Indian Journal of Science and Technology, *Vol 8(36), DOI: 10.17485/ijst/2015/v8i36/87644, December 2015*
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

Experimental Investigation of Self Healing Behavior of Concrete using Silica Fume and GGBFS as Mineral Admixtures

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Abstract

The process of self-healing of concrete has been gaining momentum nowadays due to increased deterioration of concrete structures subjected to adverse environmental conditions. Admixtures like silica fume and ground granulated blast furnace slag is one of the self healing agents being experimented recently. The method of usage of Silica fume and ggbfs, the waste derivatives from coal and steel industries, strength and durability testing of these mixes for achieving the self healing property has been presented. The effects of self-healing on normal concrete by adding small amounts of GGBFS and silica fume to concrete is studied. For this purpose, silica fume is added to concrete at percent of 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and cement has been replaced with GGBFS by 35% and 55% respectively. The adopted water binder ratio for silica fume and GGBFS mixes is 0.45. M30 mix design is being done as per the Indian Standard Code IS: 10262-1982. The specimens are first tested for compressive strength at 28 days, then 70% and 90% of the compressive load is applied to another set of specimens to generate microcracks for studying the durability properties of the specimens. The strength properties of concrete specimens made using silica fume and GGBFS are tested for compressive strength and the durability properties are studied using sorptivity index test. The pre loaded specimens are cured for 28 days and then compressive strength tests and sorptivity index measurements are being made at an interval of 14 days. The test results indicated that self healing property can be achieved using silica fume and GGBFS as mineral admixtures as well as the use of these pozzaalonic materials increased the compressive strength values also.

Keywords: Cementitious, Pre – Loading, Sorptivity, Self – Healing, Uniaxial

1. Introduction

Construction materials having cementitious property are used all over the world. Though new materials are used in concrete, the deterioration of concrete structures is unavoidable because these structures are subjected to adverse weather conditions sometimes. Concrete structures prone to deterioration must be subjected to periodic maintenance and appropriate repair works right from the start of the building's functionality. Maintenance and rehabilitation of concrete structures consume more capital and manpower too. Thus, by adding mineral admixtures to concrete if concrete structures with more durability properties can be built then it will be beneficial[1]. Indian cement industry utilizes cementitious and pozzolanic materials for producing cost effective cement and concrete. The main constituents of concrete are aggregate, cement, and water[2]. But the serious problem faced by the cement industries is that for the production of cement, high calorific fuel is being used and subsequently, for every tonne of cement produced, the same amount of hazardous gases like carbon dioxide and nitrogen oxide are released into the atmosphere, posing a serious threat to the environment. The liberation of these toxic gases into the atmosphere adversely affects our air quality. Use of pozzolanic materials[3] like silica fume, GGBFS, etc greatly reduces the emission of carbon dioxide in the cement into the atmosphere; also eco friendly concrete

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can be manufactured with desired physical and chemical properties. Also self healing property can be achieved by the use of admixtures like GGBFS, silica fume, etc, shape memory alloys, bacteria, hollow fibres[4] and so on.

Many researchers have reviewed the use of the above materials for inducing self healing effect on normal and self compacting concrete[5]. In[6] the self healing effect on concrete specimens for cyclic loading has been effected by means of injecting precatalysed monomer into the crack opening thereby forming a polymer wedge at the tip of the formed crack openings. In[7] repairing of concrete structures is experimented by means of using bacilla filla type of bacteria which when exposed to atmospheric moisture through crack openings, form calcium lactate which is the healing product. In[8] have compared various self healing agents like hollow fibers, microencapsulation of healing agents with an expansive agent, bacteria, mineral admixtures and shape memory. In[9] crack width of mortar specimens have been measured first and the crack healing ability of the additives used as a self healing agent has been investigated. In[10] dormant bacteria and organic compounds encapsulated in porous expandable clay particles, a bio-chemical mixture was employed to assess the crack healing ability. In[11] the self healing of concrete structures is effected by using the concept of human bone healing technique. In[11] bacteria has been bio mineralized and used as a crack healing agent in concrete specimens. In[13] self healing of industrial structures has been investigated using geo materials which has proven efficient crack healing, thereby increasing the functionality and service life of the structures. The current research has been carried out by taking the hints from some of the literatures mentioned above.

2. Experimental Study

Use of silica fume (Figure 1 a) and GGBFS (Figure 1 b) in concrete reduces the effect of alkali silica reaction in concrete. Use of mineral admixtures like silica fume and ggbfs offers good resistance to chloride attack[14]. It consequently reduces the corrosion of steel reinforcement. It also protects the concrete structures from sulphate attack and ingress of other harmful chemicals.

Highly durable concrete[15] can be achieved by adopting a dense concrete matrix. Dense concrete matrix typically means a very compact microstructure which increases the strength properties as well as decreasing the permeability thereby providing good resistance to transport of corrosive materials to the steel reinforcement. Use of well

(a)

(b)

Figure 1. **(a)** Silica fume in two different colors. **(b)** GGBFS.

graded particles in concrete mix conceptually produces a dense matrix which is in turn effected by the use of mineral additives such as silica fume[16], or by the use of low water-to-cement ratios. In order to produce a highly durable self healing concrete, cubes have been prepared by adding silica fume in percentage of 2.5%, 5%,7.5%, 10%, 12.5% as a binder in addition to adding cement to concrete. Also cubes are prepared by replacing 35% and 55% of cement with ggbfs. A conventional mixture without any admixture is cast for comparing the strength and durability properties of silica fume and ggbfs concretes. Microcracks are produced in the concrete specimens by applying 70% and 90% of ultimate compressive strength after 28 days curing. The preloaded concrete specimens are tested for compressive strength at 7 and 28 days and sorptivity index tests after 28 days[17]. The physical properties of the cement, fine aggregates and coarse aggregates are determined by means of conducting standard tests. M30 grade concrete was used for testing.

3. Experimental Test Results

The physical and chemical properties of silica fume have been found out and the results are given in table 1 and table 2 respectively.

Silica fume, a very effective pozzolanic material plays a main role in producing calcium hydroxide which helps in self healing of cracks[18].

The material properties of GGBFS have been determined and the results are given in table 3.

Table 1. Physical Properties Of Silica Fume

Physical Parameters	Silica fume
Particle size (typical)	< 1 μ m
Bulk density (as-produced)	130 to 430 kg/m^3
(slurry)	1320 to 1440 kg/m^3
(densified)	480 to 720 kg/m^3
Specific gravity	2.2
Surface area (BET)	13,000 to 30,000 m^2/kg

Table 2. Chemical Properties of Silica Fume

Chemical Parameters
Amorphous Silicon dioxide > 85% Trace elements depending upon type of fume

Table 3. Physical properties of GGBFS

Physical Parameters	GGBFS
Colour	Brown
Shape	Sub-rounded to angular
Grain size composition (%)	
Silt & clay	1.5
Fine sand	16
Medium sand	72.5
Coarse sand	10
Uniformity coefficient ($C_U = D_{60} / D_{10}$)	3.85
Coefficient of curvature, $C_C = (D_{30})^2 / (D_{10} \times D_{60})$	1.43
Specific gravity	2.61
Plasticity index	Non Plastic

Addition of very small particles to concrete mix improves the properties of fresh and hardened concrete[19]. This effect is termed "particle packing" or "micro filling" as shown in Figure 2.

Normal reaction between Portland cement and water produces calcium silicate hydroxide through hydration reaction. Whereas, when any pozzolan is added to concrete mix, it produces calcium silicate hydraterate in addition to calcium hydroxide.

Tests like standard consistency of cement, setting time of cement, water absorption of coarse and fine aggregates, specific gravity and bulk density were determined to evaluate the physical properties of the cement, fine aggregate and coarse aggregate used in the concrete mix and the results are given in table 4.

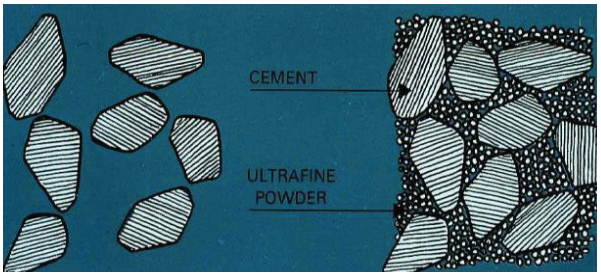


Figure 2. Particle packing.

Table 4. Test Results On Cement, Fine Aggregates and Coarse Aggregates

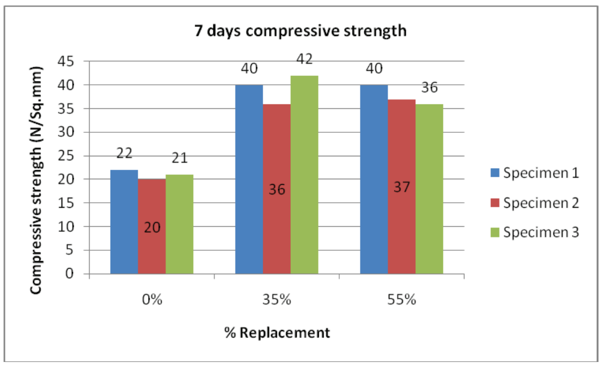
CEMENT	
Specific gravity	3.15
Fineness of cement by dry sieving	1%
FINE AGGREGATE	
Fineness modulus	3.416
D_{10}	0.25 mm
D_{30}	0.42 mm
Uniformity coefficient	3.28
Coefficient of curvature	0.86
Percentage of coarse sand	46.2%
Percentage of medium sand	45.8%
Percentage of fine sand	1.0%
Specific gravity	2.575
Bulk density in loose state	1550 kg/m^3
Bulk density in rodded state	1674.2 kg/m^3
COARSE AGGREGATE	
Fineness modulus	3.169
Bulk density in loose state	1680.22 kg/m^3
Bulk density in rodded state	1823.20 kg/m^3
Specific gravity	2.833
Water absorption	0.41%

Table 5. Compressive strength results using GGBFS as admixture

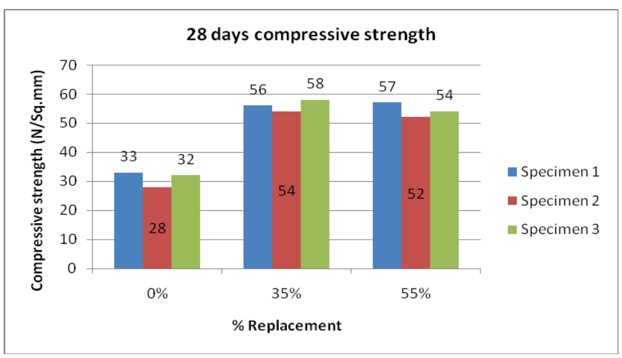
Specimen no	Days	Percentage of GGBFS		
		0%	35%	55%
1	7	22	40	40
2		20	36	37
3		21	42	36
1	28	33	56	57
2		28	54	52
3		32	58	54

Conventional concrete and the concrete made with silica fume and GGBFS are tested for compressive strength, and sorptivity tests. 7 and 28 days Compressive strength results using GGBFS as admixture is given in table 5 and the graphical form is shown in figure 3 (a) and 3 (b) 7 and 28 days Compressive strength results using Silica fume as admixture is given in table 6 and the graphical form is shown in figure 4 (a) and 4 (b).

The durability of the concrete mixes using GGBFS and Silica fume as admixtures have been determined using Sorptivity test and the healing effect was studied through Sorptivity Index values. The sorptivity test has been studied under continuous water exposure[20].



(a)



(b)

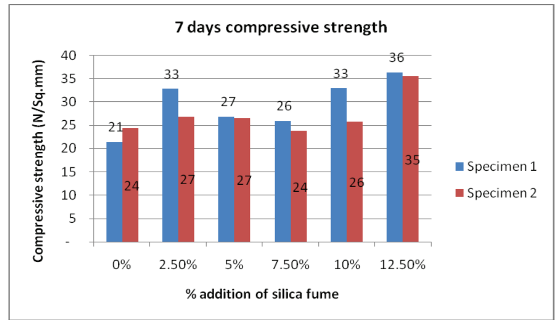
Figure 3. **(a)** 7 days compressive strength. **(b)** 28 days compressive strength.

Table 6. Compressive strength results using silica fume as admixture

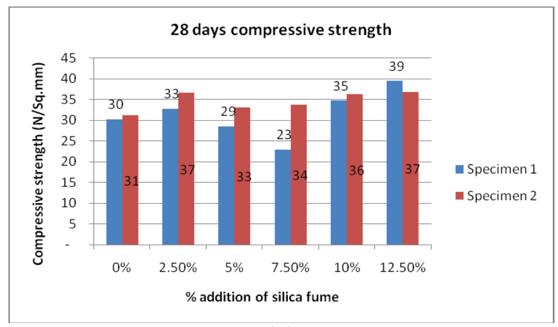
Specimen no	Days	Percentage of Silica fume					
		0%	2.5%	5%	7.5%	10%	12.5%
1	7	21	33	27	26	33	36
2		24	27	27	24	26	35
1	28	30	33	29	23	35	39
2		31	37	33	34	36	37

Sorptivity test results using GGBFS as mineral admixture is given in table 7 and the graphical form of the sorptivity index results are shown in figure 5.

Sorptivity test results using Silica fume as mineral admixture is given in table 8 and the graphical form of the sorptivity index results are shown in figure 6.



(a)



(b)

Figure 4. (a) 7 days compressive strength. (b) 28 days compressive strength.

Table 7. Sorptivity test results using GGBFS as mineral admixture

GGBFS (%)	0%	70%	90%
0	0.113	0.141	0.177
35	0.084	0.122	0.151
55	0.089	0.129	0.162

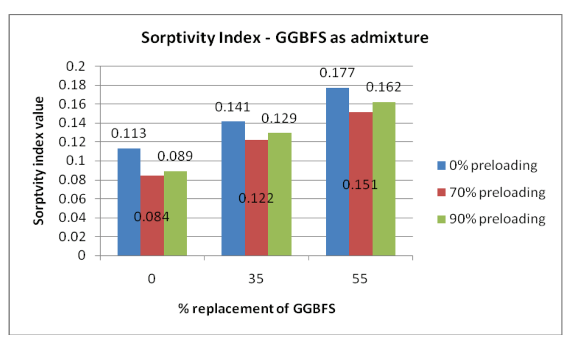


Figure 5. Sorptivity test results using GGB FS as mineral admixture.

Table 8. Sorptivity test results using silica fume as mineral admixture

Silica Fume (%)	0%	70%	90%
0	0.113	0.141	0.177
2.5	0.084	0.122	0.151
5	0.089	0.129	0.162
7.5	0.119	0.153	0.178
10	0.121	0.147	0.176
12.5	0.067	0.125	0.185

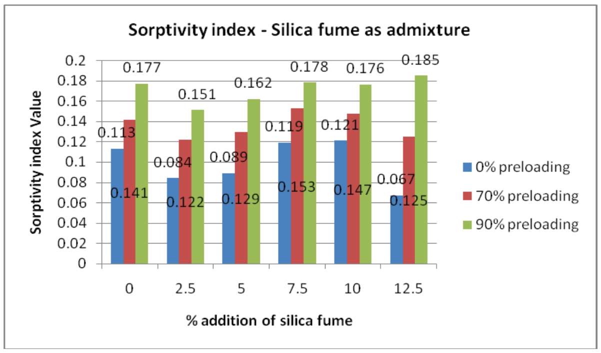


Figure 6. Sorptivity test results using Silica fume as mineral admixture.

4. Conclusion

In this research work, GGBFS and silica fume added cement concrete was tested for compressive strength at 28 days curing. It has been found that the concrete mix containing cement replaced with 35% GGBFS has given maximum compressive strength value. And it has also been found that when silica fume is added as mineral admixture, the mix has given maximum strength at 12.5% addition of silica fume.

The GGBFS and silica fume when added to concrete gave good workability properties to fresh concrete. Hardened concrete produced with these admixtures had good durability properties too. Since the concrete mixes produced using ggbfs and silica fume lessened the quantity of cement in the concrete mix, it is evident that we can produce a cost effective eco friendly concrete. The particle size of silica fume and ggbfs being less compared to that of cement, the admixtures provide a good packing effect in the concrete. Lesser particle size enables the presence of large number of unhydrated particles in ggbfs and silica fume admixtures[21]. The unhydrated particles in ggbfs and silica fume when comes in contact with the atmospheric moisture by means of crack openings, they hydrate to form calcium hydroxide[22], a white precipitate, the healing product to achieve self healing effect in concrete structures.

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