Compressive strength comparison of optimal mixes from each trial: Table 19 represents the combined strength variations of different mixes. It is observed that increase in strength at 3 days is significant for AL-4 mixes than all other mixes. And similarly, strength is increased for 7 days from control mix to AL-4 and SF-4 mix. But for 28 days, highest increase in strength is observed for the mix of AL-4 Compared to CM-6 and SF-4 Mix. As powder volume is increased strength improvements is observed and can be accounted to the filling ability, pozzolanic nature and hydration contributions of added admixtures. Further these ultrafine materials also increase the strength by improving the microstructure of resulting concrete.

Table 19

Compressive strength of optimum mixes.

Mix Designation	3 days	7 days	28 days
Control CM-6	60.0	89.4	110.8
AL-4	68.8	94.2	118.7
SF-4	60.8	80.2	96.5

3.2.2 Split tensile strength

Three cylinders were subjected to split tensile strength test and average value of split tensile strength of different optimum mixes is tabulated in Table 20. From the table it is observed that split tensile strength values linearly vary from control mix to SF-4. AL-4 mix has highest value and better than the control mix.

Table 20

Split tensile strength results of Optimum mixes.

Mix	Split tensile strength (MPa)
Control	5
AL-4	5.9
SF-4	4.7

3.2.3 Flexural strength test

Beams are tested for flexural strength in strain controlled flexural strength test machine. Test is conducted for optimum mixes and is listed in Table 21.

Table 21

Flexural strength results of optimum mixes

Mix	Flexural strength (MPa)
Control	7.8
AL-4	7.5
SF-4	6.9

Variation of flexural strength values interfered from the Table 21 that flexural strength values decreases from control mix to SF-4 mix. Unlike as in compression and tension, were trend was increasing. Possible reason for reduction in flexural strength is due to brittle nature of concrete because of high powder volume.

3.2.4 Flexural toughness

Flexural toughness is the very important safety and durability parameter of structures with high performance concrete, and it is important in the design stage and in application stage. An attempt has made been to estimate the toughness of optimum mixes of concrete.

The area under the load-deflection graph is a measure of the energy required to achieve a certain deflection and is a measure of the ductility. The term "toughness" has been coined to convey the existence of the post cracking region of the load/deflection graph for a fibre reinforced concrete. It is measured by considering the area under load deflection curve. Higher the area under the load verses deflection curve, higher will be the strain energy stored per unit volume. Even though member has reached the ultimate load, it will withstand the load for longer duration before undergoing for failure.

Table 22

Flexural strength and area under load deflection curve**.**

Mix	Flexural Strength (MPa)	Area (Under load deflection curve)
Control Mix	7.8	801.4
Alccofine Mix	7.5	4750
Silica fume Mix	6.9	8274

It can be observed in Table 22 that flexural strength of all mixes is more or equal but their strain hardening were very different. As finer materials are incorporated into the mix, delayed cracking / failure of beams under flexure was observed.

3.2.5 Water permeability test

Cylinders which are kept for water permeability test as per code are split tested to see the ingress of water in cylinder specimen. Average value of water penetration of 3 cylinders is tabulated in the Table 23. Test conducted for the control mix, Alccofine mix as well as Silica fume mix.

Table 23

Water permeability results

Mix	Water depth (mm)
Control	4
AL-4	2
SF -4	2

From the results, it can be concluded that, all the depth penetration value of water in different mixes are below the maximum permitted value of 25 mm. Because of finer powder content, hydration product and dense packing, water ingress is very low. This represents the maximum packing without any inter links or voids for penetration of water to greater depth. Lesser the penetration value, deterioration will be very low.

4. Conclusion and Future Scope

On the basis of few of the tests upon concrete for its physical parameters following conclusions can be drawn for suitability of ultra-fine materials in producing High strength/high performance concrete.

1. Least void ratio and powder to cement ratio plays very important role in HSC/HPC production.

2. As volume of paste is increased, improvement in strength is observed up to V_P = 0.38 beyond which it reduced. This can be due to the mixing difficulties because of cohesion as the volume of paste increased.

3. Alccofine addition is observed to increase the solidarity of the mix making it more cohesive but at the same time improves the strength at an optimum dosage of 6%. Water quantity is slightly increased to adjust for the cohesion of the mix.

4. Silica fume addition is observed to increase the solidarity of the mix making it more cohesive but at the same time improves the strength at an optimum dosage of 6%. Water quantity is slightly increased to adjust for the cohesion of the mix.

5. As observed from the study, upon addition of ultra-fine materials, the workability of concrete is more similar to flow able concrete (SCC). However even though flow up to 700 mm is evident, difficulty in handling the concrete because of cohesion is a considerable observation which can be attributed to high powder content of 700+ Kg/m^3 and water content of 150 Kg/m^3.

6. Early compressive strength increment can be achieved up to 70 MPa by 3 days with the incorporation of suitable admixtures, as observed for the mix AL-4. However, by the end of 28 days all concrete mixes showed similar strength in the range of 110 MPa. Highest strength of 118 MPa is achieved with 6% of Alccofine addition to concrete making it a potential mix for improvement.

7. The mixes containing Alccofine have shown improvements within concrete in terms of flexure and

split tensile strength. This could be because of the tubular structure of Alccofine holding the hydration products together under bending.

8. Materials such as Alccofine and silica fume used in the study, helped to enhance the performance of concrete. Better results can be achieved with the usage of dispersed state of nano materials in water with or without the addition of dispersing agents.

4.1. Future Scope

1. Feasibility of different types of admixtures can be worked upon with an approach towards HSC.
2. Trials can be conducted by limiting the maximum size of coarse aggregates to 10 mm down.
3. Different dosage of other available Nano material sunder different dispersion techniques with in concrete can be studied.
4. Possibilities of further reduction of water to cement ratio can be evaluated in making high performance concrete.

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