Properties of Geopolymer Concrete Produced by Silica Fume and Ground-Granulated Blast-Furnace Slag

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Abstract: ***In the construction industry, the main production of Portland cement causes the emission of air pollutants which results in environmental pollution. Geopolymer Concrete (GPCs) is a one type class of concrete based on an inorganic alumino- silicate binder system compared to the hydrated calcium silicate binder system of concrete. It possesses the advantages of rapid strength gain, elimination of water curing, good mechanical and durability properties and is eco-friendly and sustainable alternative to Ordinary Portland Cement (OPC) based concrete. This paper presents, to investigate the compressive strength of the Geopolymer concrete produced by replacement of Ground-granulated blast-furnace slag (GGBS) with SF (Silica fume) by 0%,20%,40%,60%,80% and 100% , and its studies carried out in varying molarity. The alkaline liquids were used in this study for the geopolymerization are sodium hydroxide (NaOH) and sodium silicate (Soi_2). The geopolymer concrete specimens were tested for their compressive strength at the ages of 7, 14 and 28 days under two types of curing (water curing and room curing). Experimental investigations have been carried out on workability, the various mechanical properties of GPCs.***

Keywords: Geopolymer, Concrete, GGBS, SF, Sodium Silicate, Sodium hydroxide.

1. Introduction

In the today‘s world, concrete plays an important role in the construction works like dams, buildings, roads etc. It is made with cement and other additives or aggregates are mixed. These additives are either natural or artificial, but the constant use of natural additives has lead to exhausting of this very important source. Thus the use of alternative aggregate is a natural step towards solving part of the depletion of natural aggregate and the alternative aggregate processed from waste materials would appear to be an even more good solution [1,2,3]. The search of the alternative material for concrete-making started much before more than half a century. The main objective of the reuse of material is to minimize the impact of human activities on the environment and the planet. Use of inorganic industrial by products in concrete-making will lead to sustainable concrete design. The industrial as well as other wastes such as copper slag, oil palm shells, wood waste ash, fly ash, granite sludge, cement kilns dust, steel chips, silica fume, rice husk ash etc. were used in concrete to improve the properties of concrete and to reduce the cost [5,6].

The production of Portland cement worldwide is increasing 9% annually. Portland cement (PC) production is under critical review due to high amount of carbondioxide gas released to the atmosphere and Portland cement is also one among the most energy-intensive construction material [17]. The current contribution of green house gas emission from Portland cement production is about 1.5 billion tonnes annually or about 7% of the total greenhouse gas emissions to the earth's atmosphere. Today, the world is facing the environmental pollution as a major problem. But the production of cement means the production of pollution because of the emission of CO_2 during its production.

On the other side the demand of concrete is increasing day by day for its ease of preparing and fabricating in all sorts of convenient shapes. So to overcome this problem, the concrete to be used should be environmental friendly [2]. To produce environmental friendly concrete, it is necessary to replace the cement with the industrial by products such as fly ash, GGBS etc. Disposal of FA is a growing problem, as only 15% of FA is currently used for high value addition applications like concrete and building blocks, the remaining being used for land filling. The SF increases the strength in case of hardened concrete. Another alternative but promising utility of SF in construction industry that has emerged in recent years is in Geopolymer concrete [3,4]. Geopolymer technology can be appropriate process technology utilize all classes and grades of SF and therefore there is a great potential for reducing stockpiles of waste SF materials. The present study considers SF utilization in production of geopolymer concrete since it can accommodate a major portion of the ash produced [7,8].

Geopolymer concretes' (GPC) are a type of Inorganic polymer composites, to form a substantial element of an environmentally sustainable construction and building products industry by replacing/supplementing the conventional concretes. The term geopolymer was first introduced by Davidovits in 1970s to name the three-dimensional alumino-silicates material, which is a binder produced from the reaction of a source material or feedstock rich in silicon (Si) and aluminum (Al) with a concentrated alkaline solution [5]. The source materials may be industry waste products such as fly ash, slag, red mud, rice-husk ash and silica fume may be used as feedstock for the synthesis of geopolymers. The alkaline liquids are concentrated aqueous alkali hydroxide or silicate solution, with soluble alkali metals, usually Sodium- (Na) or Potassium- (K) based. High alkaline liquids are used to induce the silicon and aluminum atoms in the source materials to dissolve and form the geopolymeric binder.

2. Materials and Methods

2.1 Ground granulated blast-furnace slag (GGBS)

The GGBS meets the ASTM C 989-99 (1999) specifications. Some of the ASTM characteristics recruitments are:
- High fineness, good particle size distribution.
- High activity index and small variation in the quality.
- The product has low energy consumption and high production efficiency.

2.2 Silica Fume (SF)

The SF meets the ASTM C 1240-93 (1993) specification. There are some characteristics for the SF such as material characteristics that conform to the requirements of ASTM C 1240, in which involve the chemical and physical requirements.

2.3 Fine Aggregate

Ordinary mining sand is used in this investigation. The BS 812, (1984) [15] described the methods for determination of the size distribution of the sample of aggregates and fillers by sieve analysis. The sample used for the test is taken in accordance with the procedure described in clause 5 of BS 812: Part 102: (1984) [15]. The sample of aggregate must be wash before the test to remove other materials such as clay and dirt that may caused agglomeration, and keep oven dried as therefore sieve analysis was done as shown in Table (1).

2.4 Coarse Aggregates

ASTM C 0033-03 (2005) [14] recruitments for coarse aggregate demands to use sizes between 5 and 20 mm and for this investigation three types of 7, 14 and 20 mm were chosen for the suitable of manufacture of geopolymer concrete.

2.5 Sodium Silicate Solution

The sodium silicate solution is commercially available in different grades. The sodium silicate solution A53 with SiO_2-to-Na_2O ratio by mass of approximately 2, SiO_2= 29.4%, Na_2O = 14.7%, and water = 55.9% by mass.

2.6 Sodium Hydroxide

The sodium hydroxide with 97-98% purity. The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in the range between 8 Molar and 16 Molar.

2.7 Superplasticizer

The addition of naphthalene sulphonate-based superplasticizer, up to approximately 4% of FA by mass to improves the workability of the fresh geopolymer concrete; however, there is a slight degradation in the compressive strength of hardened concrete when the superplasticizer dosage is greater than 2%.

3. Tests Employed

3.1 Sieve analysis test of Fine aggregates

Figure. 1 shows the sample as drying in the oven under temperature 110 ± 5° C.

Figure 1: Fine Aggregate in the Oven

Table 1: Sieve Analysis for Fine Aggregate

Sieve Size (mm)	*Weight of Sieve (gm)*	*Weight of Sieve + Sand Retained (gm)*	*Weight of Sand Retained(gm)*	*∑ Retained %*	*Pass %*
10.0	420.9	420.9	0	0	100
05.0	403	410.5	7.5	1.5	98.5
2.36	423.4	461.4	38	9.1	90.9
1.18	355.2	441.6	86.4	26.38	73.62
0.60	305.2	443	137.8	53.94	46.06
0.30	275.2	393.5	118.3	77.6	22.4
0.15	261.1	335.1	74	92.4	7.6
Pan	264.4	302.4	38	100	0
			∑= 500		

4. Mixing

4.1 Alkaline Liquids

A combination of sodium silicate solution and sodium hydroxide (NaOH) solution . It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least one day prior to use.

4.2 Mix Proportion

The mix proportion in this study was the water-to-geopolymer solids ratio by mass of 0.19, the design compressive strength is approximately 45 MPa.

Table 2: Mix Proportions

Materials		*(kg/m³)*	*In Cube*
Coarse aggregates	20 mm	277	0.935
	14 mm	370	1.249
	7 mm	647	2.184
Fine sand		554	1.87
GGBS, SF		408	1.377
Sodium silicate solution (Soi_2/Na_2O=2)		103	0.348
Sodiume hydroxide solution		41(8 Molar)	0.138
Superplasticizer		6	0.02
Extra water		None	

5. Results and Discussion

5.1 Slump Test

This test is widely used in the construction site all over the world. The slump test does not measure the workability of concrete, although ACI 116R-90 describes it as a measure of consistency. The test is very useful in detecting variation in the uniformity of a mix of given nominal proportions the slump test is prescribed by ASTM C 143 and BS 1881: Part 102: 1984[15].

Table 3: Slump Test

Materials %		*Slump*	*Date of Product*
GGBS	*SF*		
100	0	89 mm	18/05/2016
80	20	95 mm	14/06/2016
60	40	97 mm	16/06/2016
40	60	100 mm	16/06/2016
20	80	103 mm	16/06/2016
0	100	112 mm	18/06/2016

5.2 Compressive Strength Test

The study followed the design used in the British standard,BS1881 Part 116: 1983 and the experience of a single standard for each mixture at 7, 14 and 28 days. Cubes were tested for compressive at the ages of 7, 14 and 28 days to determine the resistance of concrete under different curing.

The behavior of Geopolymer concrete after replacing the SF with GGBS in several percentages is shown below.

(A).-Water Curing

Table 4: Under Water Curing

Materials %		*Strength (MPa)*						*Date of*
GGBS	*SF*	*W*	*7d*	*W*	*14d*	*W*	*28d*	*Product*
100	0	8.58	68	8.54	78	8.68	80	18/05/16
80	20	8.20	51	8.34	63	8.44	79	14/06/16
60	40	8.48	48	8.24	58	8.14	63	16/06/16
40	60	7.96	32	8.26	35	8.08	40	16/06/16
20	80	8.10	8	8.00	8	7.98	9	16/06/16
0	100	7.92	5	7.84	7	7.66	8	18/06/16

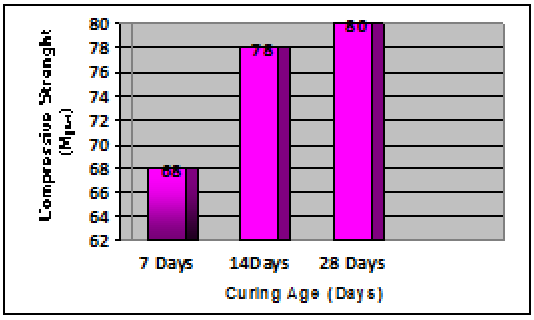

Figure 2: Geopolymer Concrete with 100 % of GGBS at different ages of Water curing

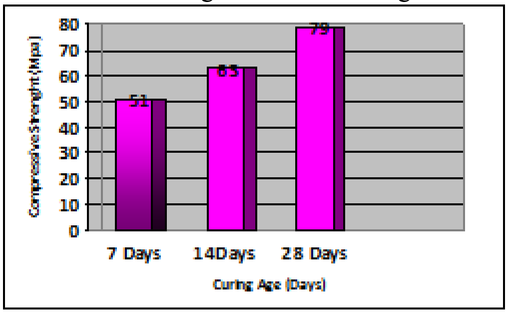

Figure 3: Geopolymer Concrete by 20% replacement SF of GGBS at different ages of Water curing

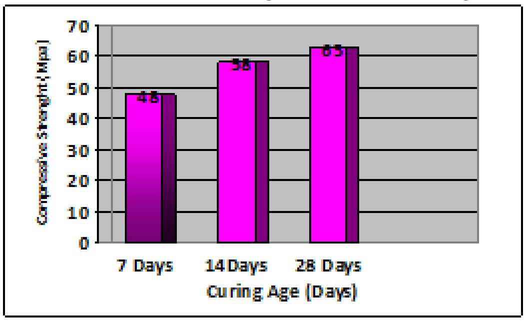

Figure 4: Geopolymer Concrete by 40% replacement SF of GGBS at different ages of Water curing

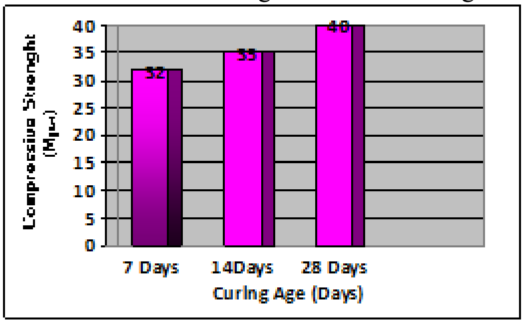

Figure 5: Geopolymer Concrete by 60% replacement SF of GGBS at different ages of Water curing

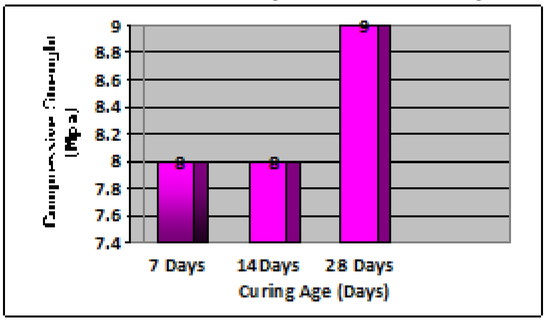

Figure 6: Geopolymer Concrete by 80% replacement SF of GGBS at different ages of Water curing

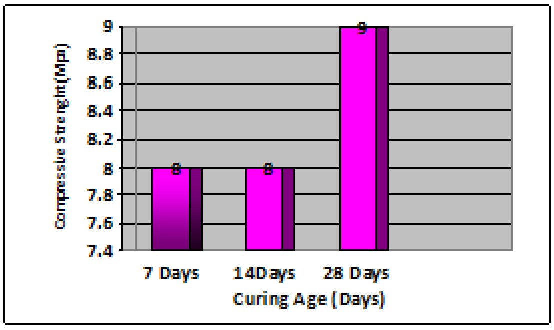

Figure 7: Geopolymer Concrete with 100 % of SF at different ages of Water curing

The graphs of results above , the geoplolyme concrete has different results and different percentage under Water curing . The cubes of geopolymer concrete which contained by 100% of GGBS given the maximum strength results at ages of 7, 14 and 28 days. From the works review it has been found that the Geopolymer concrete takes short time to react with the water, hence the early strength gained by the Geopolymer Concrete with GGBS is much than the concrete with no replacement. From the above result the 28 days strength of the geopolymer concrete decreases with the increase of the percentage of the SF with GGBS. The above test results shows the strength gain properties of the GGBS, as the GGBS starts gaining the strength littel in strength is taken place and the compressive strength increases with time.

From interpreting the above results given conclude that the strength of the Geopolymer concrete is increases with increase the percentage of the GGBS.

(B) Temperature Room Curing

Materials %		*Strength (MPa)*						*Date of*
GGBS	*SF*	*W*	*7d*	*W*	*14d*	*W*	*28d*	*Product*
100	0	7.56	73	8.04	76	8.34	81	18/05/16
80	20	8.26	59	8.50	71	8.44	74	14/06/16
60	40	8.16	50	8.14	54	8.00	56	16/06/16
40	60	7.98	22	7.84	25	7.78	29	16/06/16
20	80	7.94	2	7.56	8	7.86	10	16/06/16
0	100	7.89	1	7.69	2	7.00	2	18/06/16

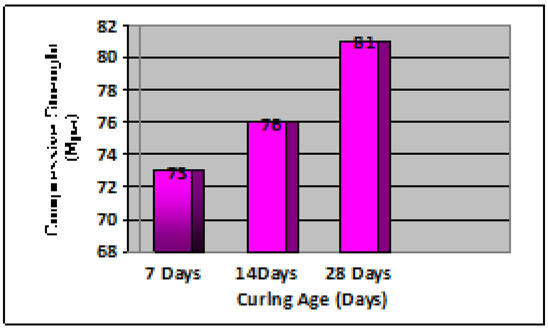

Figure 8: Geopolymer Concrete with 100 % of GGBS at different ages of Room curing

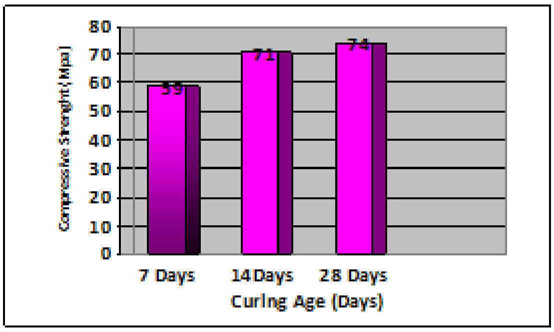

Figure 9: Geopolymer Concrete by 20% replacement SF of GGBS at different ages of Room curing

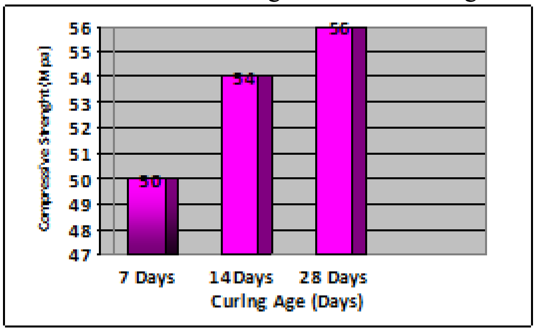

Figure 10: Geopolymer Concrete by 40% replacement SF of GGBS at different ages of Room curing

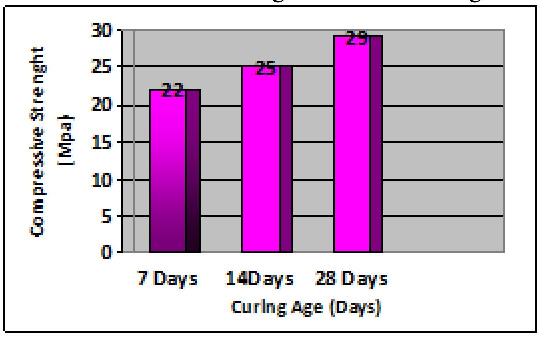

Figure 11: Geopolymer Concrete by 60% replacement SF of GGBS at different ages of Room curing

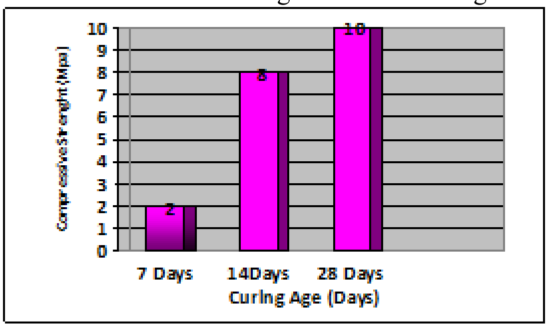

Figure 12: Geopolymer Concrete by 80% replacement SF of GGBS at different ages of Room curing

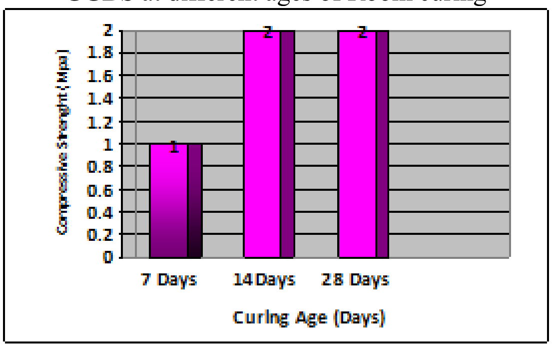

Figure 13: Geopolymer Concrete with 100 % of SF at

different ages of Room curing

From the graphs of results above,the mixture of geopolymer concrete has several results and different replacement of SF to GGBS under Room curing. The Compressive test has given the highest results at ages 7,14 and 28 days to the concrete predicted by 100% of GGBS. Furthermore, the strength of geopolymer concrete increases with curing age and replacement of GGBS to SF.

By comparison of the results of Geopolymer concrete under two types of processors curing can be seen clearly that the Geopolymer concrete is gaining strength early. And there is no significant difference between temprature room curing and Water curing.Also,Geopolymer concrete achieved the strength of the Mix design at above 40% of GGBS with 60% of SF.

6. Conclusion

Based on the experimental investigations carried out on geopolymer concretes, it can be concluded that:

1) The incorporation of SF in the geopolymer concrete mixes resulted in finer pore structure thus produce low permeability concrete.
2) The geopolymer concretes produced with different combination of SF and GGBS are able to produce structural concretes of high grades (much more than 45MPa) by self curing mechanisms only and percentage 40% of SF to 60% GGBS.
3) The GPC mixes were produced easily using equipment similar to those used for production of conventional cement concretes.
4) The influences of SF on strength of geopolymer concrete mixes were studied. It has been observed that the decreasing the quantity of SF increase of Compressive strength of geopolymer .
5) Apart from less energy intensiveness, the GPCs utilize the industrial wastes for producing the binding system in concrete. There are both environmental and economical benefits of using SF, fly ash and GGBS.

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