Effect of Grinding on Strength and Durability of GGBFS-based Concrete

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ABSTRACT

This paper presents laboratory investigations on the use of ultra fine ground granulated blast furnace slag (UFGGBFS) as a mineral admixture in concrete and cement mortar cubes. Ground granulated blast furnace slag (GGBFS) is available in plenty as a waste product resulting from steel industries and posing disposal problems subsequently leading to environmental problems. GGBFS obtained in the present work was subjected to grinding for two hours using agate pestle mortar and the effect of grinding on size was monitored by testing particle size with the help of a particle size analyzer, where reduction in size was observed. The sample was later used as a partial substitute to cement. A high strength concrete mix with a characteristic compressive strength of 40 MPa was selected for the present study, and cement was replaced with UFGGBFS in three different percentages; namely 3, 5 and 7%. Compressive strength of mortar and strength and sorptivity characteristics of concrete made with UFGGBFS were studied. Test results showed that replacement of cement with 5% UFGGBFS yielded better resistance to compression and sorption in normal and aggressive environments compared to control specimens.

KEYWORDS: Ultra fine, Grinding, Particle size analyzer, Acid curing, Compressive strength, Sorptivity.

INTRODUCTION

Construction industry consumes a huge volume of concrete every year, and it is expected that it may reach a billion tons soon (Pathak, 2009). Portland cement is the most expensive component in a concrete mix. There is a very familiar statement about the manufacture of cement stating that every ton of Portland cement production releases a similar amount of carbon dioxide as a byproduct which affects the environment. So, to protect the environment from being polluted by carbon dioxide released by cement industries and to meet the rising demand in the world economically without affecting the strength characteristics of concrete, mineral admixtures are used as supplementary cementing materials (Misra et al., 2011).

The concrete has to be modified with pozzolanic and cementitious materials for a long standing infrastructure development. These are generally classified under the term mineral admixtures. Ground granulated blast furnace slag, fly ash, silica fume and rice husk ash are some examples of mineral admixtures. In this work, GGBFS has been used as the mineral admixture.

Ground granulated blast furnace slag is a byproduct obtained in the manufacture of pig iron (Oner and Akyuz, 2007). It is very much useful in designing and

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developing high quality cement paste, mortar and concrete cubes (Siddique and Bennacer, 2012). The packing effect, porosity and pore size distribution of cement pastes and mortars cast using ultra fine slag were improved due to the complete hydration action of the ultra fine slag (Niu et al., 2002). Very high performance concrete with a compressive strength of 200 MPa can be achieved using ultra fine powder such as pulverized fly ash, pulverized granulated blast furnace slag and silica fume (Guangcheng et al., 2002). Slag can be used as a mineral admixture because it is a mixture of lime, silica and alumina, containing the same oxides present in the Portland cement, but the proportion is different (Sha and Periera, 2001; Domone and Soutsos, 1995).

GGBFS due to its high content of silica and alumina in an amorphous state shows pozzolanic behavior similar to that of natural pozzolans such as fly ash and silica fume (Atis and Bilim, 2007). GGBS can be used as an ingredient in cement, as a mineral admixture or as a component of blended cement to encourage the reuse of byproducts from industries. The use of GGBFS in concrete increases workability, reduces bleeding of fresh concrete or mortar, improves strength, reduces heat of hydration, reduces permeability and porosity and reduces the alkali silica reaction (Sakai et al., 1992; Aldea et al., 2000). In recent years, finer particles are being used in construction industry. Several works were performed on incorporating nano-particles into concrete specimens as mineral admixtures to improve physical and mechanical properties (Nazari and Riahi, 2011). Many researchers have focused their research on nano-SiO_2, nano-Al_2O_3, nano-Fe_2O_3 and zinc-iron oxide nano-particles as mineral admixtures in concrete (Li et al., 2004; Qing et al., 2007; Jo et al., 2007a, 2007b; Li et al., 2006; Lin et al., 2007, 2008). Also, the use of nano-sized mineral admixtures was also studied on self-compacting concrete using SiO_2, Fe_2O_3, ZnO_2 and TiO_2 (Nazari and Riahi, 2010, 2011a, 2011b, 2012a, 2012b; Riahi and Nazari, 2011).

In addition, the effects of several types of nano-particles on the properties of concrete specimens cured in different curing media were investigated in several works. It was observed from the literature that the use of nano-particles in concrete improves the mechanical properties and durability characteristics of the specimens in addition to the improvement in microstructure of the concrete specimens. The partial replacement of cement by ground granulated blast furnace slag has inhibiting effects on both total charge-pass and permeability (Cheng et al., 2005).

Significance of the Present Research

Though nano-particles play a major role in increasing the compressive strength of concrete, improving microstructure and pore structure of concrete, the cost of manufacturing nano-sized particles is very high which limits their use. The aim of this study is to investigate the strength and permeability characteristics of concrete incorporating UFGGBFS as a partial replacement for Ordinary Portland Cement (OPC) in an economical way.

EXPERIMENTAL INVESTIGATIONS

Material Properties

Cement

The cement used was ordinary Portland cement of grade 43, having a specific gravity of 3.16. The chemical composition of the cement is presented in Table 1.

UFGGBFS

GGBFS was supplied from steel industries in Salem, Tamil Nadu, India, and its specific gravity was noted as 2.4. Its chemical composition was obtained by X-Ray Fluorescence test using XRF-analyzer of model Tiger 88 to determine major and trace elements in solids. Table 1 shows the main elements (expressed as oxides) present in slag. CaO and Silica (SiO_2) constitute 68.86% and are the major components in slag, followed by Al_2O_3 and MgO with 16.62% and 9.91 %, respectively. All the other components constitute only 4.61%. Raw slag can be used as replacement for cement from 5% to 70% depending upon the requirement. The same slag can be used effectively when it is converted into UFGGBFS. This would improve the performance of the slag as the surface area increases. The size of GGBFS as supplied was found to be 45µm (see Fig.2). In the present work, UFGGBFS was obtained by grinding using a mechanically operated Agate Pestle Mortar shown in Fig.1. The raw slag of size 45 µm was loaded in Agate Pestle Mortar and ground for 2 hours. The size reduction has been checked using Particle Size Analyzer. It was observed that the particle size of GGBFS has been reduced to 30%-35% from its original size and the reduced size was 30 µm (see Fig.3).

Table 1. Chemical composition of Cement and GGBFS

Formula	Concentration (%)	
	Cement	GGBFS
CaO	68.05	34.85
SiO_2	25.91	34.01
Al_2O_3	5.85	16.62
MgO	0.07	9.11
Fe_2O_3	0.12	1.71
SO_3	-	1.55
TiO_2	-	0.69
Na_2O	-	0.48
K_2O	-	0.46
MnO	-	0.27
BaO	-	0.10
P_2O_5	-	0.04
SrO	-	0.04
Cl	-	0.03
ZrO_2	-	0.03
As_2O_3	-	37 ppm

Aggregate

River sand was used as fine aggregate. The fineness modulus (FM) of the fine aggregate was 3.17, and it belongs to coarse sand category which can be used for concrete mixing. The specific gravity of the fine aggregate was noted as 2.63.

Aggregate passing through 16 mm sieve and retained on 12.5 mm sieve was used as coarse aggregate in the concrete mixture. The specific gravity of the coarse aggregate was noted as 2.65. It belongs to single size aggregate category. The fineness modulus of the coarse aggregate was obtained as 7.5.

Plasticizer

A commonly available super-plasticizer CONPLAST SP 430 from FOSROC Company was used through this project to obtain the workable concrete mix.

Concrete Mix Proportions

In the present work, a high-strength concrete grade to obtain a characteristic compressive strength of 40 MPa has been adopted. The design mix ratio was 1:0.69:2.33 (Cement: Fine aggregate: Coarse aggregate). The target mean strength was 48 N/mm^2. Water to cement ratio was taken as 0.38, and for mortar the mix ratio used was 1:3 and w/c ratio adopted was 0.12.

Table 2. Details of Specimen Cast for Strength and Durability Tests

Curing/ Environment	Concrete/ Mortar	Test	Size in mm	International Standard	Number of Specimens
Normal	Concrete	Compression	100 x 100 x 100	BS 1881	12 (4 x 3)
	Mortar	Compression	70.7 x 70.7 x 70.7	BS 4551	12 (4 x 3)
	Concrete	Sorptivity	100 mm (dia) x 50 mm height	ASTM C1585	8 (4 x 2)
HCl	Concrete	Compression	100 x 100 x 100	BS 1881	12 (4 x 3)
	Mortar	Compression	70.7 x 70.7 x 70.7	BS 4551	12 (4 x 3)
H_2SO_4	Concrete	Compression	100 x 100 x 100	BS 1881	12 (4 x 3)
	Mortar	Compression	70.7 x 70.7 x 70.7	BS 4551	12 (4 x 3)
				Total	80

Figure (1): Agate Pestle Mortar

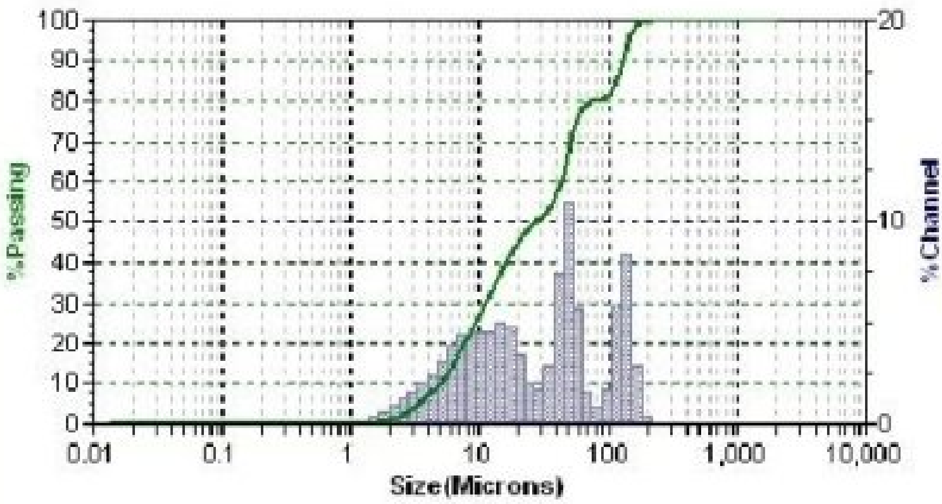


Figure (2): Particle Size before Grinding

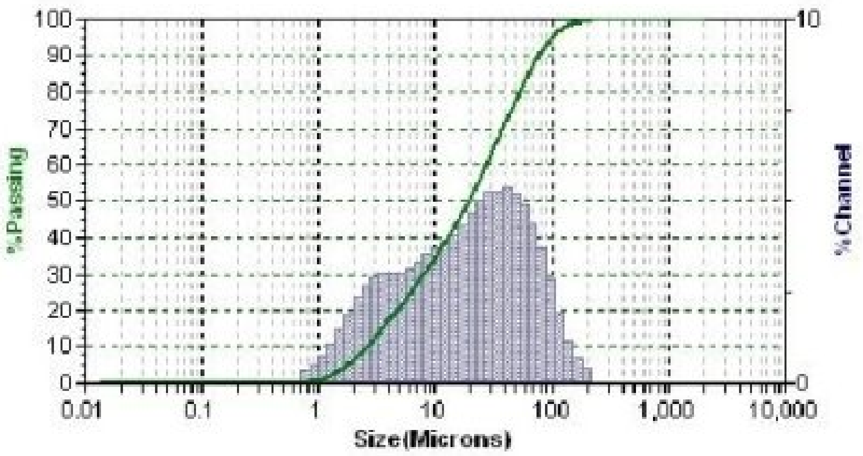


Figure (3): Particle Size after Grinding

Specimen Details

Specimens were cast as per BS and ASTM standards to study the durability and strength characteristics. A total of 88 specimens were cast, and the details are given in Table 2. Compressive strength of cube specimens was tested in an automatic compression testing machine with a capacity of 3000 kN.

Specimens were subjected to stress controlled loading. The specimens were prepared by partially replacing cement in the concrete mix in 3%,5% and 7% of UFGGBFS. In addition, control concrete specimens were also cast in which no partial replacement was done. Sorptivity of specimens was tested as per ASTM C1585.

RESULTS AND DISCUSSION

General

The variations of compressive strength of specimens for different combinations of mix proportions and permeability characteristics are discussed in the following paragraphs. A total of 4 combinations were prepared for the present research work to assess the above parameters. The combinations are: conventional concrete and ultra fine GGBFS. Cement has been partially substituted with 3%, 5% and 7% of UFGGBFS while preparing the concrete mix. The specimens were also subjected to curing in HCl and H_2SO_4 to test their strength in acid environment.

Analysis of Micro-Structure Using Scanning Electron Microscopy (SEM)

Figures 4, 5 and 6 depict the details of SEM images for the concrete with 3, 5 and 7% of UFGGBFS. They give an idea of how the ultra fine particles could improve the microstructure and strength of cement concrete. When a small quantity of UFGGBFS (3%) was added as partial substitute to cement, it was uniformly dispersed in the paste and modified the micro-structure in terms of micro-fillers to some extent (Figure 4). Further increase of UFGGBFS from 3% to 5% made the hydrate products of cement deposit on the ultra fine particles because of their greater surface energy during hydration and grow to form conglomeration containing the ultra fine particles as nucleus. In this process, UFGGBFS available in the cement paste as nucleus further geared up the process of hydration. Hence the ultra fine particles uniformly dispersed in the concrete and made concrete denser and more compact. It also encouraged the prevention of crystal from growing $CaOH_2$ and was useful in favoring strength development (Figure 5). When the percentage of UFGGBFS increases further to 7% the ultra fine particles were not well dispersed due to higher fraction and aggregation of ultra fine particles called agglomeration occurred. The process of aggregation of ultra fine particles content created a weak zone in the form of voids and the result is the formation of heterogeneous micro-structure. It forced reduction in strength (Figure 6). The strength of the cement concrete with UFGGBFS improved the strength not only due to the modification of micro-structure but also due to interface between paste and aggregates.

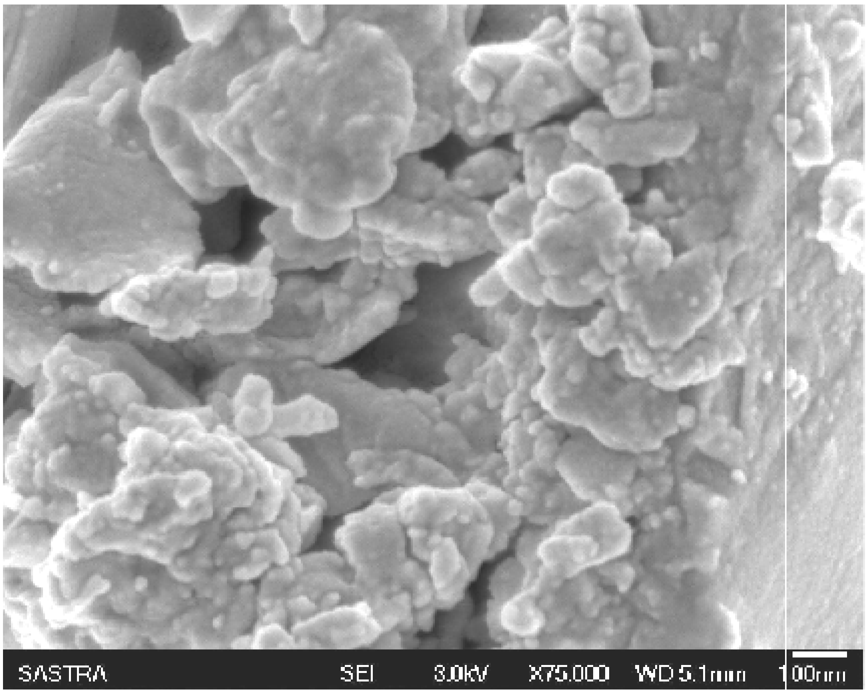


Figure (4): Morphology of Concrete with 3% UFGGBFS Using SEM

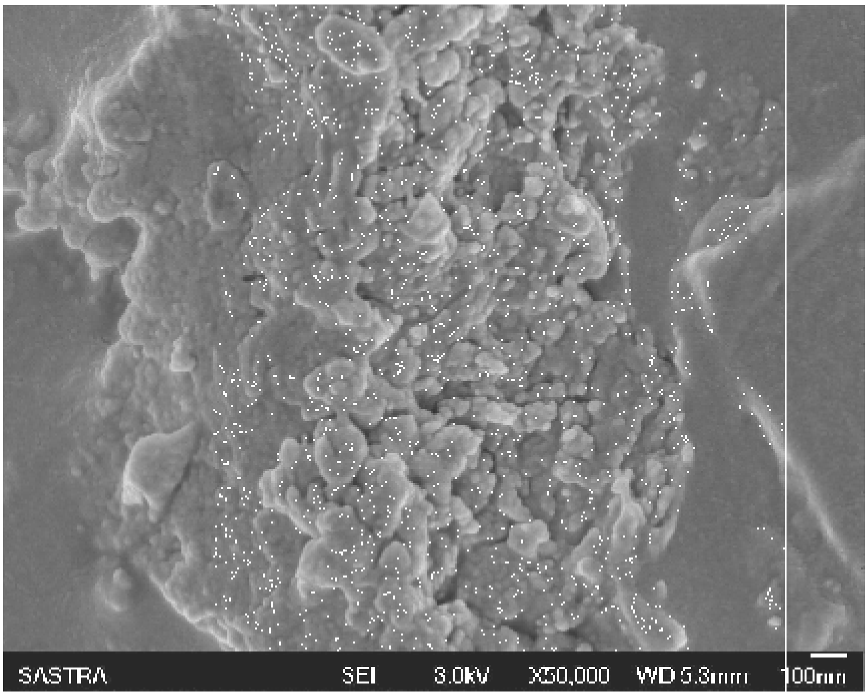


Figure (5): Morphology of Concrete with 5% UFGGBFS Using SEM

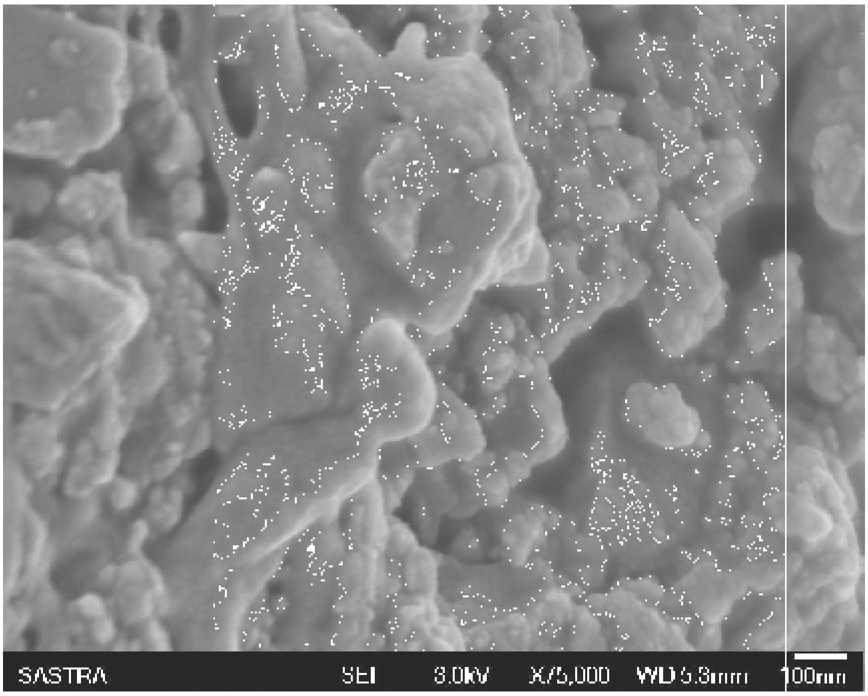


Figure (6): Morphology of Concrete with 7% UFGGBFS Using SEM

Effect of UFGGBFS in Normal Environment

The variation of compressive strength of concrete due to the replacement of cement with different percentages of UFGGBFS after subjecting to 28 days of curing is shown in Fig. 7. From the results, it is inferred that at the age of 28 days conventional concrete gives a compressive strength of 47.38 MPa, which is close to the target mean strength of 48 N/mm^{2}and is more than the characteristic compressive strength of 40 MPa. Hence, it is ensured that the quality control during preparation of concrete is up to the desired standard. On analyzing the 28 day compressive strength results of concrete cubes cast with UFGGBF, it was observed that the strength of the cubes decreased by 15.15%, 11.01% and 22.22% when replaced with UFGGBFS in 3%, 5% and 7%, respectively. The short-term strength of cubes when replaced with supplementary cementitious materials will be less initially when compared with the control concrete cubes, but the long-term strength will be more. Among the various percentages of replacements adopted, cubes replaced with 5% of UFGGBFS are showing less variation in strength when compared with control concrete. A substitute of 7% is showing more deviation in strength compared to control concrete. From the literature, it was inferred that concrete with normal GGBFS (without grinding) develops its strength at a slower rate. At the age of 28 days, the compressive strength of concrete with UFGGBFS was found to be slightly lower than that of control concrete in all the cases of UFGGBFS as substitute. However, among the admixed concretes, concrete with 5% UFGGBFS yielded higher strength than other mixes. The reason might be, for 3% UFGGBFS concrete, that it did not attain its full strength because of its least contribution in concrete, and for 7% UFGGBFS concrete it was due to agglomeration of ultra fine particles leading to improper filling of voids. Concrete with 5% UFGGBFS might have filled the micro-voids resulting in enhanced strength. This indicates that partial replacement of 5% of UFGGBFS could give better strength compared to all other combinations. The percentage decrease in strength of concrete is shown in Fig. 8.

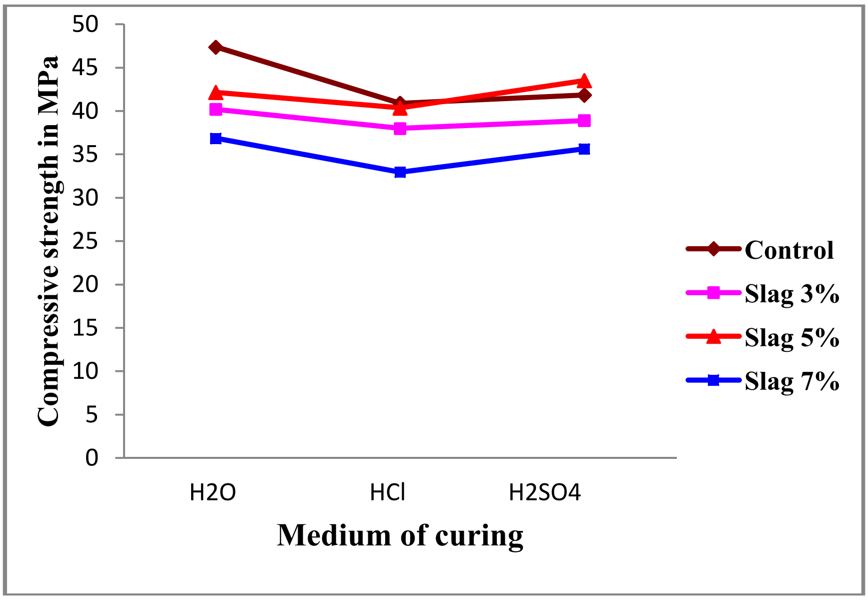


Figure (7): Compressive Strength of Concrete at the Age of 28 Days

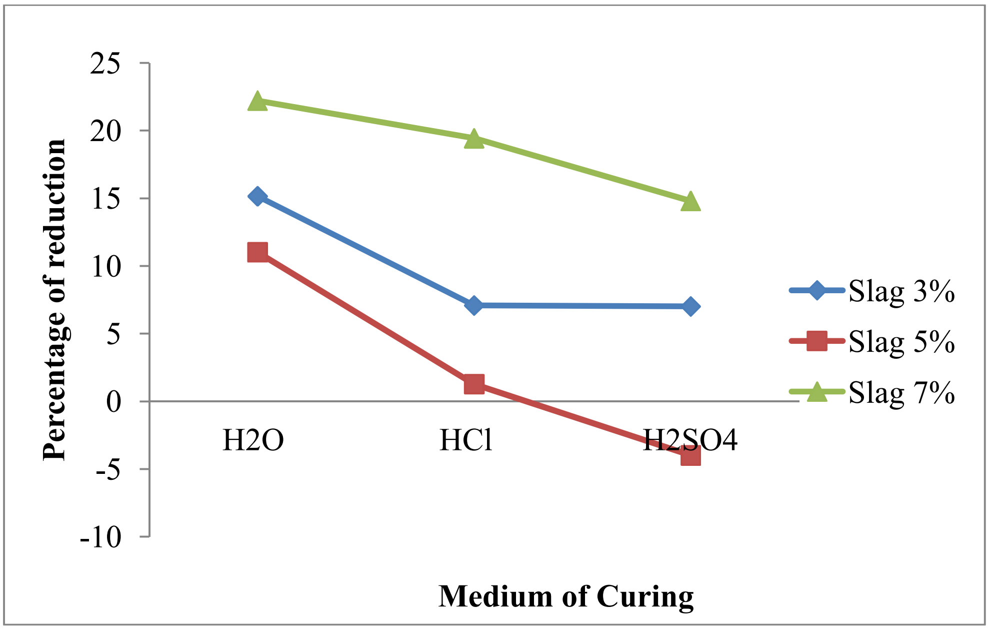


Figure (8): Percentage Reduction in Compressive Strength of Concrete with Respect to Control Concrete

Similar trend was also seen while analyzing the strength results of mortar cubes. Strength of mortar cubes cast with partial replacement of UFGGBFS was compared with control mortar cubes, and the results are shown in Fig.9. The percentage decrease in strength is shown in Fig.10.

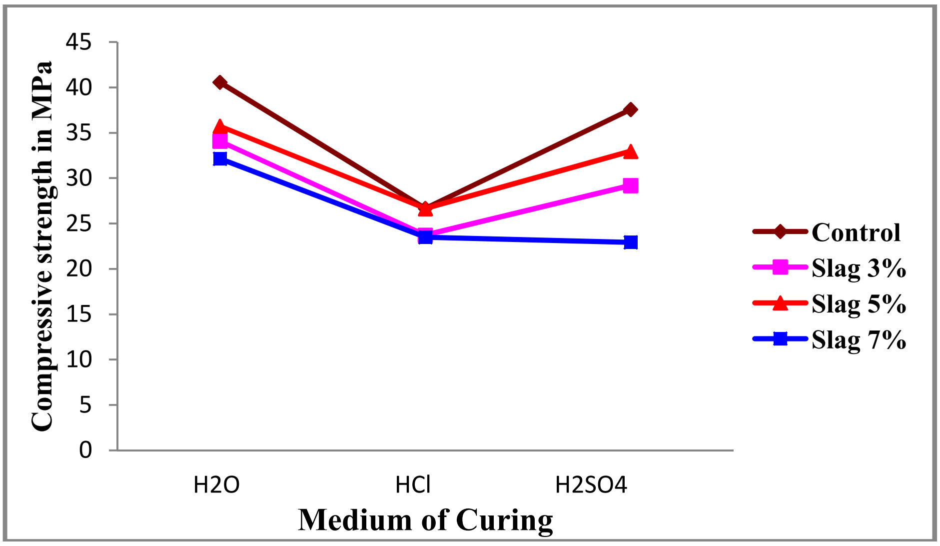


Figure (9): Compressive Strength of Mortar at the Age of 28 Days

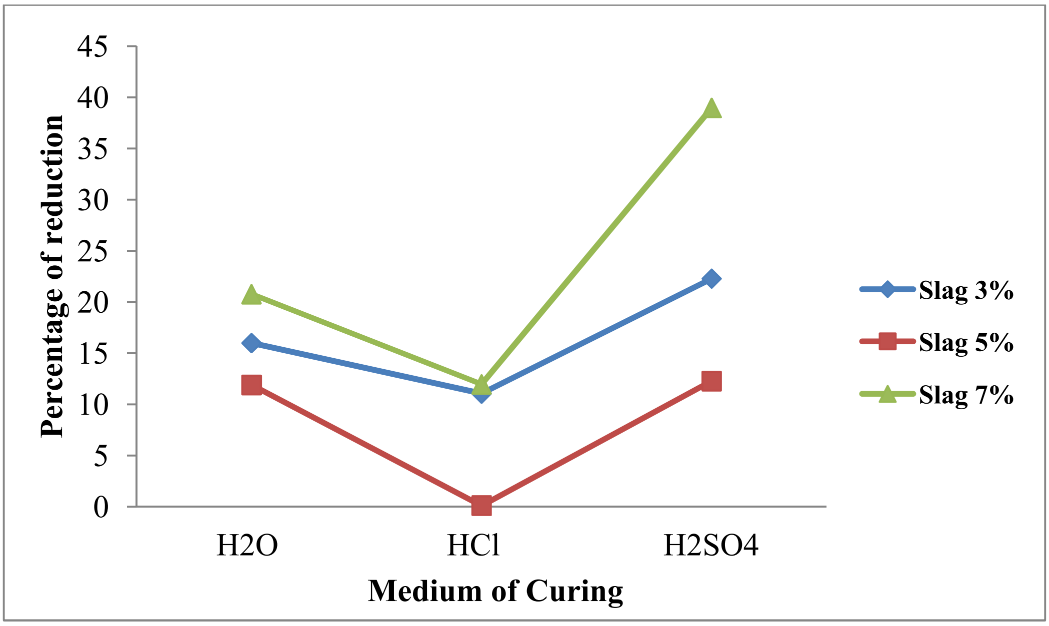


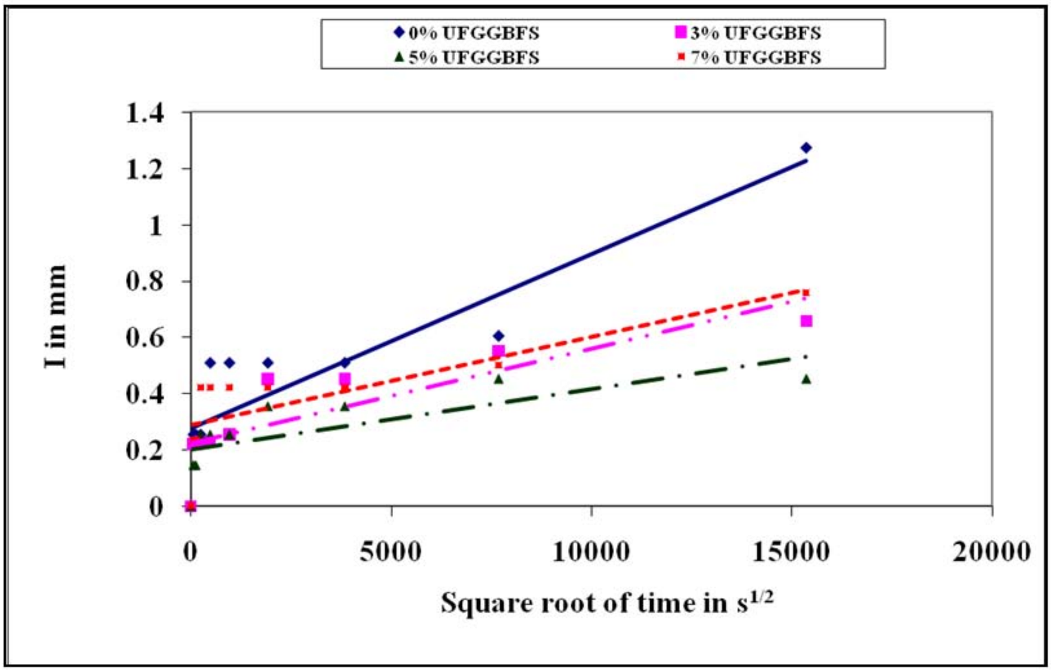
Figure (10): Percentage Reduction in Compressive Strength of Mortar with Respect to Control Mortar

Effect of UFGGBFS in Acid Environment

Concrete is not only to be used in normal environments, but should be prepared to possess sufficient strength when exposed to acid or industrial and marine environments without getting deteriorated. Deterioration of concrete is a slow process, and it takes several months for a structure in an industrial or marine environment to deteriorate. Hence, to accelerate the deterioration process and to study the behavior of concrete in such environments, the cubes were subjected to curing in water diluted with 1%HCl and 0.3% H_2SO_4 acids. Curing can be carried out in any acid, and we have chosen the acids mentioned above as they are familiar and mostly used in many industrial environments. The variation in compressive strength of concrete cubes cast with replacement of UFGGFS when cured in acid environment is presented and the percentage decrease in strength is shown in Fig.7 and Fig. 8.

The control concrete specimen after subjected to curing in HCl and H_2SO_4 showed strength values of 40.80 MPa and 41.84 MPa which are close to the mean target strength of 40 MPa. Among the cubes cast with replacement of 3%,5% and 7% UFGGBFS and cured in acid environment, cubes with 5% replacement are showing better resistance to acid attack as the decrease in compressive strength of such cubes was only 1.28 % from the control cubes cured in HCl and 3.99% in H_2SO_4. The cubes replaced with 3% and 7% are showing more deviation in compressive strength, and particularly cubes with 7% replacement show a major decrease in strength of about 19.44% when cured in HCl and 14.81% when cured in H_2SO_4. This indicates that cubes cast with a partial replacement of 5% UFGGBFS show a better resistance to deterioration when exposed to acid environment and can handle chloride and sulphate attacks effectively.

Similar trend was seen while analyzing the strength results of mortar cubes cured with diluted HCl and diluted H_2SO_4 acid. Strength of mortar cubes cast with partial replacement of UFGGBFS was compared with that of control mortar cubes, and the results are shown in Fig.9 and the percentage decrease in strength is shown in Fig.10.



[R^2 = 0.818 (0% UFGGBFS) R^2 = 0.713 (3% UFGGBFS), R^2 = 0.610 (5% UFGGBFS) R^2 = 0.614 (7% UFGGBFS)]

Fig 11 Sorptivity Test results of UFGGBFS concrete

Effect of UFGGBFS on Permeability

The permeability characteristics were measured in terms of sorptivity, which is the ability to permit water through the bottom surface of concrete called as capillary suction. Fig. 11 depicts the values of sorptivity with respect to time elapsed. By taking the slope of the line of best fit for each and every case, sorption coefficient of respective concrete was obtained. It was inferred that R^2 values varied from 0.818 to 0.60 for different concretes. It was understood that capillary suction has a higher value for control concrete, and addition of 3% UFGGBFS makes heavy impact on reduction of capillary suction meaning that it has got higher resistance against permeability. Further addition of UFGGBFS by 5% also reduced the capillary suction, and further addition in concrete does not make any significant improvement in reducing the permeability, but the observed sorptivity coefficients are very much less than the control concrete which means that addition of UFGGBFS controls the capillary action making the concrete less permeable. Among the various percentages of UFGGBFS partially replaced with cement in concrete, the 5% mix shows a greater improvement in resisting the capillary action in concrete. Hence, it is assessed from the results that 5% UFGGBFS gives better results in terms of reducing the permeability.

CONCLUSIONS

From the detailed experimental investigations conducted on high strength concrete with UFGGBFS, following conclusions can be made:

- The particle size distribution shows the effect due to grinding, and it is observed that the mean size of the particles reduced to 30 μm from 45 μm when subjected to 2 hours of grinding.
- Though the compressive strength of UFGGBFS

concrete was found to be less than that of control concrete, the magnitude of compressive strength of UFGGBFS concrete is equal to required characteristic compressive strength.

- Among three different percentages of UFGGBFS used in concrete and mortar, 5% replacement yielded better strength and was found to be an optimum percentage of replacement.
- It was understood from the results that that concrete with UFGGBFS yielded better resistance against permeability than that of control concrete.
- Higher rate of resistance to permeability was observed in specimens with 5% UFGGBFS, and hence this was found to be optimum from durability point of view.

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