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Studies on Geopolymer Concrete with GGBS as Partial Replacement to Fly Ash

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Abstract - *The current work reports the mechanical and durability characteristics of Geopolymer concrete (GPC) using GBBS as a replacement to that of Flyash obtained from thermal powerplant. Since GGBS exhibits more pozzolanic character and it contributes to the later strength which can be used as a replacement to flyash. Flyash and GGBS are obtained from industrial waste. In this study GGBS are used a replacement to flyash at 0%, 30%, 60%, 90% and 100%. Class F Flyash is used as geopolymer binder. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) of (8,10,12) molarity are used as alkali activator. Mechanical properties like, compressive strength, flexural strength and split tensile strength were tested at 14days and 28days once it is oven cured at 90^0 for 24 hours. It is concluded that mechanical properties were maximum for 12 molar concentration of alkaline activator and 100 percent content of GGBS in flyash.*

***Key Words*: Geopolymer concrete, GGBS, Flyash, Molarity, Oven curing.**

1. INTRODUCTION

Concrete is the most widely used material in the construction work. The Ordinary Portland cement (OPC) is the fundamental element of the concrete which is the significant factor for the global warming. For around 7% of total carbon-di-oxide emission in to the world yearly is from the production of around 1.6 billion tons of cement. The raw materials required for manufacturing OPC are exhaustible. On the other side industrial derivatives such as Fly ash and GGBS are disposed as waste materials that cover a hectare of land which contributes to the environmental pollution. Thus, by using suitable industrial by-product with geopolymer binder it is possible to minimize the emission of carbon-di-oxide in to the environment and by product can be used effectively rather than disposing off in exposed land.

Davidovits invented the word ' geo-polymer ' in 1978. Geo-polymer is a polymerization reaction between silicon (Si) and aluminum (Al) which contains alkaline fluid and pozzolanic material. This response to polymerization leads to the creation of a three-dimensional polymer ring of "Si-O-Al-O" bonds termed as "silicon oxo aluminates." The sodium (Na) or Potassium (K) based minerals can be used as alkaline fluid. A mixture of sodium hydroxide (NaOH) together with sodium silicate (Na_2SiO_3) is generally the most frequently used alkaline liquid.

2. OBJECTIVES

The major objective of this study is on the use of GGBS as replacement in different variations to flyash based geopolymer concrete to evaluate its mechanical properties and also to study the durability properties.

3. MATERIALS USED

3.1 Fly ash

In this study we are using Class F fly ash, obtained from Raichur thermal power plant (RTPS) collected in accordance with IS: 12089-1987 with a specific gravity of 2.33.

3.2 Ground granulated blast furnace slag (GGBS)

In this study JSW GGBS was obtained from the retailer Quality Polytech Mangalore with a specific gravity of 2.91.

3.3 Fine aggregates

In the present study crushed stone aggregates was used as fine aggregate and test were conducted as per IS:2386-1997 Part-III and IS:383-1970.

Table 1: Test result of fine aggregates

Properties	Results
Specific gravity	2.66
Fineness Modulus	2.9
Grading Zone	II
Bluck Modulus (kg/m^3)	1670

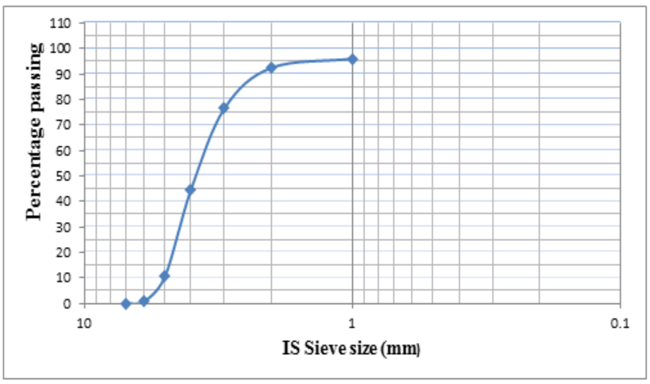

Figure 1: Gradation of fine aggregates

3.4 Coarse aggregate

The stone aggregate of 20 mm size is used in this work. The shape of these aggregates is angular. They were evaluated in accordance with IS: 2386-1997, Part-III and determining their physical characteristics.

Table-2: Properties of coarse aggregate

Properties	Results
Specific gravity	2.68
Water Absorption	0.20%
Bulk density in loose sate	1450 (kg/m^3)
Bluck density in compacted state	1670(kg/m^3)

3.5 Alkaline Activators

Sodium hydroxide and Sodium silicate solution were combined together to form alkaline activators. Sodium hydroxide in flakes form and sodium silicate solution of industrial grades were purchased from SP enterprises, Bengaluru.

4. EXPERIMENTAL PROCEDURE

In the present study, three sequence of geo polymer concrete were prepared by altering the molarity of alkaline solution that is 8M, 10M, 12M. In each molarity concentration again five sets of geo polymer concrete mix were prepared by changing the percentage of fly ash with GGBS that is 0%, 30%, 60%, 90%, 100%.

Table 3: Mixture of geopolymer concrete proportions

Material	Mass (kg/m^3)				
	GP0	GP30	GP60	GP90	GP100
Coarse aggregate	1300	1300	1300	1300	1300
Fine aggregate	555	555	555	555	555
Flyash	409	287	164	41	0
GGBS	0	123	245	368	409
Sodium silicate solution	72	72	72	72	72
Sodium hydroxide solution	72	72	72	72	72
Extra water	90	90	90	90	90
Alkaline solution/flyash	0.35	0.35	0.35	0.35	0.35
Water/ geopolymer solid ratio	0.17	0.17	0.17	0.17	0.17
$NaOH/Na_2SiO_3$	1	1	1	1	1

4.1 Preparation of alkaline liquid

For the activation of geo polymer concrete, the alkaline solution ($NaOH+Na_2SiO_3$) is used. We use three distinct NaOH concentrations in the study, that is 8M, 10M, 12M. Since it is exothermic reaction, one day before the alkaline solution was prepared.

For preparation of 8M NaOH solution, 320grams (molarity * molecular mass of NaOH) of NaOH pellets were dissolved in one liter of water and Na_2SiO_3 solution was added and mixed together at room temperature. Polymerization reaction took place when this solution was mixed together, wherein alkaline solution behaves as a binding agent.

Similarly for 10M of NaOH solution 400 grams and for 12M 480 grams of NaOH pellets are taken.

Figure 2: Preparation of alkaline liquid before casting

4.2 Preparation of Geopolymer Concrete Mixtures

Geo polymer concrete mix was prepared for varying molarity by varying the percentage of GGBS. The calculated quantity of (fly ash + GGBS) and fine aggregate were dry blended in an attempt to get a standardized mixture. Then the saturated surface dry coarse aggregate was introduced and these components were mixed together to obtain a standardized mix of concrete. In addition to the calculated quantity of water, the calculated alkaline solution is added to the mix to obtain the required workability.

4.3 Specimen Casting and Curing

For each concrete mixture, Standard Cubes, standard cylinders and standard prisms were casted. 150mm cubes were used to determine the compressive strength, 150mm×300mm cylinders were used to evaluate the split tensile strength, 100mm×100mm×500mm prisms were used to evaluate flexural strength and 100mm×50mm cylinders were used to evaluate the sorptivity value of the concrete specimen.

The specimens were compacted on vibration table. All moulds were demoulded after 24hours and then placed in an over for thermal curing at 90^0 C for 24hrs. To avoid the sudden variation in temperature, the concrete specimens were allowed to cool down for room temperature inside the oven.

Figure 3: Casting of geopolymer concrete

Figure 4: Oven curing

4.4 Specimen testing

After the curing period of 14 days and 28 days, specimens are taken out for testing. Tests were conducted for compression strength, split tensile strength and flexural strength as per IS:516-1959. Sorptivity test was conducted for durability.

Figure 5: Compression testing

Figure 6: Split tensile testing

Figure 7: Flexural testing

5. TEST RESULTS

5.1 Workability of concrete

Slump cone method is used to determine the workability of the concrete.

Table 4: Slump cone test values

Molarity	Percentage of replacement of fly ash by GGBS	Slump values (mm)
12	0	75
	30	73
	60	71
	90	68
	100	67
10	0	58
	30	56
	60	53
	90	51
	100	50
8	0	40
	30	38
	60	36
	90	35
	100	34

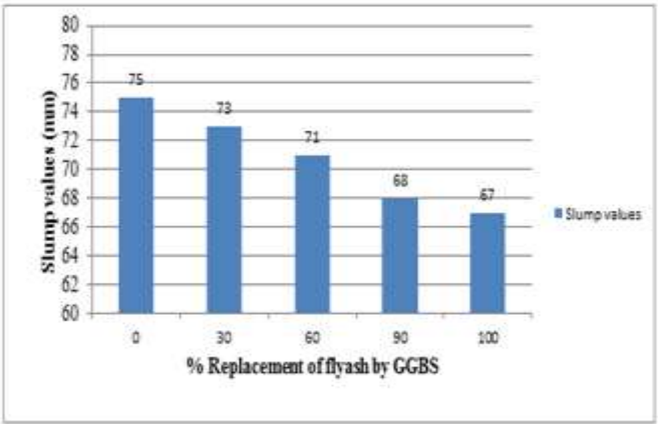

Figure 8: Slump cone value for 12M alkaline solution.

The value of slump increases as the molarity of the alkaline solution increases and value of the slump decreases as the percentage of GGBS increases for the specific molarity of alkaline solution. At higher molarity of alkaline solution, the solution contains more NaOH and this dissolution of NaOH gives more liquid content to the concrete mix. Hence the workability increases for 12M of alkaline solution and 30% replacement of Fly ash by GGBS.

5.2 Mechanical Properties of Concrete

Table 5, Table 6, Table7, shows the compressive strength, split tensile strength and flexural strength.

Table -5: Compressive strength (MPa) result of GPC

Molarity (M)	Percentage replacement of flyash by GGBS	Age (days)	
		14	28
12	0	35.45	43.55
	30	39.45	45.09
	60	41.03	47.53
	90	42.85	40.54
	100	43.53	53.28
10	0	35.55	40.69
	30	36.15	41.50
	60	38.45	43.29
	90	40.53	45.46
	100	41.48	46.83
8	0	29.26	35.64
	30	35.52	37.27
	60	33.97	40.83
	90	35.69	42.92
	100	36.62	44.53

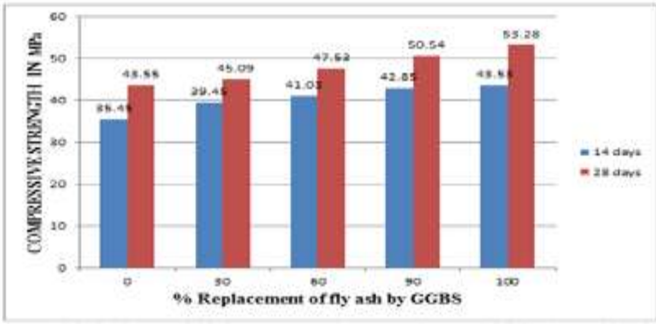

Figure 9: Compressive strength test result of 14days and 28days for 12M alkaline solution

The above outcome indicates that the compressive strength improves as the alkaline solution molarity increases and the proportion of GGBS substitute in fly ash increases. For 12M alkaline solution and 100% substitution of fly ash by GGBS, the highest compressive strength is obtained, since the GGBS is more pozzolanic when compared to flyash

Table -6: Split tensile strength (MPa) result of GPC

Molarity (M)	Percentage replacement of flyash by GGBS	Age (days)	
		14	28
12	0	4.35	4.49
	30	4.43	4.54
	60	4.59	4.65
	90	4.64	4.74
	100	4.79	4.88
10	0	4.26	4.34
	30	4.42	4.49
	60	4.47	4.59
	90	4.55	4.67

	100	4.59	4.73
8	0	3.9	4.12
	30	4.08	4.19
	60	4.16	4.28
	90	4.24	4.36
	100	4.30	4.42

Table-7: Flexural strength (MPa) result of GPC

Molarity (M)	Percentage replacement of flyash by GGBS	Age (days)	
		14	28
12	0	4.16	4.41
	30	4.49	4.81
	60	4.59	4.94
	90	4.67	5.13
	100	4.88	5.22
10	0	4.16	4.57
	30	4.25	4.69
	60	4.40	4.83
	90	4.57	4.96
	100	4.61	5.04
8	0	3.97	4.2
	30	4.14	4.36
	60	4.24	4.48
	90	4.39	4.59
	100	4.43	4.63

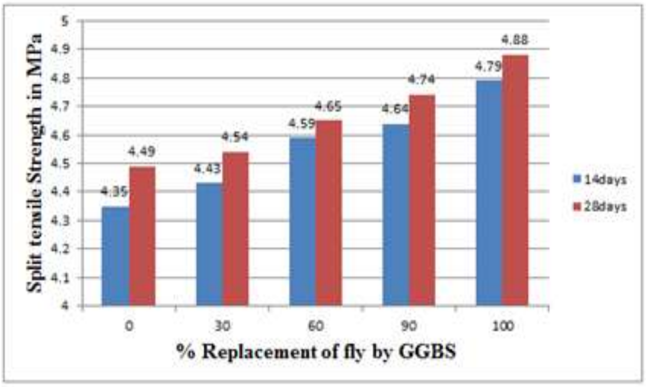

Figure 10: Split tensile strength test result of 14days and 28days for 12M alkaline solution

The above result shows that the split tensile strength increases with increase in the molarity of the alkaline solution and portion of GGBS in fly ash. Since the GGBS is more pozzolanic when compared to flyash. The maximum split tensile strength is achieved for 12M alkaline solution and 100 percentage substitute for fly ash by GGBS.

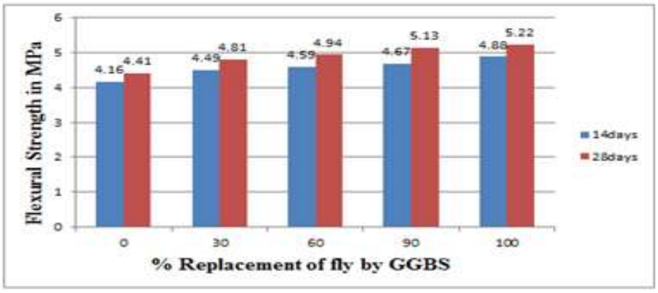

Figure 11: Flexural strength test result of 14days and 28days for 12M alkaline solution

The above outcome indicates that the flexural strength improves with the increase in alkaline solution's molarity and the proportion of GGBS substitute in fly ash. Since the GGBS is more pozzolanic when compared to flyash. For 12M alkaline solution and 100% substitution of fly ash with GGBS, the highest flexural strength is obtained

5.3 Durability properties of concrete

5.3.1 Sorptivity

This test was conducted on 100mm X 50mm size cylinder specimen after 28 days of curing. The dry and wet weight of the specimens was noted.

Table 8: Sorptivity values of GPC

Molarity (M)	Percentage replacement of flyash by GGBS	Sorptivity values
12	0	1.31
	30	1.20
	60	1.04
	90	0.95
	100	0.90
10	0	1.43
	30	1.35
	60	1.15
	90	1.09
	100	1.01
8	0	1.52
	30	1.40
	60	1.29
	90	1.13
	100	1.06

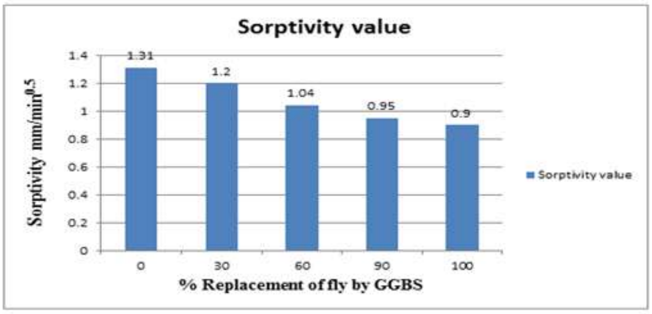

Figure 12: Sorptivity values of GPC for 12M alkaline solution

The above outcome demonstrates that the water absorption capacity of the geo polymer concrete reduces with a rise in alkaline solution molarity and also reduces with an increase in portion of GGBS in fly ash, since GGBS is more resistance to water absorption.

6 Effect of marine environment on geo polymer concrete

The better mechanical properties were observed for 12M alkaline solution. Hence this 12M alkaline solution specimen were subjected to marine condition by alternate wetting and drying cycles for every 6 hours over a period of 7 days after the completion of oven curing at 90^{0}C for 24hours to determine its mechanical properties like: compressive strength, split tensile strength, flexural strength for 28days

Table 9: Compressive strength (MPa) for 12M alkaline solution

Percentage replacement of flyash by GGBS	Compressive strength (MPa)
0	35.25
30	38.17
60	40.24
90	42.58
100	45.11

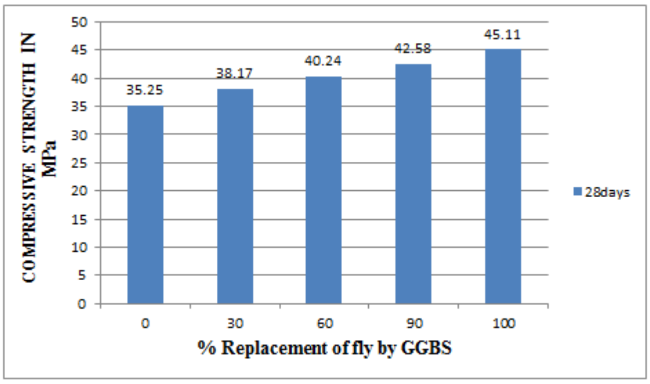

Figure 13: 28days compressive strength for 12M alkaline solution

The above result shows that the compressive strength decreases when the geo polymer concrete is subjected to marine environment. The rate of decreases in the compressive strength is around 15 to 19 percentage when compared to that of the normal curing.

Table 10: Flexural strength (MPa) for 12M alkaline solution

Percentage replacement of flyash by GGBS	Compressive strength (MPa)
0	3.84
30	3.97
60	4.13
90	4.37
100	4.52

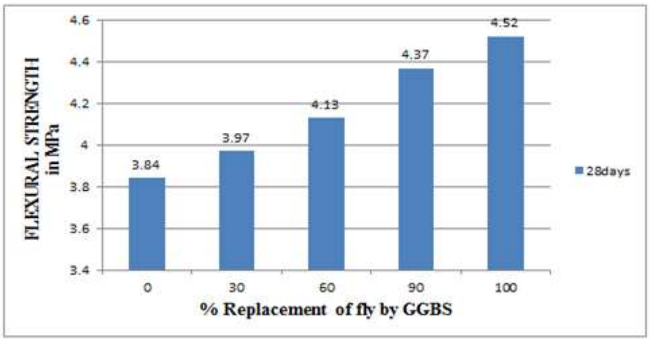

Figure 14: 28days flexural strength for 12M alkaline solution

The above result shows that the flexural strength decreases when the geo polymer concrete is subjected to marine environment. The rate of decreases in the flexural strength is around 12.5 to 13.5 percentage when compared to that of the normal curing.

Table 11: Split tensile strength (MPa) for 12M alkaline solution

Percentage replacement of flyash by GGBS	Split tensile strength (MPa)
0	3.61
30	3.76
60	3.94
90	4.06
100	4.17

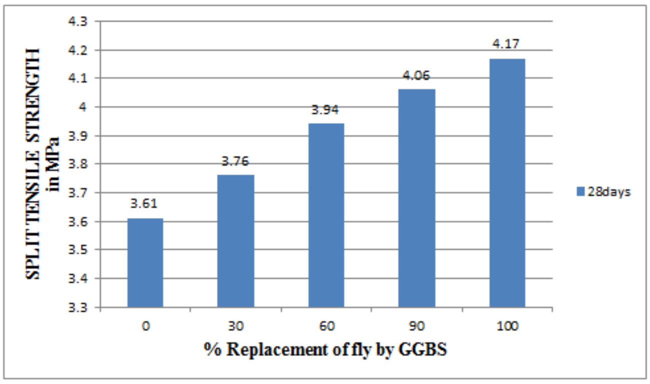

Figure 15: 28days Split tensile strength (MPa) for 12M alkaline solution

The above result shows that the split tensile strength decreases when the geo polymer concrete is subjected to marine environment. The rate of decreases in the flexural strength is around 14.5 to 19.5 percentage when compared to that of the normal curing

7. CONCLUSIONS

The following outcomes can be drafted from the above investigation:

- Green-house effect can be minimized to a greater effect by using GPC as a replacement for the OPC.
- Environmental pollution occurring due to the disposal of industrial by product can be reduced.
- The rate of strength gain is minimum for later days of curing, because the polymerization reaction takes place with in the 24 hours of curing of GPC specimen at 90^0C for 24 hours.
- The GPC concrete are less workable, hence using super plasticizer better workability can be achieved.
- The mechanical properties of hardened geo polymer concrete increases with increase in molarity, higher strength is obtained for 12M of NaOH.
- The mechanical properties of hardened geo polymer concrete increases with increase in the percentage of GGBS in flyash, higher strength is obtained for 100 percent replacement.
- The GPC are more resistance to water absorption at higher molarity of NaOH.
- The mechanical properties of hardened geo polymer concrete decreases when GPC are subjected to marine environment.

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