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AN EXPERIMENTAL STUDY ON TERNARY BLEND BASED STEEL FIBRE REINFORCED GEO POLYMER CONCRETE

M. Jothilingam[1], Pratheeba Paul[2],

[1]Depart. of Civil Engineering, SRM Institute of Science and Technology, Chennai, Tamil Nadu – 600089, India
[2]Depart. of Civil Engineering, Hindustan Institute of Science and Technology, Chennai, Tamil Nadu -603103, India
E.mail: lingam7907@gmail.com, pratheebap@hindustanuniv.ac.in,

ABSTRACT

Cement is the second most consumed product and as per the year 2010 status the quantity assessed was 3.3 billion tons at global level. Cement industry accounts for 5% to 8% of world's carbon dioxide emissions. It is also well-known fact that cement production consumes large amount of natural resources such as limestone, chalk, clay, etc. which are extracted from the quarry by blasting. On the other hand, Thermal Power Plants generates huge quantities of Fly ash while utilizing the coal for their process. As assessed by Central Electricity Authority, the total quantity of Fly Ash generated during 2015-2016 in India was 83.64 million MT. As per the Report of Indian Minerals year book 2014 issued by Ministry of Mines, Government of India, around 10 million tons of Blast Furnace slag is generated in India from iron & steel industry. Substantial quantity of this fly ash and GGBFS are used for landfills only. Both fly ash and GGBFS exhibits Cementitious as well as pozzolana characteristics. So, fly ash and GGBFS can be effectively utilized for production of concrete. One of the current research trends in Civil Engineering is to find an alternate material for Cement concrete. Geo Polymer Concrete is one such alternate for Cement Concrete. But, steam/ heat curing is required for producing Geo Polymer Concrete which makes it difficult for using the same for in situ applications. This project aims at finding the viable solutions for producing cast-in-situ geopolymer concrete without compromising on mechanical and durability properties of geopolymer concrete by using locally available industrial wastes such as Fly Ash & GGBS. The compression and flexural strength along with durability properties of Geopolymer concrete were investigated in this work. This study consisted of casting cubes and prisms and curing was done at ambient temperature to suit the cast-in-situ conditions. The specimens were tested for 7 & 28 days strength. Durability studies were carried out after the age of 28 days. It can be concluded that Geopolymer concrete can be produced cast-in-situ without any special curing requirement such as steam/ heat curing, and without compromising on mechanical and durability properties

Key words: Carbonation Test, Rapid Chloride Test, Geopolymer Composite.

INTRODUCTION

Cement Concrete is a major construction material used world over and it commonly consists of Cement, Stone aggregate, River Sand, Admixture and water. In the Cement Concrete, cement acts as binding material and binds the Stone Aggregates, River Sand, together to form a material which resembles like a stone after hardening. The strength parameters of OPC concrete mainly depends upon the amount of Cement used and w/c ratio. During the hydration of OPC, large amount of heat is liberated. After the World War II, there was a need of high-speed construction to accelerate the development which in turn accelerated the production of cement. However, the production of cement accounts for 5% of the world's CO_2 emissions. The production of cement was 3300 million tons during 2010. The volume of cement produced increases every year. Geopolymer is an inorganic binder which is prepared by the material that is rich in silica and alumina with an alkaline solution and that can be used as an alternative binder to the OPC for concrete manufacturing (Kolli Ramujee, 2014), conducted an experiment for developing Low Calcium Fly Ash based Geopolymer Concrete by using fly ash as the source material and Sodium-based activators were used as alkaline solution. The fresh geopolymer concrete was cast into the moulds immediately after mixing and the specimens were cured at 60°C for 24 hours. Maneeshkumar, et al., (2015) conducted investigations on geopolymer concrete by using GGBFS, Fly ash and quarry dust and activator as Sodium Silicate and Sodium Hydroxide solution (10M), granite jelly as a coarse aggregate, water and superplasticizer. Krishnan, et al., (2014) found geopolymer concrete as an eco-friendly construction material. Geopolymer concrete was developed by GGBFS and Fly ash as a source material, Sodium Silicate and Sodium Hydroxide as alkaline liquids, river sand as a fine aggregate, granite jelly as a coarse aggregate, water and superplasticizer (CONPLAST SP 430). It was reported that the compressive strength of Geopolymer concrete was observed for the mixes of 12 Molarity of sodium hydroxide and the alkaline liquid to fly ash and GGBFS ratio as 0.4. The ratio of sodium hydroxide to sodium silicate as 2.5. Maria Rajesh et al., (2014) conducted an experiment on behavior of geopolymer concrete by using fly ash (class- F), GGBFS, Steel fibre, aggregates and Alkaline activators. They cast cube and cylinder specimens cured in hot chamber and conducted the compression and split tensile test.

MATERIALS AND PROPERTIES

FLY ASH: The major constituent of fly ash is Silica (SiO_2), alumina (Al_2O_3), ferric oxide (Fe_2O_3) and calcium oxide (CaO). This type of fly ash is produced in thermal power plant from burning of anthracite or bituminous coal and possesses pozzolana properties.

GROUND GRANULATED BLAST FURNACE SLAG (GGBFS): The main components of blast furnace slag are CaO (30-50%), SiO_2 (28-38%), Al_2O_3 (8-24%), and MgO (1-18%). In general increasing the CaO content of the slag results in raised slag basicity and an increase in compressive strength. The MgO and Al_2O_3 content show the same trend up to respectively 10-12% and 14%, beyond which no further improvement can be obtained. From the available study, GGBFS based GPC has given high mechanical strength and it is very cheaper. The GGBFS obtained from a local commercial dealer at Ambattur was used as another base material.

SILICA FUME: Silica fume as a ferrosilicon alloy product which is Nano sized material used in this project.

ALKALI ACTIVATORS

Sodiumhydroxide: The most common alkaline activator used in geopolymerisation is a combination of NaOH and Sodium Silicate or potassium hydroxide (KOH) and potassium silicate. Based on the literatures reviewed, it was found that the sodium-based activators are cheaper than the potassium based activators. So, NaOH and sodium silicate was selected as alkali activators. Sodium hydroxide in pellets form was obtained from the Astrra Chemicals at Ambattur, Chennai.

Sodium Silicate: Sodium silicate known as sodium meta silicate is used as liquid form in the experiments were conducted and results were obtained

EXPERIMENTATION: The following program was used to find the mechanical and durability properties of GPC as shown in the Table 1 and the material proportions are shown in the Table 2. The alkali activators, NaOH solution of 14M was prepared one day prior to preparation of test specimen by mixing 14x40 = 560 grams of NaOH solids per litre of water, where 40 is the molecular weight of NaOH and sodium silicate is available as liquid. The Stone Aggregate, GGBFS, River Sand and fly ash, 0.3% of steel fibers were dry mixed in the pan mixer for about three minutes. Then mixer of sodium silicate solution, and sodium hydroxide solution in the ratio of 2, water, and super plasticiser @ 2% by mass of cement was added to the solid component and further, mixing continued for another four minutes. This procedure was repeated for silica fume content of 3%, 5%, 7% and 10%. The workability was found between 75 and 120 mm depends upon silica fumes content.

Table 1: Program Chart to find Mechanical properties of M60GPC

Silica Fume in %	0	3	5	7	10
No of Cubes (150x150x150mm)	3 Nos for 7day strength and 3 Nos for 28day strength respectively for each Silica Fume % along with 6 Nos of OPC Concrete Specimens				
No of Prisms (150x150x700mm)	3 Nos for each Silica Fume % along with 3 Nos of OPC Concrete Specimens				

Table 2: Quantity of ingredients required for 1m^3 M60 of GPC

Sl. No	% of Silica Fume (SF)	Fly ash (Kg)	GGBFS (Kg)	Silica Fume (Kg)	Fine Aggregate (Kg)	Coarse Aggregate (Kg)		NAOH, Kg	Sodium Silicate, Kg	Admixture (Kg)
						20mm	10 mm			
1	0	187.50	187.50	0	845	653	422	35	70	7.50
2	3	181.88	181.88	11.25	845	653	422	35	70	7.50
3	5	178.13	178.13	18.75	845	653	422	35	70	7.50
4	7	174.38	174.38	26.25	845	653	422	35	70	7.50
5	10	168.75	168.75	37.50	845	653	422	35	70	7.50

PREPARATION OF TEST SPECIMENS: After mixing, the moulds of size 150mm x150mm x 150mm cubes for compression, 150mm x 150mm x 700mm prisms for flexural strength and 100mm dia x 200mm height cylinders for RCPT test were filled with M60 GPC in three layers and each layer was compacted well by tamping rod of standard size, so as to avoid entrapped air and honey combs. Cast specimens were cured in room temperature of 27 ± 3° C.

Fig. 1: Cubes and prisms casting

COMPRESSIVE STRENGTH TEST: Three identical specimens of 150mm cubes were tested at the age of 7 days and 28 days to evaluate compressive strength in surface dry condition as prescribed in IS:516 using 2000kN capacity Compression Testing Machine. Load was applied at the rate of 140 Kg/cm^2/min till the failure of cubes and the load at failure was recorded and the average test results were given in Table 3.

FLEXURE STRENGTH TEST: The specimen was placed on the bed of the machine and tested at four point bending stress which was having two steel rollers of 38mm diameter. These rollers were mounted 600mm distance apart. The load was applied through two rollers spaced at 200 mm centre to centre from top. The load was divided equally between the two loading rollers such that the application of load was in axial direction without any torsional stresses or restraints and the average test results were given in Table 3.

WATER ABSORPTION TEST: This test was done as per ASTM C-1585. Mass of 150mm cube specimens was recorded and dried in an oven at 100 to 110 °C for 24 h and then allowed to cool in dry air to 20 to 25 °C and the mass was recorded. The difference between the two masses was calculated and which was less than the 0.5 % of the lesser value. If not, the specimens will be dried in oven for an additional 24-h period, and the above process will be repeated until the difference between any two-successive mass become less than 0.5 % of the lowest value obtained. This last value was designated as A. Absorption after immersion, % = [(B – A)/A] x 100, where: A = Mass of oven-dried sample in air, gram, B = Mass of saturated surface-dry sample in air after immersion, gram. The test results were given in Table 3.

RAPID CHLORIDE PENETRATION TEST: The test specimens were prepared from 100mm dia x 200mm height cylinder and are sized to 50 mm x 100mm disc for RCPT. The amount of electrical current passed through 50 mm x 100 mm concrete specimen during 6h period was used to relate to the resistance of the concrete specimen to chloride ion penetration. This test was performed as per ASTM C-1202. Figure 2 shows the RCPT experimental test setup.

Fig. 2: RCPT Experimental setup

The extracted specimen from core cutter was treated in desiccators for 21 hours and after applying sealant around the specimen boundary surface the exposed face was covered with plastic sheets. After curing in the similar manner second half of cell was also attached and the sample was inserted and clamped the two halves of the test cell together to seal. One side of the cell containing the top surface of the specimen which was filled with 3 % NaCl solution and connected to the negative terminal of the power supply. The other side of the cell was filled with 0.3 N NaOH solution and which was connected to the positive terminal of the power supply. Electrical connection was made to voltage application and data readout apparatus then power supply was turned on to set 60 plus or minus 0.1 V to start the experiment. The room temperature was maintained between 20 and 25°C. Current was recorded for every 30 minutes and calculated the charges passed by using the formula

$$\mathbf{Q = 900(I_0 + 2I_{30} + 2I_{60} + \ldots\ldots + 2I_{300} + 2I_{330} + I_{360})}$$

Where: Q = Charge passed in Coulombs, I_0 = Current immediately after application of voltage in Amperes, I_t = Current at t min after the application of voltage in Amperes.

CARBONATION TEST: 150mm size GPC cube specimens after casting and curing at room temperature for 24 hours was placed in a airtight chamber. Then the chamber was filled with carbon dioxide gas to a pressure of 1 bar after reducing the pressure inside the chamber to about 0.7 bars. The specimens after 4 hours of exposure of CO_2 were kept at room temperature and were tested at the age of 28 days for carbonation by spraying 1% phenolphthalein indicator on the crushed face of the cubes. Color of the phenolphthalein did not disappear, since there was no notable penetration of CO_2.

Table 3. Mechanical and Durability properties of GPC and OPC specimens

S. No	Description	Compressive strength (N/mm^2)		Flexural strength @ 28 days (N/mm^2)	% Water Absorption	Carbonation depth at the age of 28 days (mm)
		7 Days	28 Days			
1	GPC-0% SF	47.52	62.85	3.79	1.21	4
2	GPC-3% SF	63.40	73.78	4.34	1.30	3
3	GPC-5% SF	71.88	86.89	5.42	1.10	3
4	GPC-7% SF	71.42	85.3	5.09	1.21	3
5	GPC-10% SF	54.26	62.06	5.00	1.57	2
6	OPC	42.96	64.77	4.43	1.20	4

Note: Values given in the table are average of three identical specimens.

DISCUSSION ON TEST RESULTS

COMPRESSION TEST: Geo Polymer Concrete cube specimens of 14 molarity with 0.3% of steel fibers and silica fume content of 3%, 5%, 7% and 10% were cast and tested. The obtained results were shown in figure 3. Comparing to GPC with 0% silica fume, the strength of GPC with 3%, 5%, 7% and 10% silica fume are increasing as given in Table 3 and the maximum strength is achieved at GPC with 5% silica fume for both 7 and 28 days test results. The increase of strength of GPC with 5% silica fume is 51.3% higher than GPC compared with 0% silica fumes for 7 days and 38.2% for 28 days strength. Further the 28 days strength of GPC with 5% silica fume is found 20.88% higher than 7 days strength.

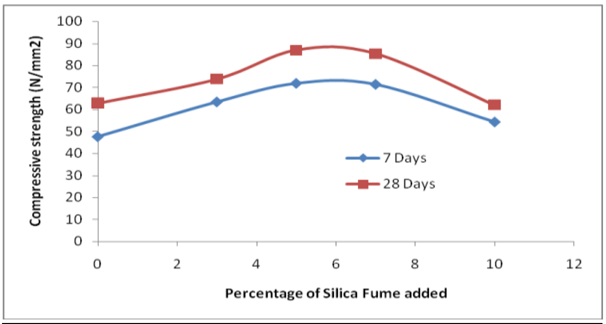

Fig. 3: Compressive strength of GPC Vs % of Silica fume at 7 and 28days

FLEXURE STRENGTH TEST: GPC prism specimens of 14 M with 0.3% of steel fibers and silica fume content of 3%, 5%, 7% and 10% were cast and tested. The obtained average test results were shown in figure 4. Comparing to GPC with 0% silica fume, the strength of GPC with 3%, 5%, 7% and 10% silica fume are increasing as given in Table 3 and the maximum strength is achieved at GPC with 5% silica fume. The increase of strength of GPC with 5% silica fume is 43% higher than GPC compared with 0% silica fumes.

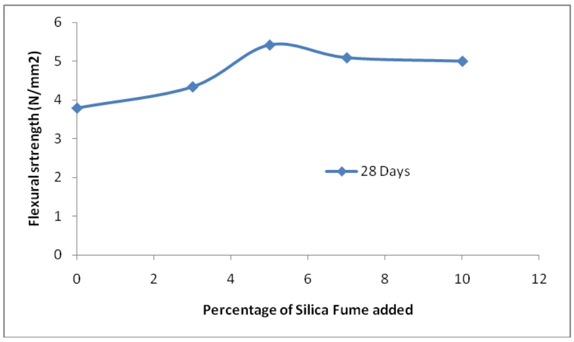

Fig. 4: Flexural strength of GPC Vs % of Silica fumes added

WATER ABSORPTION TEST: GPC specimens of 14 M with 0.3% of steel fibers and silica fume content of 3%, 5%, 7% and 10% were cast and tested after 28 days. The obtained results were shown in figure 5. The percentage of water absorption for both OPC and GPC with 0% silica fume is found almost same and compared to GPC with 5% silica fume is 9.09% lesser than GPC with 0% silica fume.

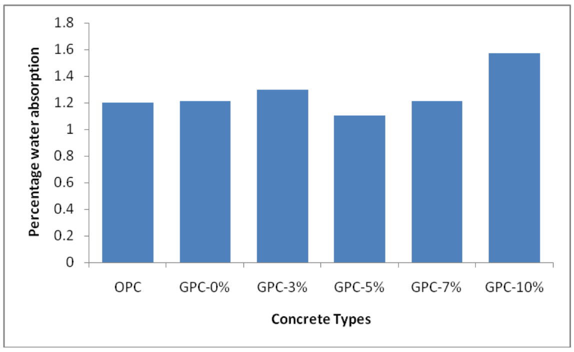

Fig. 5: Water absorption of GPC Vs % of Silica fumes added

RAPID CHLORIDE PENETRATION TEST: GPC specimens of 14 molarity with 0.3% of steel fibers and silica fume content of 0%, 3%, 5%, 7% and 10% were cast and tested. The obtained average test results were shown in Table 4 and the chloride permeability is found to be moderate.

Table 4: RCPT Test results

Description	Avg. Charge Passed in Columbs	Chloride Permeability
GPC-0%	2240	Moderate
GPC-3%	2377	Moderate
GPC-5%	2385	Moderate
GPC-7%	2383	Moderate
GPC-10%	2419	Moderate
OPCC	1050	Low

Carbonation Test: The carbonation test was carried out for the test specimens after 28 days curing with 99.99% pure CO_2 and 0.5 kg/cm^2 pressure for 18 hours exposure at room temperature and 55% relative humidity It was observed that the carbonation depth was 2 mm to 4 mm by using phenolphthalein indicator as per RILEM procedure. The mechanical and durability properties of Geopolymer concrete were furnished in Table 3.

CONCLUSION

1. It is observed that the compressive strength of Steel Fibre Reinforced GPC increased with the addition of Silica fume and maximum compressive strength of 71.88 N/mm^2 at the age of 7 days & 86.89 N/mm^2 at the age of 28 days was obtained at the optimum silica fume content of 5%.
2. The flexural strength of Steel Fibre Reinforced GPC increased with the addition of Silica fume and maximum flexural strength of 5.423 N/mm^2 at the age of 28 days was obtained at the optimum silica fume content of 5%.
3. Addition of Silica fume beyond 5%, reduced the flexural strength and flexural strength of 5.001 N/mm^2 at the age of 28 days was obtained at the Silica fume content of 10%.
4. Water absorption test was carried out and minimum of 1.082% of Water by mass of Concrete was absorbed by Steel Fibre Reinforced GPC with 5% of Silica fume and the corresponding value was 1.571% for GPC with 10% of Silica fume content.
5. The Chloride Ion penetrability of Steel Fibre Reinforced GPC was moderate and the corresponding value for OPCC was low when measured by RCPT method conforming to ASTM standard C-1202.
6. The penetration of CO_2 into Steel Fibre Reinforced GPC was 2 to 4 mm at the age of 28 days when tested with 1% phenolphthalein indicator, after 18 hours of carbonation.
7. It is concluded that steel fibre reinforced Geo polymer concrete can be considered as an alternate to cement concrete of the same grade.

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