MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE USING FLY ASH, GGBS AND BASALT FIBRE.

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Abstract- **The second most consumed product in the world is Cement. It contributes nearly 7% of the global carbon dio xide emission. Geopolymer concrete (GPC) manufactured using industrial waste like fly ash, GGBS is considered as a more eco-friendly alternative to Ordinary Portland Cement (OPC) based concrete. Geopolymer Concrete (GPCs) is a new 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 are eco-friendly and sustainable alternative to Ordinary Portland Cement (OPC) based concrete. In the construction industry mainly the production of Portland cement causes the emission of air pollutants which results in environmental pollution. This paper presents the details of the studies carried out on development of strength for various grades of geopolymer concrete with varying molarity. The alkaline liquids used in this study for the geopolymerization are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Different molarities of sodium hydroxide solution (8M,10M and 12M) are taken to prepare different mixtures. The test specimens were 100 x 100 x 100 mm cubes, 100 x 200mm cylinders prepared and oven cured at 75ºC. The geopolymer concrete specimens are tested for their compressive strength at the age of 7,14 and 28 days. GPC mix formulations with compressive strength ranging from 12.33 to 82.10MPa have been developed. The test results indicate that the combination of fly ash and ground granulated furnace slag (GGBS) can be used for development of Geopolymer concrete**

Index Terms- **GGBS, Flyash, Basalt fibre, Sodium silicate, Sodium hydroxide and oven curing.**

I. INTRODUCTION

To produce concrete, Ordinary Portland cement (OPC) is used as binder conventionally. For the production of One tonne of cement one tonne of Carbon dioxide is liberated into the atmosphere due to the calcination of limestone and combustion of fossil fuel. The extent of energy required to produce OPC is only next to steel and aluminium. On the other hand, the availability of fly ash worldwide is abundant which creates opportunity to utilise this by-product, as a substitute for OPC. Research has already been made on partial replacement of OPC with fly ash. While partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. Father of Geopolymer Davidovits (1978) proposed that binders could also be produced by polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials or by-product materials such as fly ash and rice husk ash. Portland cement is still the main binder in concrete construction prompting a search for more environmental friendly materials. Furthermore, it has been reported that the durability of ordinary Portland cement concrete is under examination, as many concrete structures especially those built in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life.

II. EXPERIMENTAL PROGRAM

2.1 Materials

2.1.1 Fly Ash

Flyash used in this experimental work was obtained from Tuticorin Thermal Power Station (TTPS), fly ash from the bituminous and anthracite coals is referred as ASTM Class F fly ash or low-calcium fly ash. It consists of mainly an aluminosilicate glass, and has less than 10 percent of CaO. The colour of fly ash can be tan to dark grey, depending upon the chemical and mineral constituents Mean particle size ranges from less than 1 µm to no more than 150 µm. and finer than cement. It consists of mainly an aluminosilicate glass, and has less than 10 percent of CaO. The specific gravity, fineness modulus, specific surface area and density of flyash are 2.2, 1.320, 300 m^2/kg and 1.4 kg/m^3 respectively.

2.1.2 Ground Granulated Blast furnace Slag

Ground granulated blast furnace slag of fineness modulus 0.16 was used in the work.

2.1.3 Aggregate

Locally available river sand having fineness modulus 3.20, specific gravity 2.66 and conforming to grading zone-II as per I.S: 383 - 1970. Coarse aggregate is of angular shaped crushed granite with different sizes of 20mm and 12.5mm were used. Its fineness modulus and specific gravity are 7.38 and 2.72 respectively. Potable water with pH value 7.0 was used for the geopolymer concrete.

2.2 Mix design

Unlike conventional cement concretes GPCs are a new class of construction materials and therefore no standard mix design approaches are yet available for GPC. GPC involves more constituents in its binder (viz., FA, GGBS, sodium silicate, sodium hydroxide and distilled water).In the design of geopolymer concrete mix, assume the unit-weight of concrete is 2400 kg/m3.

Take the mass of combined aggregates as 75% of the mass of concrete, i.e. 0.75x2400=1800 kg/m3. The combined aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, the coarse aggregates (62%) may comprise 1116 kg/m3. (2/3) of 20 mm aggregates is 744 kg/m3 and (1/3) of 12.5 mm aggregates is 372 kg/m3.Fine aggregate occupies 38% by mass, i.e. 576 kg/m3.Binders(GGBS and Fly ash) constitute 19% by mass of concrete i.e. 456 kg/m3.Alkaline solutions occupies 6% by mass of concrete i.e. 144 kg/m3. Knowing the density of concrete, the combined mass of alkaline liquid and flyash can be arrived at. By assuming the ratio of alkaline liquid to flyash as 0.315, 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 2.43. In the present investigation, concentration of NaOH solution is taken as 8M and 10M.

2.3 Preparation of Geopolymer concrete:

For 8 M, 320 g (molarity x molecular weight) of sodium hydroxide flakes dissolved in one litre of distilled water to prepare sodium hydroxide solution. 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 ti mes are very low.

2.4 Mixing and casting

The required mass of coarse aggregate, fine aggregate, ggbs, fly ash are weighed prior to mixing. The solids constituents of the fly ash-ggbs based geopolymer concrete, i.e. the aggregate sand the fly ash, ggbs were dry mixed in the polythene sheet for about three minutes. The liquid part of the mixture, i.e. the sodium silicate solution, the sodium hydroxide solution, added water (if any), and the super plasticiser (if any), were premixed then added to the solids. The wet mixing usually continued for another four minutes. The fresh fly ash, GGBS-based geopolymer concrete was dark in colour and shiny in appearance. The mixtures were usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. Compaction of fresh concrete in the cylinder steel moulds and cube moulds was achieved by applying twenty five manual strokes per layer in three equal layers.

2.5 Curing

Curing is the process in which the concrete is protected from loss of moisture and kept within a reasonable temperature range. This process results in concrete with increased strength and decreased permeability. Curing is also a key player in mitigating cracks, which can severely affect durability. Unlike Conventional concrete, GPC members requires special type of curing. Here, Oven curing is adopted for GPC specimens. The temperature for curing ranges from 60˚C-90˚C. Temperature adopted for present investigation is 75˚C for about 24 hours. The main polymerization process or the chemical reaction of geopolymer concrete takes place with the temperature imposed to it during the curing. It may attain almost its 70% strength with in the 24 hours of hot curing. Longer curing time enhanced the polymerization process and results in a higher compressive strength. The rate of increase of strength is rapid in the initial 24 hours of curing beyond that the gain of strength was moderate, hence the specimens are cured for 24 hours only

2.6 Testing

The members casted were tested to study the strength of geopolymer concrete as per IS 516:1959 for various periods like 7 days , 14 days and 28 days. The tests conducted on the GPC members were compressive strength test and split tensile strength test.

III. RESULTS AND DISCUSSIONS.

3.1 Compressive Strength Test Results

The following are the results (refer table 1) on the GPC members (100mmX100mmX100mm) cast with varying molarity and the effects due to GGBS in replacing flyash in GPC.

Table No.1 Compressive strength, N/mm^2 for 8M

Mix	Compressive strength, N/mm^2			Strength Effectiveness %
	7 days	14 days	28days	
M1	8.00	9.77	12.33	--
M2	20.10	23.30	26.23	113.54
M3	38.10	42.13	44.27	259.43
M4	45.20	48.17	51.60	318.49
M5	48.95	51.43	56.73	360.10
M6	66.50	68.50	71.47	479.64

Table No.2 Compressive strength, N/mm^2 for 10M

Mix id	Compressive strength, N/mm2 for 10M			Strength Effectiveness, %
	7 days	14 days	28days	
M1	9.2	12.3	14.2	--
M2	24.3	27.9	31.4	121.13
M3	41.5	48.3	50.7	257.04
M4	49.6	56.0	58.1	309.15
M5	54.1	61.2	64.5	354.22
M6	69.0	73.7	76.4	438.03

Table No.3 Compressive strength, N/mm^2 for 12M

Mix id	Compressive strength, N/mm2 for 12M			Strength Effectiveness, %
	7 days	14 days	28days	
M1	11.1	13.4	14.9	--
M2	27.6	29.8	31.4	110.74
M3	45.3	53.3	56.1	276.51
M4	54.4	60.7	64.2	330.87
M5	59.7	64.4	66.5	346.31
M6	74.2	79.4	82.1	451.00

The above tables (refer TableNo.2 &3) shows the compressive strength of various GPC mixes. It is clear that compressive strength varies from 5 to 10 N/mm^2 for various curing periods. Replacing fly ash with GGBS in various percentages increases the compressive strength of GPC. This increase in compressive strength of GPC is maximum when GGBS fully replaces fly ash and it was observed to 479.64% when compared with the GPC containing fly ash alone. Though the molarity was varied with different mix , it increases the strength. Also the role of GGBS in GPC shows remarkable increase in the compressive strength upto 82.1MPa for 100% GGBS in 12Molarity.

3.2 Split Tensile Strength Test Results.

Following tables No. 4,5 &6 shows the tensile strength of GPC.

Table No.4. Split Tensile strength for 8M

Mix id.	Tensile Strength, MPa for 8M		
	7 days	14 days	28days
M1	0.84	0.68	0.63
M2	1.1	0.99	0.84
M3	2.08	1.67	1.2
M4	3.33	3.07	2.91
M5	3.48	3.23	3.17
M6	3.85	3.64	3.38

Table No.5, Split Tensile Strength for 10M

Mix id.	Tensile Strength, MPa for 10M		
	7 days	14 days	28days
M1	1.01	0.91	0.89
M2	1.53	1.47	1.17
M3	2.15	1.80	1.90
M4	3.46	3.27	3.01
M5	3.69	3.49	3.26
M6	3.93	3.59	3.48

Table No.6, Split Tensile Strength for 12M

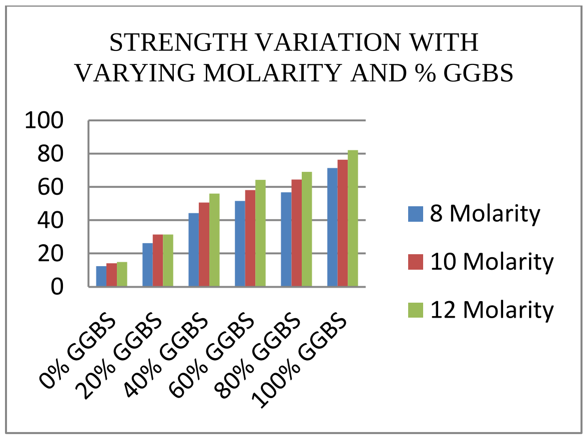
Mix id	Tensile Strength, MPa for 12M		
	7 days	14 days	28days
M1	0.92	0.84	0.96
M2	1.74	1.59	1.33
M3	2.67	2.31	2.07
M4	3.52	3.37	3.19
M5	3.81	3.52	3.38
M6	4.03	3.74	3.51

The above table proves that the split tensile strength of the GPC decreases with age for each mix and increases with GGBS content in the mix. The split tensile strength directly measures the tensile property of GPC. The increase in GGBS content in GPC improves the tensile strength of concrete, but the increased GGBS content beyond certain percentage affects the workability of GPC. The split tensile strength increases with increase in molarity upto about 1%. But as the concrete is basically a weaker material in tension , hence the increase in split tensile strength to a meager extent would also find to be advantageous.

3.3 S*trength comparison with varying molarity and % GGBS*

Molarity	0% GGBS	20% GGBS	40% GGBS	60% GGBS	80% GGBS	100% GGBS
8M	12.33	26.33	44.27	51.60	56.73	71.47
10M	14.2	31.40	50.7	58.1	64.5	76.4
12M	14.9	31.4	56.1	64.2	69.0	82.1

By increasing the molarity of alkaline solution used in the production of GPC and also different percentages of GGBS used to replace Fly ash in GPC, the increase in strength with respect to molarity was gradual and up to 21.62%. The mix which contains no GGBS content also shows the same rate of increase in strength with varying molarity. Hence increase in concentration of alkaline solution increases the strength irrespective of addition of GGBS.



The addition of GGBS to replace fly ash increases the compressive strength progressively. But it accelerates the initial setting time to less than 6 minutes when it completely replaces the fly ash content in geopolymer concrete. Hence it is observed that the GGBS content content in GPC can well be optimized based on the setting time.

But the role of fly ash in GPC is to increase the setting time , thereby the GPC mix may be handled easily . Also the size and shape of the fly ash grains play an important role making the GPC a more workable one.

IV. CONCLUSION

The samples of Geopolymer concrete for various proportion of GGBS and Fly ash with varying concentration of alkaline solution were tested for compressive strength, split tensile strength and water absorption . By the keen observation of test results the following conclusion were arrived.

- The maximum compressive strength was attained at M6 proportion, i.eFA0-GGBS100 for 8, 10 and 12 Molarity of alkaline solution.
- Using fly ash alone in GPC remains unset till 120 minutes , beyond which only the initial setting of concrete starts. As the percentage of GGBS increases in replacing the fly ash content in GPC , the strength increases enormously.
- But the addition of GGBS in GPC accelerates the setting time of concrete to a greater extent. Hence the addition of GGBS involves in giving early strength to the GPC with all concentration of alkaline solution.
- The increase in strength for each molarity with varying GGBS content with respect was observed to be around 21.62%.
- The addition of GGBS up to 100 percent (M6) in GPC increases the strength up to 479.64% for 8Molarity, 438.03% for 10 Molarity and 451.00% for 12 Molarity compared to the mix with 0% GGBS.
- It is also observed that the maximum split tensile strength was also attained at the same mix proportion with different molarities.
- The addition of GGBS in GPC shortens the setting even to less than 6 minutes when the GPC contains no fly ash content.

Hence from this research it is inferred that the GPC can be handled easily in good workable condition only with GGBS content less than 40% at which the strength of concrete was 56.1MPa for 12M, 50.5 MPa for 10M and 44.27MPa for 8M at an elevated temperature curing of 75ºC.

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