Specimen Size Effect on Ultra High Strength Geopolymer Concrete (UHSGC)

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Abstract: **In recent years a lot of research has been carried out on Geopolymer concrete (GPC). The reaction mechanism of Portland cement concrete and GPC are completely different. The performance of GPC mainly depends upon the quality of the geopolymeric source materials (GSMs), type of activator solutions used and rate of Geopolymerisation etc. This paper reports an experimental study carried out to investigate the specimen size effect of Ultra High Strength Geopolymer concrete (UHSGC) produced under ambient temperature conditions. Ground Granulated blast furnace slag (GGBS) and silica fume (SF) was used as GSMs and a combination of potassium hydroxide and potassium silicate solution was used as alkali activator solutions. The ratio of silicate to hydroxide was 3 and the molarity of the potassium hydroxide solution used was 10. Cubes of different size has been cast to determine the specimen size effect on compressive strength of concrete at the ages of 28 days. Cubes of size 50 mm, 70 mm, 100 mm of 10 numbers each were cast. To determine the relation between cylinders to cube strength, cylinders of size 100 x 200 mm cylinders (10 nos) were also cast. Micro steel fibers with a diameter of 0.14mm and aspect ratio of 85 was used. The relation between compressive strength of 50 mm cube ($f_{c,\,50}$), 70 mm cube ($f_{c,\,70}$), 100 mm cube ($f_{c,\,100}$) and cylinder -100x 200 mm, ($f_{cy,\,100}$) were determined. As expected when the size of the specimen decreased the compressive strength increased. The highest average compressive strength obtained for 50 mm cube at the age of 28 days was 143 N/mm^2. The compressive strength of 70 mm cube, $f_{c,\,70}$= 0.98 $f_{c,50}$= 1.04 $f_{c,\,100}$. The ratio of cylinder to cube compressive strength ($f_{cy,\,100}$/ $f_{c,\,100}$) was 0.67.**

Keywords: Compressive strength, Geopolymer Concrete, Grand granulated blast slag, Silica Fume, specimen size effect, ultra high strength concrete, steel fibre.

1. INTRODUCTION

The property of any material is considered to be unique when they are independent of the specimen size and shape. The compressive strength of concrete is accepted as the basic and most important material property for design purposes. The common fact that compressive strength is actually absurd since, the compressive strength of concrete changes based on the specimen size depending on its fracture characteristics.

Compressive strength test is the most common test carried out on concrete. To determine the compressive strength, testing standards like American Concrete Institute code, American Society for Testing and Materials International code, Bureau of Indian Standard code etc. use different geometries of specimen, the most commonly used specimen are the cubes and cylinders. It's known, that cubes have higher strength than cylinders (Gonnerman, 1925; Gyengo, 1938; Murdock 1957, Ambily, 2015). For Ultra High Strength concrete the size and shape effect is less affected when compared with normal strength concrete. Many researcher's focused their interest on size effect on compressive strength (Bazant and Xiang, 1994; Jen and Shah, 1991, Kim and Yi, 2002).

In this paper a study Ultra High strength Geopolymer concrete (UHSGC) developed under ambient temperature conditions was used for determination of specimen size on the compressive strength of concrete is reported.

1.1 Reaction Mechanism

Geopolymerisation is nothing but a reaction between alkaline solution and aluminosilicate source . The aluminosilicate source material used in the present study was ground granulated blast furnace slag (GGBS) and silica fume (SF), which forms a 3D polymeric chain structure consisting of Si-O-Al-O bonds. The alkaline activator solution(AAS) which contains the alkaline ions such as Na, K and Ca, which speeds up the activating process of Al and Si and acts as an accelerator.

2. EXPERIMENTAL INVESTIGATIONS

In this study, the effect of specimen sizes and specimen shapes, on concrete compressive strengths of concrete is evaluated. The UHSGC mix consists of GGBS, SF, standard sand (SS) of grade I (GI) and grade III (GIII), steel fibres, AAS solution (A combination of Potassium Hydroxide solutions and Potassium Silicate Solution). To see the effect of fibres on the properties of UHSGC mix, the mix without fiber ie, High strength geopolymer concrete mix (HSGC) was also presented.

2.1 Material properties

2.1.2 Silica fume

Silica fume confirming to ASTM C1240-12 were used. The chemical composition and physical property are given in Table 1 and Table 2.

2.3 Ground Granulated Blast Furnace Slag

GGBS is the by-product obtained from steel and iron manufacturing industries, consisting mainly of silicon dioxide, calcium oxide and aluminium oxide. GGBS confirming to IS 12089:1999 (BIS, 1999) were used. The chemical composition and physical property are given in Table 1 and Table 2.

TABLE 1
CHEMICAL COMPOSITION OF SF AND GGBS

Compound	Silica fume	GGBS
SiO_2	94.73	43.4
Al_2O_3	_	12.5
Fe_2O_3	_	0.3
CaO	_	40.0
MgO	_	1.5
Na_2O	0.51	0.9
K_2O	_	0.6
SO_3	0.20	_

TABLE 2
PHYSICAL PROPERTIES OF SF AND GGBS

Property	Silica fume	GGBS
Specific gravity	2.25	2.9
Fineness (m^2/kg)	20000	400
Loss on Ignition(%)	1.5	2.1
Bulk density (kg/m^3)	220	1108

2.4 Alkaline Activator Solution

The alkaline activator solution is a combination of hydroxides and silicates of Potassium. This solution for the geopolymeric mix is obtained by dissolving Potassium Hydroxide flakes into distilled water, due to its exothermic reaction the temperature developed during the preparation will be high allow this solution to be thermal equilibrium with the atmospheric temperature (to cool down to normal room temperature28˚c). Then the Potassium silicate solution (PS) is mixed with the Potassium Hydroxide (PH) solution. The property of Potassium silicate solution is given in Table 3.

TABLE 3
PHYSICAL PROPERTIES OF FINE AGGREGATE

Materials	Specific gravity	Size: mm
Quartz sand (QS)	2.45	0.075-1.180
Grade I sand (GI) (coarse)	2.63	0.60-2.36
Grade III sand (GIII) (fine)	2.63	0.075-0.150

TABLE 4
PROPERTIES OF SILICATE USED

Parameter	PS(K_2SiO_3)
Specific gravity	1.38
K2O: % by mas	12.50
SiO2: % by mass	26.30
Total solids: %	38.8
Baume ´ @ 25 °C	40
Viscosity(cp)	440

2.5 Fine Aggregates

The property of fine aggregate is given in Table 4. Standard Ennore sand of grade I (GI) and grade III (GIII) confirming to IS 650:2004(BIS, 2004) and quartz sand (QS) with specific gravity 2.45 were used as fine aggregate. The maximum size of aggregate used for UHSGC was 2mm.

2.6 Steel Fibres:

In this study steel fibres of length 12 mm were used. They are added in percentage of the volume of the total mix. The diameter of steel fibre is 0.14 mm, having a tensile strength of 2000MPa and aspect ratio (length/diameter) of 85. The main reason to use steel fibre is to increase its mechanical property and the removal of brittle failure. The size of steel fibre is decided based on the size of the aggregate.

3. METHODOLOGY

To develop an UHSGC mix, the methodology developed by Ambily et al, 2013 were utilised 1)Particle packing for optimization of granular mix 2)Removal of coarse aggregate 3)Geopolymerisation of the industrial waste, 4)Curing at ambient temperature conditions. In this experimental study the molarity (M) of PH solution used was 10M and the ratio of PS to PH solution was 3 from the trial studies conducted by the co-author to obtain an ultra high strength concrete of greater than 120 MPa.

3.1 Preparation of UHSGC mix and specimens

No specific standard mix design approaches are available for geopolymer concrete, since geopolymers are a new class of construction materials, unlike conventional cement concrete. Considering the strength and workability parameters, the formulation of UHSGC was done by trial and error. The UHSGC mix details are tabulated in Table 5. Two mixes are prepared, with and without steel fibres that is U_2 (2% steel fibres), U_0(0% steel fibres) respectively.

The following steps were adopted for the preparation of mixes using a Hobart planetary mixer of 10 kg capacity (Figure 1).

- First, the dry mix consisting of GGBS, SF, QS and SS are mixed slowly in the mixer bowl of Hobart mixer, rotating at slow speed.
- Secondly, the AAS solution was added slowly into the dry mix and proceeded at slow speed until a uniform flowable uniform mix was formed. The mixing time ranged from 10 to 15 min.
- Thirdly, the steel fibres were added slowly to mixer (Figure 2) to get a uniform distribution of fibres. Then the speed was increased for further mixing.

After the addition of steel fibres, the mixer operated at different speed for couple of minutes. After mixing, the flow of fresh mix (Figure 3) was determined with flow table. Then the Geopolymer concrete mix is poured onto cubes (50 cu.mm, 70 cu.mm, 100 cu.mm) and cylinders (100 mm dia x 200 mm long) using a scoop and vibrated using a high frequency vibrating table, note that the cubes were filled in three layers. To avoid fibre protrusion on finished surface, sufficient vibration were provided.

The specimen was cured at under ambient temperature (average-25˚c) in open air with relative humidity of 71% (average) until testing.

Figure 1: Hobart planetary type mixer

TABLE 5
MIXES DETAILS

Materials	Mix 1 0% fibre (U0)	Mix 2 2% Fibre (U2)
Molarity (KOH)	10 M	10 M
$KOH:K_2SiO_3$	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
Fibers (kg/m^3)	_	157

Figure 2: Addition of steel fibres

4. EXPERIMENTAL RESULTS

4.1 Workability of UHSGC mix

The flow was determined as per ASTM C1437-07 (ASTM, 2007). As expected the flow got decreased by the addition of steel fibres (Table 6).

Figure 3: Flow of UHPGC mix

4.2 Compressive strength test

After 28 days of curing cubes specimens of size 50 mm, 70 mm, 100 mm and cylinders of 100 x 200 mm were tested according to ASTM C109-12. The compressive strength test was carried out on a compression testing machine (CTM) of 3000 kN capacity, load was applied at uniform rate (1.5 kN/s) until the specimen fails. Ten numbers of cubes and cylinders of each size were tested at the age of 28 days and the average was reported as compressive strength. Figure 4 shows the typical failure pattern of cube specimens without fibre and figure 5 shows a view of the cube specimen with fibres. Table 6 and 7 gives properties of the UHSGC mix and compressive strength of the cubes and cylinders at the age of 28 days.

Figure 4: Failure of cube specimen without fibre

Figure 5: Failure of cube specimen with Steel with fibre

TABLE 6

PROPERTIES OF UHSGC MIX (CUBES)

Cube Size (mm)	Compressive Strength, fcu (MPa)					Fresh Density kg/m^3	Flow %
	% Steel fibre (ID)	No.of cubes	Average	Std.dev	Co-eff var		
50	0% (U0)	10	69.7	4.26	6.11	2267	150
70		10	68.16	4.73	6.95		
100		10	65.3	5.2	7.9		
50	2%(U0)	10	143.40	3.65	2.54	2330	136
70		10	140.30	4.97	3.54		
100		10	135.24	4.97	3.67		

TABLE 8

CONVERSION FACTORS FOR CUBES AND CYLINDER

Specimens	cube 50	cube 70	cube 100	cylinder 100
cube 50	1	0.98	0.94	0.63
cube 70	1.02	1	0.96	0.65
cube 100	1.06	1.04	1	0.67
cylinder 100	1.58	1.55	1.49	1

TABLE 7

PROPERTIES OF UHSGC MIX (CYLINDER)

Cyl dia (mm)	Compressive Strength, fcy (MPa)				
	% Steel fibre (ID)	No. of cylinders	Average	Std.dev	Co-eff var
100	0%(U0)	10	63.83	6.5	10.18
100	2%(U2)	10	90.6	5.4	6.0

Results and discussion:

The mixes with and without steel fibres were highly workable and did not show any signs of segregation or bleeding. As expected the flow decreases with the presence of fibre. The incorporation of 2% fibres shows two times increase in the compressive strengths. With the presence of fiber the fresh density was increased. With increase in specimen size there is a decrease in compressive strength of concrete, 50 mm cubes gave the highest compressive strength value. Hence for UHSGC, an equation stating the order of compressive strength value can be given by $f_{c,\ 70} = 0.98\ f_{c,50} = 1.04\ f_{c,\ 100}$. The observations are different from those reported by Ambily et al 2015, Magureanu et al 2012, indicated fc,cube100mm = 0.90 fc,cube70.7mm. and are close to that of Graybeal and Davis who indicated fc,cube100mm = 0.94fc,cube70.7mm for ultra high strength concretes. The ratio of cylinder to cube compressive strength ($f_{cy,\ 100}$/ $f_{c,\ 100}$) was 0.67.

CONCLUSIONS

Based on the studies the following conclusions were made.

1. Workability of the high strength geopolymer concrete (HSGC) mix reduced with incorporation of steel fibres. The flow percentage of 150% for HSGC was reduced to 136% for ultra high strength geopolymer concrete (UHSGC).
2. The fresh density of the HSGC increased from 2267 kg/m^3 to 2330 kg/m^3 for UHSGC.
3. With incorporation of steel fibres the compressive strength of HSGC increased two times.
4. When the size of the cube specimen decreased the compressive strength increased.
5. For the UHSGC developed under ambient temperature conditions, the highest average compressive strength obtained for 50 mm cube at the age of 28 days was 143 MPa and the value was 135 MPa .
6. The conversion factor for compressive strength of 70 mm cube, fc, 70= 0.97 fc,50= 1.05 fc, 100.
7. The ratio of cylinder to cube compressive strength (fcy, 100/ fc, 100) was 0.67.
8. The coefficient of variation of compressive strength for UHSGC is less compared to HSGC.

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