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A Study on Strength Properties of Geopolymer Concrete with Addition of G.G.B.S

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***Abstract*—Flyash based geopolymer concrete is introduced in 1979 by Davidovits to reduce the use of OPC in concrete. Geopolymer is an inorganic alumino-hydroxide polymer synthesized form predominantly silicon and aluminum materials of geological origin and by product materials such as flyash (with low calcium). In this paper an attempt is made to study strength properties of geopolymer concrete using low calcium flyash replacing with slag in 5 different percentages. Sodium silicate (103 kg/m^3) and sodium hydroxide of 8 molarity (41kg/m^3) solutions were used as alkalis in all 5 different mixes. With maximum (28.57%) replacement of flyash with slag (Mix no5), achieved a maximum compressive strength of 57MPa for 28 days. The same mix (Mix no5) is shown 43.56 MPa after exposure of 500°C for 2 hours.**

***Keywords*—Geopolymer concrete, sodium silicate, sodium hydroxide, flyash, slag, compressive strength, split tensile strength, flexural strength, and temperature effect.**

I. INTRODUCTION

The geopolymer technology is proposed by Davidovits and gives considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the geopolymer technology could reduce the CO_2 emission in to the atmosphere, caused by cement and aggregate industries about 80%. In this technology, the source material that is rich in silicon (Si) and Aluminium (Al) is reacted with a highly alkaline solution through the process of geopolymerisation to produce the binding material. The term 'geopolymer' describes a family of mineral binders that have a polymeric silicon-oxygen-aluminium framework structure, similar to that found in zeolites, but without the crystal structure. The polymerisation process involves a substantially fast chemical reaction under highly alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymer concrete is emerging as a new environmentally friendly construction material for sustainable development, using flyash and alkali in place of OPC as the binding agent. This attempt results in two benefits. i.e. reducing CO_2 releases from production of OPC and effective utilisation of industrial waste by products such as flyash, slag etc by decreasing the use of OPC.

II. OBJECTIVE AND SCOPE

To evaluate the different strength properties of geopolymer concrete mixture with G.G.B.S replaced in percentage to flyash. Making workable, high strength and durable geopolymer concrete containing G.G.B.S (Slag) without usage of ordinary Portland cement

III. SIGNIFICANCE

This paper aims to reduce the usage of ordinary Portland cement and to improve the usage of the other by product G.G.B.S (Slag). This product helps in reducing the carbon emissions caused by the conventional concrete. This also produces high strength concretes with the use of nominal mixes when compared to conventional concrete.

IV. MATERIALS

Flyash used in this experimental work was obtained from National Thermal Power Corporation (NTPC), Visakhapatnam. Flyash is finely grained residue resulting from the combustion of ground or powdered coal. Mean particle size is about 0.1 to 0.2 μm and finer than cement and consist mainly of glassy spherical particles as well as residues of hematite and magnetite. The specific gravity, fineness modulus, specific surface area and density of flyash are 2.82, 1.375, 310 m^2/kg and 1.4 kg/m^3 respectively. Ground granulated blast furnace slag of fineness modulus 0.16 was used in the work.

Locally available river sand having fineness modulus 2.22, specific gravity 2.4 and conforming to grading zone-III as per I.S: 383 - 1970. Coarse aggregate is of angular shaped crushed granite with maximum size 20mm and its fineness modulus and specific gravity are 7.17 and 2.89 respectively. Potable water with pH value 7.15 was used for the geopolymer concrete.

V. EXPERIMENTAL WORK

1. Mix design of geopolymer concrete

In the design of geopolymer concrete mix, total aggregates (fine and coarse) taken as 77% of entire concrete mix by mass. This value is similar to that used in OPC concrete in which it will be in the range of 75 to 80% of the entire concrete mix by mass. Fine aggregate was taken as 30% of the total aggregates. From the available literature, it is observed that the average density of flyash-based geopolymer concrete is similar to that of OPC concrete (2400 kg/m3). Knowing the density of concrete, the combined mass of alkaline liquid and flyash can be arrived at. By assuming the ratios of alkaline liquid to flyash as 0.4, mass of flyash and mass of alkaline liquid was found out. To obtain mass of sodium hydroxide and sodium silicate solutions, the ratio of sodium silicate solution to sodium hydroxide solution was fixed as 2.5. In the present investigation, concentration of NaOH solution is taken as 8 M.

2. Preparation of geopolymer concrete

320 g (molarity x molecular weight) of sodium hydroxide flakes dissolved in one litre of water to prepare sodium hydroxide solution of 8M. The mass of NaOH solids in a solution vary depending on the concentration of the solution expressed in terms of molar, M. The mass of NaOH solids was measured as 248 g per kg of NaOH solution of 8 M concentration. The sodium hydroxide solution is mixed with sodium silicate solution to get the desired alkaline solution one day before making the geopolymer concrete. After solution is prepared the composition is weighed and mixed in concrete mixture as conventional concrete and transferred into moulds as early as possible as the setting times are very low.

3. Mixing and Casting

It was found that the fresh geopolymer masonry mix was grey in colour and was cohesive. The amount of water in the mix played an important role on the behaviour of fresh mix. Davidovits (2002) suggested that it is preferable to mix the sodium silicate solution and the sodium hydroxide solution together at least one day before adding the liquid to the solid constituents. The author suggested that the sodium silicate solution obtained from the market usually is in the form of a dimmer or a trimmer, instead of a monomer, and mixing it together with the sodium hydroxide solution assists the polymerization process.

The effects of water content in the mix and the mixing time were identified as test parameters in the detailed study .From the preliminary work; it was decided to observe the following standard process of mixing in all further studies. Mix sodium hydroxide solution and sodium silicate solution together at least one day prior to adding the liquid to the dry materials. Mix all dry materials in the pan mixer for about three minutes. Add the liquid component of the mixture at the end of dry mixing, and continue the wet mixing for another four minutes. Compaction of fresh concrete in the cube moulds was achieved by compacting on a vibration table for ten seconds. After casting, the specimens were left undisturbed for 24 hours. Five different mixes were developed in this study, for each mix 12 cubes of 150mm, 12 cylinders of diameter of 150mm x height 300mm and 3 beams of 150mm x 150mm x 750mm were cast to study compressive, split and flexural strengths of each mix.

4. Curing

Curing is not required for these geopolymer blocks. The heat gets liberated during the preparation of sodium hydroxide which should be kept undisturbed for one day.

5. Testing

The specimens were tested as per IS 516:1959 and strengths were calculated for 3, 7, 14 and 28 days and the results were tabled.

***Figure** 1*

***Figure** 2*

Figure 3

Figure 4

VI. RESULTS AND DISCUSSIONS

In this investigation, to study the strength properties of geopolymer concrete, 5 different mixes were prepared by replacing of flyash with slag and the 5 different mixes were presented in Table 6.1. Different cube strengths and split tensile strengths of 5 mix proportions were presented in Table 6.2 and Table 6.3 respectively.

Table 1 **Mix proportions**

Materials		**Mix 1 (kg/m^3)**	**Mix 2 (kg/m^3)**	**Mix 3 (kg/m^3)**	**Mix 4 (kg/m^3)**	**Mix 5 (kg/m^3)**
Coarse aggregate	20mm	277	277	277	277	277
	12.5mm	370	370	370	370	370
	4.75mm	647	647	647	647	647
Fine aggregate		554	554	554	554	554
Flyash		408	370.091	340	313.85	291.43
Slag		0	37.091	68	94.15	116.57
Sodium hydroxide		41(8M)	41(8M)	41(8M)	41(8M)	41(8M)
Sodium silicate		103	103	103	103	103
Extra added water		22.5	22.5	22.5	22.5	22.5

'M' indicates molarity

Table 2 **Compressive strengths for different ages of geopolymer concrete**

Mix	**Cube strengths(N/mm^2)**			
	3days	7days	14days	28days
Mix No 1	4.25	6.2	7.14	8.27
Mix No 2	9.48	17.89	19.55	24.29
Mix No 3	15.26	31.26	36	41.04
Mix No 4	25.55	39.17	40.63	45.76
Mix No 5	31.85	46.52	53.63	57.33

From the Table 2, it can be observed that the compressive strength of geo-polymer concrete increases enormously with increase in percentage of slag (GGBS) to flyash. The strength is varying significantly in line with conventional concrete with increase in age of concrete.

Table 3 **Split tensile strengths for different ages of geopolymer concrete**

Mix	**Split tensile strengths (N/mm^2)**			
	3days	7days	14days	28days
Mix No 1	0	0.63	1.2	1.77
Mix No 2	2.3	3.7	4.0	5.35
Mix No 3	3.45	5.39	8.98	10.32
Mix No 4	5.17	7.59	9.20	12.43
Mix No 5	9.05	10.56	10.94	11.40

From Table 3, it can be observed that the tensile strength of geopolymer concrete increases continuously up to 28 days with increase in percentage of slag (GGBS) to flyash. The tensile strength increases continuously with increase in age of geopolymer concrete.

Table 4 **Flexural strengths of geopolymer concrete at 28 days**

Mix	**Flexural strength of beams (N/mm^2)**
	28 days
Mix No 1	0.00
Mix No 2	1.00
Mix No 3	5.00
Mix No 4	5.77
Mix No 5	7.06

From Table 4, it can be observed that the geopolymer concrete without slag (Mix No.1) has not gained flexural strength. The remaining mixes have shown significant flexural strengths.

Table 5 Initial setting time and mixing time of all mixes

Mix	**Final setting**	**Mixing time**
Mix No 1	6hrs	6mins
Mix No 2	6hrs	5mins
Mix No 3	5hrs	5mins
Mix No 4	3hrs	7mins
Mix No 5	1hr	7mins

From Table 5, it is inferred that the setting times of concrete are reduced with increase in slag content. With the further increase in slag content, setting time of geopolymer concrete is reduced and hence slag content was increased up to 28.57% (Mix No.5).

Table 6 **Compressive strengths of cubes exposed to 500° C for two hours**

Mix	**Strength(N/mm^2)**
Mix No 2	27.50
Mix No 3	34.67
Mix No 4	39.11
Mix No 5	43.56

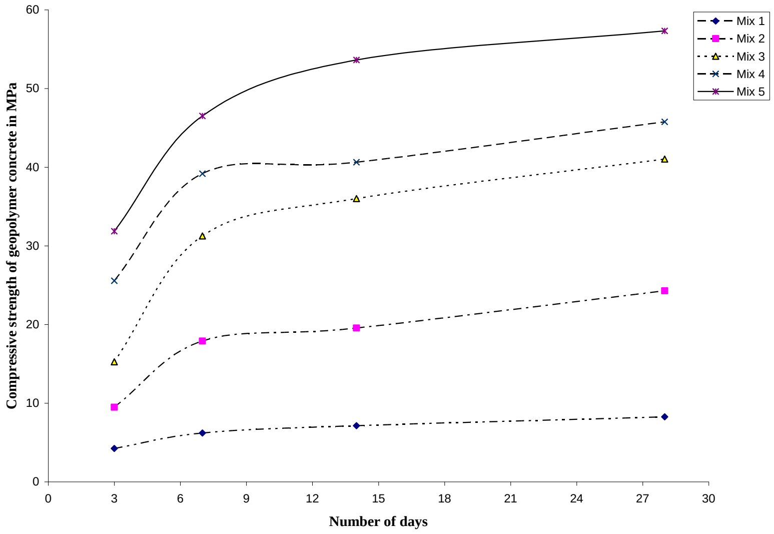

***Figure** 5,* **Compressive strength of geopolymer concrete versus number of days**

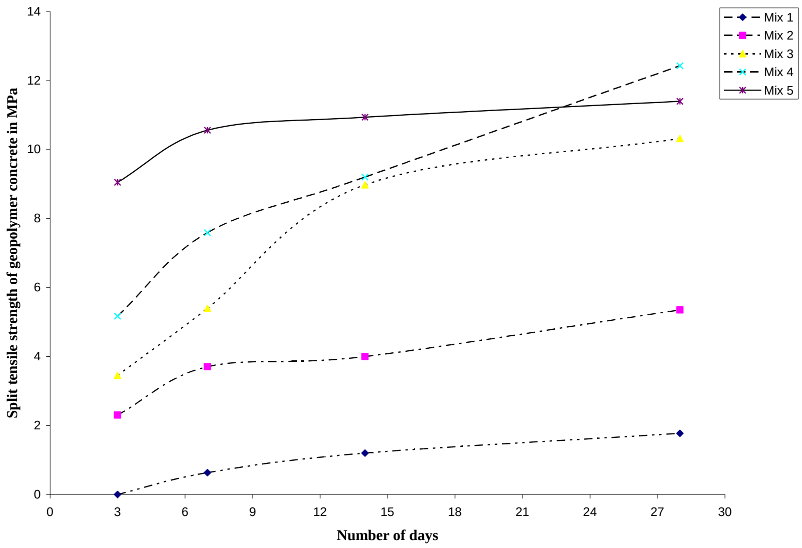

***Figure** 6*, **Split tensile strength of geopolymer concrete versus number of days**

From Figure 6, Mix 1 has gained a compressive strength of 8.27N/mm^2 for 28 days. If Mix 1 is continuously exposed to 60°C to 90ºC for 5 days then the compressive strength recorded more than 20MPa and confirmed to M20 grade. As it is not possible in practical, compressive strength of more than 20MPa can be attained by partial replacement of flyash with the addition of GGBS without exposure to 60°C-90ºC.

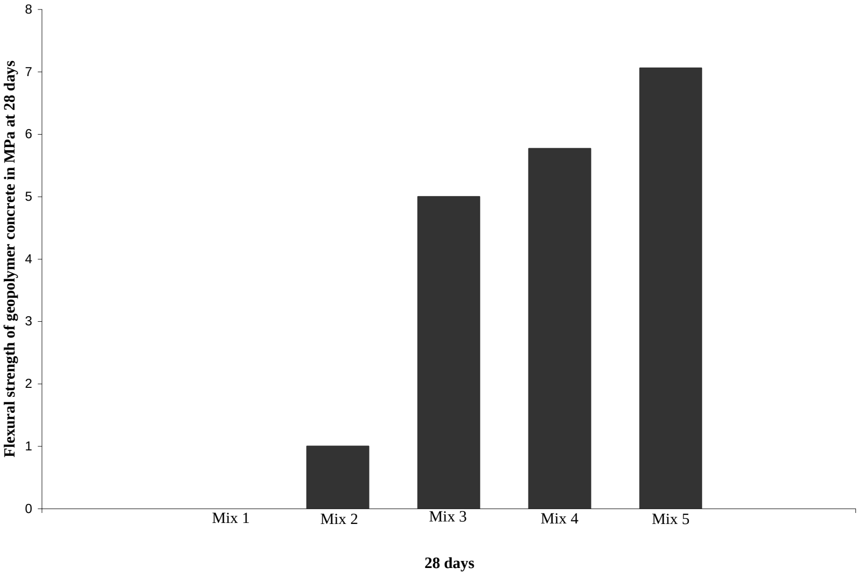

***Figure** 7*, **Flexural strength of geopolymer concrete for 28 days of different mixes**

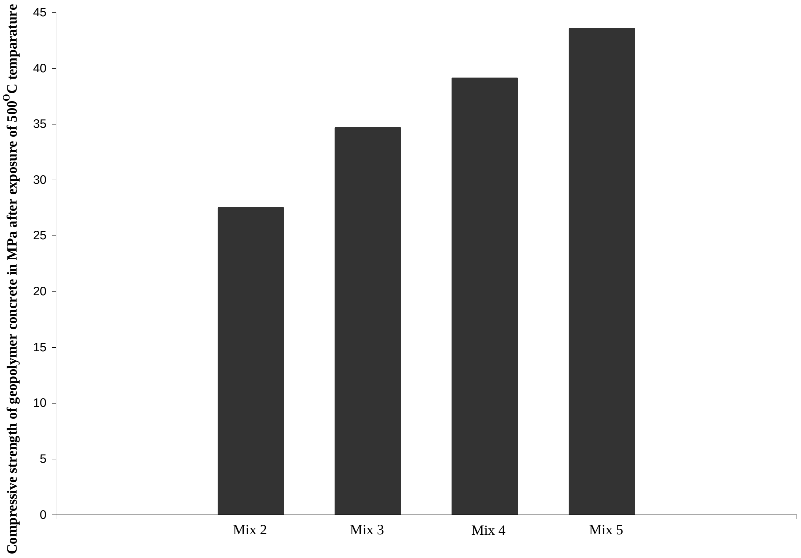

***Figure** 8,* **Compressive strength of geopolymer concrete cubes of exposed to 500°C temperature**

VII. MINERALOGICAL ANALYSIS

XRD, SEM and EDS tests

The microstructure of flyash was analyzed using scanning electron microscope (SEM). From Figure 9 and 10, the microstructure of flyash is appeared to be a glassy, hollow, spherical particle which is cenospheres (thin walled hollow spheres). Furthermore, surface texture appears to be smooth and dense to highly porous.

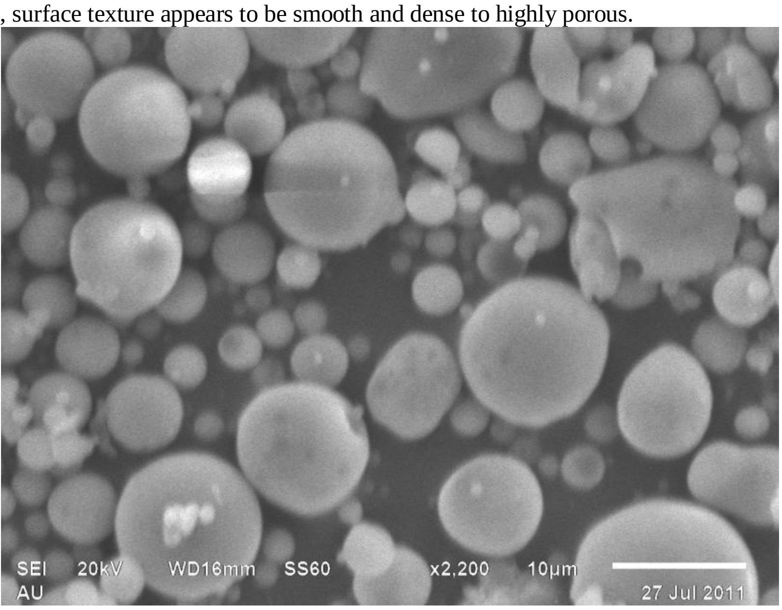

***Figure** 9*, **Scanning Electron Microscopic view for flyash (10µm)**

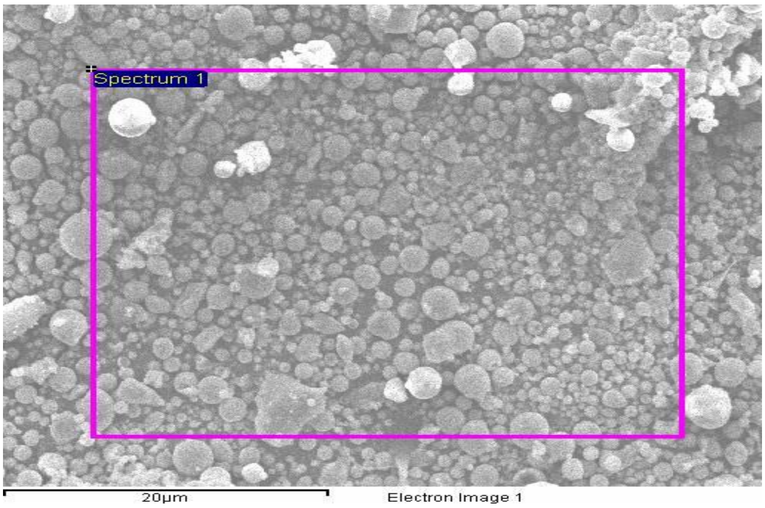

Figure 10**, EDS test for flyash**

Table 7 **Composition of flyash from EDS test**

Element	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Mn	Total
Weight (%)	37.27	0.21	0.85	16.63	35.78	0.24	0.51	1.65	2.72	0.60	3.56	100
Atomic wt (%)	52.06	0.20	0.78	13.77	28.47	0.17	0.35	0.94	1.52	0.28	1.45	-

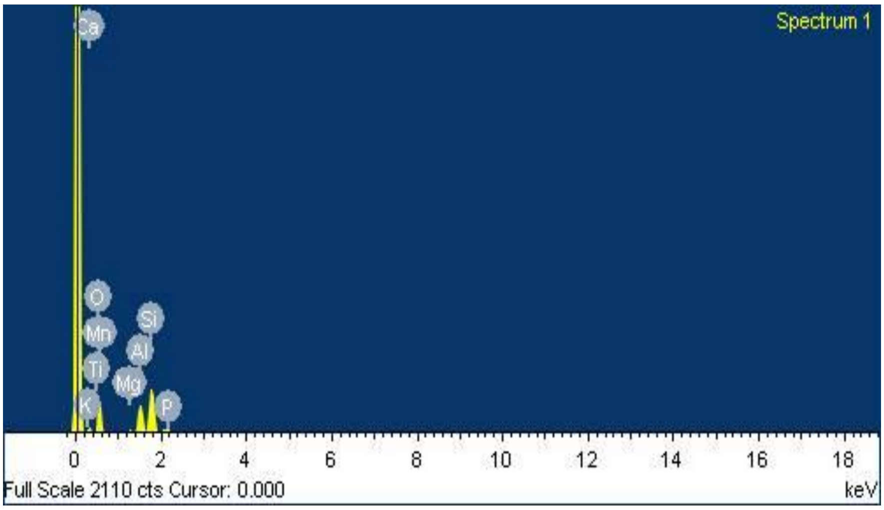

***Figure** 11* **, EDS scale for flyash**

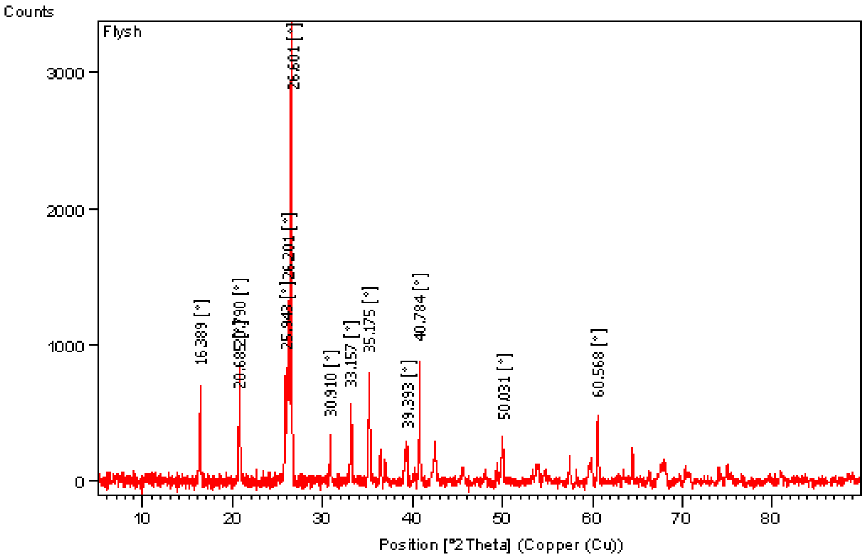

***Figure** 12*, **XRD of flyash**

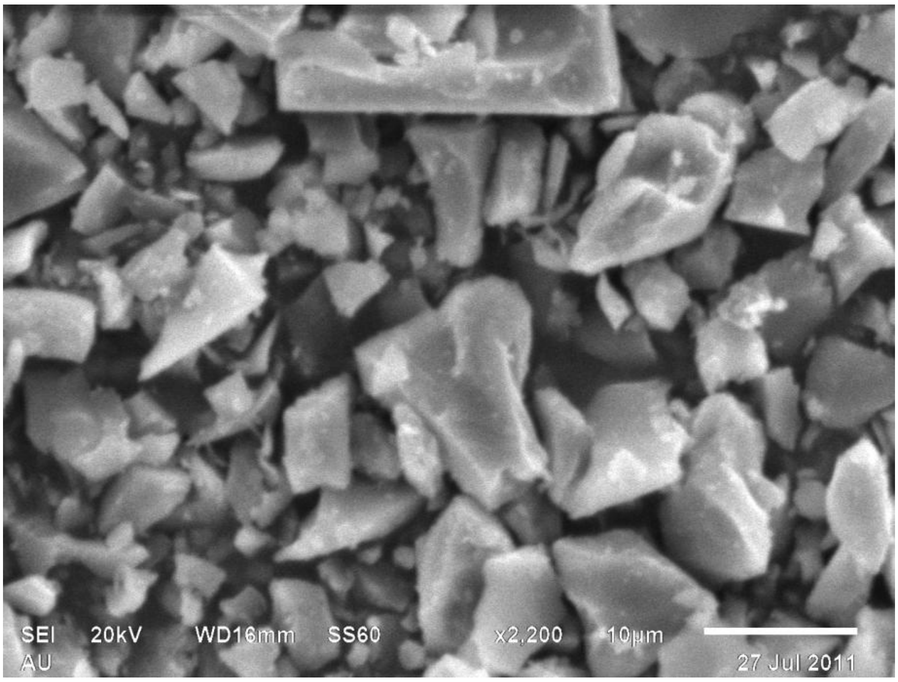

***Figure** 13*, **Scanning Electron Microscopic view for slag (10µm)**

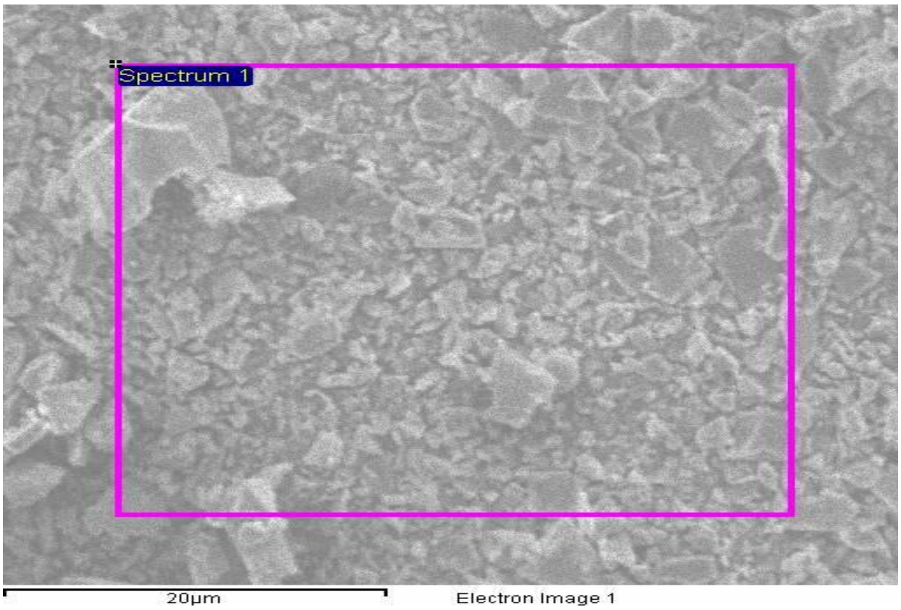

***Figure** 14*, **EDS Test for slag**

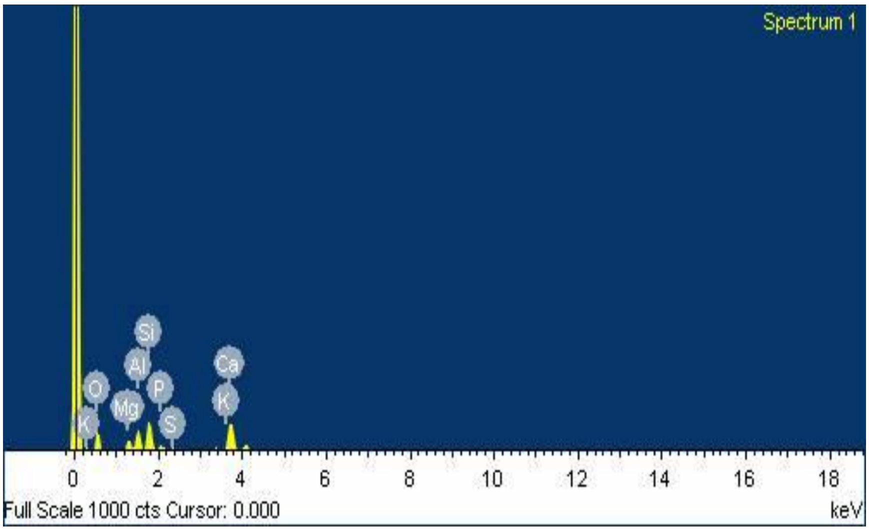

***Figure** 15*, **EDS scale for slag**

The microstructure of Slag was analyzed using scanning electron microscope (SEM). From Figures13 and 14 the microstructure of Slag is appeared to be flaky particle.

Table 8 **Chemical composition for slag**

Element	O	Na	Mg	Al	Si	P	S	K	Ca	Co	Ni	Total
Weight (%)	25.99	0.42	3.21	6.85	14.64	0.61	1.43	2.12	43.15	0.99	0.6	100
Atomic wt (%)	43.07	0.49	3.50	6.73	13.82	0.52	1.18	1.44	28.54	0.44	0.27	-

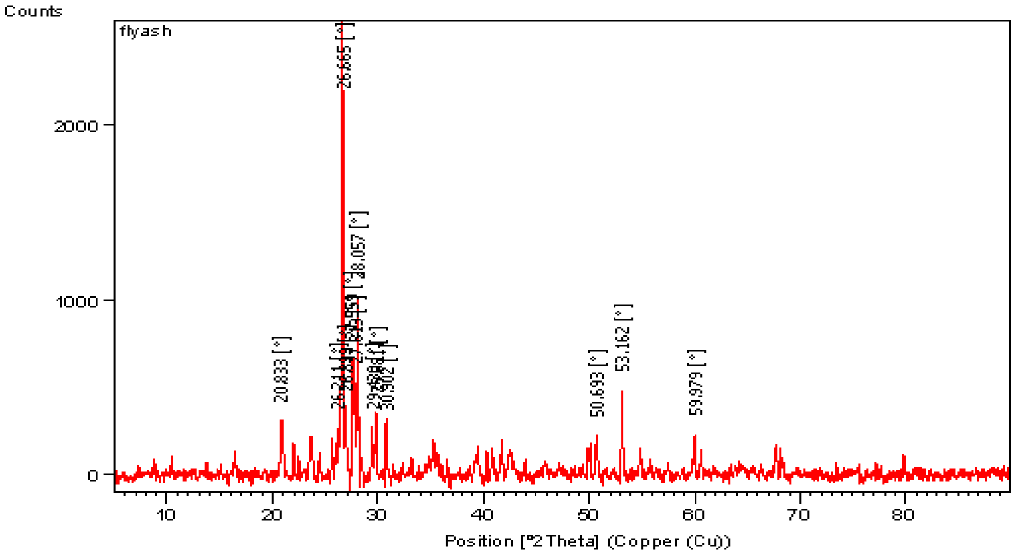

***Figure** 16*, **XRD of slag**

VIII. CONCLUSIONS

Based on the experimental work the following conclusions are drawn:

- Higher concentrations of G.G.B.S (Slag) result in higher compressive strength of geopolymer concrete. Mixing of G.G.B.S was tested up to 28.57%, beyond that immediate setting was observed.
- There is no necessity of exposing geopolymer concrete to higher temperature to attain maximum strength if minimum 9% of flyash is replaced by GGBS.
- Compressive strength of geopolymer concrete increases with increase in percentage of replacement of flyash with GGBS. Flyash was replaced by GGBS up to 28.57%, beyond that fast setting was observed.
- A maximum of 25% loss in compressive strength was observed when geopolymer concrete exposed to a temperature of 500°C for two hours.
- 90% of compressive strength was achieved in 14 days.
- The average density of geopolymer concrete was equal to that of OPC concrete.

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