

Mechanical and Durability Properties of UHSGC Using Industrial Waste

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Abstract- Ultra High Strength Geopolymer concrete (UHSGC) seems, by all accounts, to be a superior decision for durable structure. UHSGC mixtures were developed by totally removing Portland cement and by geopolymerisation of industrial by-products like ground granulated blast furnace slag and silica fume. Steel fibres, quartz sand and local standard sand were also utilized. In the present work, ambient temperature cured UHSGC mixes were developed to investigate the durability aspects. Potassium hydroxide and potassium silicate were used as alkaline activators. Cube specimens of size 70 mm, ten cubes each were utilized to determine the compressive strength of concrete. Disc specimens of size 100 mm diameter and 50 mm thick were cut from 100 mm diameter and 200 mm long cylinders and a minimum of three specimens were tested for each durability test. All the tests were executed according to ASTM standards. In this paper, studies on durability properties such as water absorption and sorptivity were reported. Specimens with and without fibres were studied. It was observed that for the increase in the percentage of fiber there was increase in the water absorption and sorptivity which essentially shows a remarkable change in strength and durability characteristics of concrete.

Keywords:- Ultra high strength geopolymer concrete, Water Absorption, Sorptivity, Steel Fibres.

I. INTRODUCTION

Concrete is a permeable material which interacts with the surrounding environment. The durability of mortar and concrete depends to a great extent on the permeation of water and gas enters and through it. Water penetrability can be characterized as the extent to which a material allows the transport of gasses, fluids, or ionic species through it. These properties are connected to the execution of porosity, since the harmful particles enter into the concrete paste through the pores. Water absorption and sorptivity estimation are few methods to find the water penetrability of concrete. Concrete is one of the most widely used construction materials; it is usually associated with Portland cement as the main

component for making concrete. Unfortunately, the production of Portland cement releases large amounts of CO₂ in to the atmosphere (production of 1 tone OPC releases 1 tone CO₂), and this gas is a major contributor to the greenhouse impact and the global warming planet. According to Davidovits (1991), geopolymers are polymers because they transform, polymerize and harden at low temperature. Ultra High Performance Concrete (UHPC) is characterized by being a steel fiber-reinforced bond composite material with compressive strength in excess of 120 MPa, up to and potentially exceeding 250 MPa. Geopolymer concrete is environmentally agreeable and the same time it can be used to make a ultra high strength geopolymer concrete (UHSGC) (Vignesh et al., 2015). Industrial by-products such as Ground Granulated Blast Furnace Slag (GGBS) and Silica Fume (SF) can be advantageously used in producing UHPGPC at ambient temperature conditions (Ambily et al., 2013). Bakharev et al., 2003, conducted durability tests on alkali activated slag and found that they perform better than ordinary Portland cement (OPC) concretes. Alkali-activated binders have risen as an alternative to OPC binders, which appears to have superior durability and environmental impact. In this paper a study on durability properties of UHSGC is reported.

II. EXPERIMENTAL PROGRAMME

MATERIALS USED

Experimental work was done to study the durability properties on Ultra High strength Geopolymer concrete. The materials utilized for making UHSGC were Silica fume, GGBS, standard sand Grade I, Grade III, Quartz sand, steel fibers and alkaline solution.

III. MATERIAL PROPERTIES

A. GROUND GRANULATED BLAST FURNACE SLAG

Granulated blast furnace slag (GBFS) is a smooth granular material structured when molten blast furnace slag is

quickly chilled, as by submersion in water. The cementations activity of a granulated blast furnace slag is dependent to vast degree on the glass content. When GBFS is ground to the fineness of cement it is called GGBS. GGBS hydrates are generally found to be more gel like than the results of hydration of Portland cement, so it thick the cement paste. GGBS conforming to IS 12089:1999 (BIS, 1999) was used in the present study. Chemical composition and physical properties are given in the Table 1.

B. SILICA FUME

Silica fume is fine non- crystalline silica, delivered in electric arc furnaces, which is a byproduct of the production of elemental silicon or alloys containing silicon otherwise called consolidated silica fume or micro silica.

TABLE1: CHEMICAL AND PHYSICAL PROPERTIES OF SF AND GGBS.

	SF	GGBS
Silica SiO ₂ : % by mass	94.73	43.4
Alumina Al ₂ O ₃ : % by mass	—	12.5
Ferric oxide Fe ₂ O ₃ : % by mass	—	0.3
Calcium Oxide CaO: % by mass	—	40.0
Magnesium oxide MgO: % by mass	—	1.5
Sulfur trioxide SO ₃ : % by mass	0.20	—
Sodium oxide Na ₂ O: % by mass	0.51	0.9
Potassium oxide K ₂ O: % by mass	—	0.6
Fineness: m ² /kg	20 000	400
Loss on ignition: %	1.5	2.1
Bulk density: kg/m ³	220	1108
Specific gravity	2.25	2.9

It is mainly amorphous silica with high SiO₂ content, extremely small particle size and large surface area, highly reactive pozzolana used to enhance mortar and cement. It enhances durability basically by reducing permeability to water and chlorides. Micro silica was delivered during the high temperature diminishment of quartz, to give silicon or ferrosilicon metal. SF conforming to ASTM C1240-12

(ASTM, 2012a) was used in this study. The chemical and physical properties are given in Table 1.

C. STEEL FIBRE

In this investigation two different steel fibres of length 6mm and 12mm were used. They are included in percentage by volume of the concrete mixture. The diameter of the steel fiber was 0.14 mm and having tensile strength of 2000MPa.

D. ALKALINE SOLUTION

Potassium hydroxide (KOH) in the form of flakes and potassium silicate (K₂SiO₃) in solution form are utilized to make alkaline activator solution to get the geopolymeric reaction. Potassium hydroxide (KOH) and potassium silicate (K₂SiO₃) were added in the ratio 1:3. Potassium hydroxide flakes were dissolved in distilled water to get individual alkali solutions one day prior to remove the excessive heat generated due to exothermic response of the fluid. The potassium hydroxide solution reaches thermal equilibrium with the atmosphere potassium silicate solution was added, the resulting liquid was used for preparing UHSGC mix. The properties of the potassium silicate solution used are given in Table 2.

TABLE 2: PROPERTIES OF SILICATE USED

Parameter	PS((K ₂ SiO ₃))
Specific gravity	1.38
K ₂ O: % by mass	12.50
SiO ₂ : % by mass	26.30
Total solids: %	38.8
Baume ' @ 25 8C	40
Viscosity: Pa s	0.44

E. FINE AGGREGATES

Standard sand according to IS 650:2004 (BIS, 2004) grade I (GI) and grade III (GIII) with a specific gravity of 2.63 and quartz sand (QS) with a specific gravity of 2.45 were utilized as fine aggregates. The maximum size of the aggregates used for UHSGC mix was 2 mm.

IV. PREPARATION OF UHSGC MIX

The UHSGC mix is prepared by utilizing GGBS, SF, GI sand, GIII sand, Quartz sand, steel fibers and alkali activator solution (AAS) which is prepared of potassium

hydroxide and potassium silicate solution as suggested Ambily et al, 2015. The details of UHSGC mix are presented in Table 3.

Two mix UG₀ (0% fibre volume), UG₁₂ (1% 6 mm fibre volume and 2% 12 mm fibre volume) were prepared. The following procedure was adopted for preparation of the mixes utilizing a Hobart planetary mixer of 10kg capacity.

TABLE 3: MATERIAL PROPERTIES

Materials	MIX 1 UG ₀	MIX 2 UG ₁₂
Molarity (KOH)	10 M	10 M
KOH/K ₂ SiO ₃ (kg/m ³)	1:3	1:3
Silica Fume(kg/m ³)	254.5	243.9
GGBS(kg/m ³)	805.9	772.4
AAS(kg/m ³)	402.9	386.2
Grade I Sand(kg/m ³)	422	404.5
Grade III Sand(kg/m ³)	180	172.6
Quartz Sand(kg/m ³)	200.9	208
Fibres Used	–	157

Dry materials (GGBS, SF, quartz sand, GI and GIII sand) were gradually added to the mixer bowl while the mixer was rotating at a moderate speed. After dry mixing of the materials, AAS was gradually added and mixing was continued at moderate speed. The mixing speed was extended until a uniform mix was achieved and the mixture changed to a flowable self compacting consistency. The material mixing time for the mixes ranged from 10 to 15 minutes. For UHSGC mixes with fibers, after all the ingredients were mixed and a flowable consistency was accomplished, fibers were added to the mixing bowl gradually with the mixer working in low speed. After addition of steel fibres the mixer was operated with varying speed from low to high for few minutes. After mixing the flow of the fresh mix was determined with the assistance of a flow table. The cementitious mixture with fibers was then precisely set in a mould of 70 × 70 × 70 mm cubes by utilizing a wide scoop and vibrated utilizing a high frequency vibrating table. Sufficient time of vibration was given to ensure suitable consolidation. During mixing and placing of the fresh mixture uniform fiber distribution was ensured. The specimens were demoulded after 3 hours of casting. The specimens were then kept at room temperature (28°C) at a relative humidity of 71% until testing.

V. EXPERIMENTAL INVESTIGATIONS

A. COMPRESSIVE STRENGTH TEST

The test was completed on 70 × 70 × 70 mm cube specimen. Test was done after curing for 3hrs, 1, 3, 7, 14 and 28 days. The test was carried out in the standard Universal Testing Machine (UTM) of 1000 kN capacity and the loading was applied at a uniform rate until the specimen failed completely. The reported strengths were the mean of minimum of three cubes. The values were recorded and the compressive strength was calculated and indicated in table 4. The values were recorded and compressive strength is calculated using the equation 1.

$$\text{Compressive Strength} = \frac{\text{Load (P)}}{\text{Cross Sectional Area (A)}} \quad (1)$$



Figure 1: Experimental Setup for Compressive Strength Test

VI. DURABILITY

B. WATER ABSORPTION TEST

The measure of water entering the concrete through its voids has an important role in deciding its durability. Water Absorption test was performed according to ASTM C 642-13 for UG₀ and UG₁₂ mix. Specimens having 50mm thick slices cut from cylinders of 100mm diameter and 200 mm height was utilized. The mass of specimens were determined, and dried in an oven at a temperature of 100 to 110°C for not less than 24 h. After removing each specimen from the oven, it is permitted to cool in dry air to a temperature of 20 to 25°C, after which the mass is determined. The procedure was repeated till the difference between any two successive values is less than 0.5% of the lowest value obtained. This last value is assigned as A. The specimen is again immersed, in water at approximately 21°C for not less than 48 hours and after surface drying, the mass is determined and designated as B. The specimen is covered with tap water and boiled for 5 hours after permitting it to cool by heat loss for not less than 14 hours to a final temperature of 20°C to 25°C, is taken as C. The mass is calculated after immersion and boiling as D.



Figure 2: Setup for Water Absorption

The values are calculated by using the following equation.

$$\text{Absorption after immersion, \%} = ((B-A)/A) \times 100.$$

Volume of permeable pore space

$$\text{voids, \%} = ((G_2 - G_1) / G_2) \times 100.$$

A (g) = mass of oven-dried sample in air, B (g) = mass of surface-dry sample in air after immersion, C (g) = mass of surface-dry sample in air after immersion and boiling, D (g) = apparent mass of sample in water after immersion and boiling, G1 = Dry Bulk density, mg/m³, G2 = Apparent density (mg/m³) and ρ = Density of water = 1 mg/m³.

C. SORPTIVITY TEST

This test was carried out as per ASTM C 1585-13. For this study, 50 mm thick slices were cut from cylinders of 100 mm diameter and 200 mm height. The slices were kept in the oven for 48 hours at 100±5°C and then after taking out it were permitted to cool for 24 hours. The slices were put on a welded mesh to provide free access of water at the bottom surface. The water level kept was 1 to 3 mm from the base of the specimen. Record the mass at the intervals after first contact with water. The first point shall be at 60 ± 2 s and the second point at 5 min ± 10 s. Subsequent measurements shall be within ± 2 min of 10 min, 20 min, 30 min, and 60 min. The actual time shall be recorded to within ± 10 s. Continue the measurements every hour, ± 5 min, up to 6 h, from the first contact of the specimen with water and record the time within ± 1 min. The sorptivity is computed by equation 2.

$$I = S \cdot t^{1/2} \text{ therefore } S = I / t^{1/2} \quad (2)$$

Where; S= sorptivity in mm, t= elapsed time in minute. I=Δw/Ad, Δw= change in weight = W2-W1 W1 = Oven dry weight of cylinder in grams, W2 = Cylinder weight after 30 minutes capillary suction of water in grams. A= surface area of the specimen through which water penetrated. d= density of water.



Figure 3: Setup for Sorptivity

VII. RESULTS AND DISCUSSIONS

The compressive strength attained were 135.5 MPa for UHSGC with steel fibres (1% 6 mm and 2% 13 mm) and 69.7 MPa for UHSGC without steel fibres. The compressive strength values were tabulated in Table 4. From the table it is seen that the rate of strength development is faster in case of UHSGC. Table 5 gives the water absorption and volume of permeable voids of UHSGC. Specimen with fiber (UG₁₂) recorded average values of 7.20% water absorption and 17.9% volume of permeable voids whereas specimens of UG₀ showed comparatively lower corresponding values of 5.84% and 13.39%, respectively. Table 5 shows that UHSGC with fibers has more volume of voids than the UHSGC without fiber. The water absorption and percentage of voids results are graphically represented in figure 4 and 5.

The graphs show that with increase in the percentage of fiber there was an increase in the water absorption and volume of permeable voids. The presence of fibres probably results in the creation of channels at the interface between the fibre and paste that promote the uptake of water that could result in an increased absorption and volume of permeable voids. The evaluation for sorptivity consists of measuring the capillary absorption of water with time. The study curves for cumulative absorption of water and square root of time is shown in Figure 6. UG₁₂ specimen recorded 2.7x10⁻² mm/sec^{1/2} average sorptivity whereas specimens of UG₀ showed comparatively lower corresponding value of average sorptivity of 2.5x10⁻² mm/sec^{1/2}. The presence of fibres did not alter considerably the sorptivity in the UHSGC.

TABLE 4: PROPERTIES OF UHPGC MIX

	Compressive Strength N/mm ²	
	0% (UG ₀)	3% (UG ₁₂)
3hrs	7.48	11.04
1day	30.28	43.16
3 day	55.88	79.81
7day	57.19	98.59
14 day	66.8	117.17
28 day	69.74	135.52
Fresh density kg/m ³	2257	2358
Flow (%)	150	135

Specimen ID	Water absorption (%)	Volume of Permeable Voids (%)
UG ₀	5.82	12.98
	5.91	12.75
	5.82	13.02
	5.96	14.18
	5.79	13.76
	5.77	13.65
UG ₁₂	7.08	17.62
	7.06	17.12
	7.10	17.72
	7.33	19.01
	7.31	18.56
	7.35	18.40

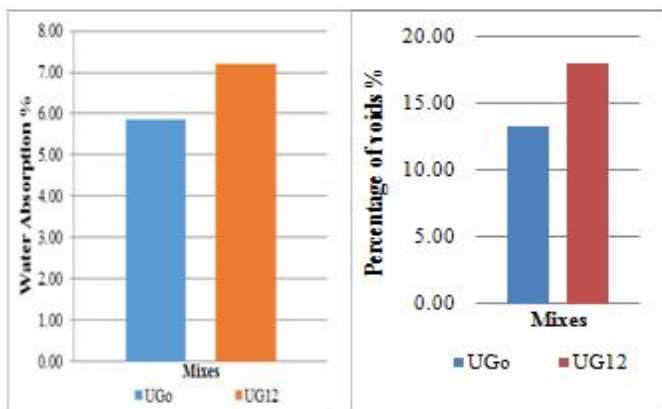


Figure 4: Water Absorption % for two mixes

Figure 5: Percentage of voids for two mixes

TABLE 5: RESULTS OF WATER ABSORPTION, APPARENT POROSITY

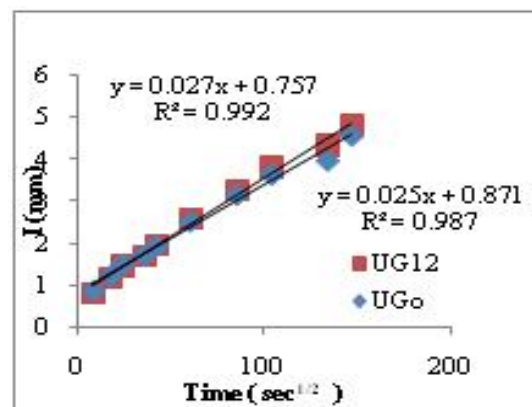


Figure 6: Sorptivity Comparison of two mixes

VIII. CONCLUSION

Ambient temperature cured ultra high strength geopolymer concrete (UHSGC) was prepared using ground granulated blast furnace slag (GGBS) and silica fume (SF) as geopolymeric source material (GSM) and Potassium based hydroxide and silicates as activator. The molarity used for UHSGC was 10M. The compressive strength of UHSGC with fiber was around 1.95 times higher than UHSGC without fiber. The durability results of water absorption, sorptivity and volume of permeable voids clearly shows that UHSGC with the presence of fiber there is an increase in water absorption, volume of permeable voids and sorptivity. The plots obtained for sorptivity test for both the mixes (with and without fiber) varied linearly. The initial rate of absorption, Si, got for UG₁₂ was $Si=2.79 \times 10^{-2}$ mm/ $\sqrt{\text{sec}}$ with a coefficient of correlation of 0.99 and for UG₀ $Si=2.52 \times 10^{-2}$ mm/ $\sqrt{\text{sec}}$, correlation

coefficient 0.98, respectively. Hence UG₁₂ had a higher rate of water absorption and sorptivity than UG₀.

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LIST OF SYMBOLS AND ABBREVIATIONS

UHSGC -	Ultra High Strength Geopolymer concrete
GGBS -	Ground Granulated Blast Furnace Slag
SF -	Silica Fume
OPC -	Ordinary Portland cement
KOH -	Potassium Hydroxide
K ₂ SiO ₃ -	Potassium Silicate
UG ₀ -	UHSGC mix (0% fibre volume)
UG ₁₂ -	UG ₁₂ (1% 6 mm fibre volume and 2% 12 mm fibre volume)
GI, GIII -	Grade I Sand, Grade III Sand
QS -	Quartz Sand
AAS -	Alkaline Activator Solution.
UTM -	Universal Testing Machine

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