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Study of Mechanical Properties of Steel Fiber Reinforced Geopolymer Concrete

Dr. Sunilkumar S. Patil[1], Amol Ashok Patil[2]
[1,] *Professor, Civil Engineering Department, Walchand Institute of Technology, Solapur, Maharashtra, India.*
[2,] *Scholar M.E (Structural Engineering), Civil Engineering Department, Walchand Institute of Technology, Solapur, Maharashtra, India*
Email: amolpatil818@gmail.com[2]

Abstract- This paper presents the results of an experimental investigation on the mechanical properties of Geopolymer Concrete (GPC) containing 100% Fly ash (FA), alkaline liquids and steel fibers. The study analyses the impact of steel fibers on the mechanical properties such as density, Compressive Strength, Split Tensile strength and Flexural strength of hardened GPC and workability of fresh steel fiber reinforced geopolymer concrete (SFRGPC). Mixtures were prepared with alkaline liquid to fly ash ratio of 0.5 with Steel fibers were added to the mix in the volume fractions of 1.5% of 60 aspect ratio, 1.5% of 100 aspect ratio and hybridization of both i.e. 0.75% 0f 60 aspect ratio and 0.75% of 100aspect ratio volume of the concrete. The influence of fiber content in terms of volume fraction on the compressive, split tensile strength and flexural strengths of GPCC is presented. Based on the test results, compressive strength, split tensile strength and flexural strength of Steel fiber reinforced GPC in terms of volume fraction of steel fiber are higher than that of GPC without fiber and also convectional concrete

Index Terms- Geopolymer Concrete, Steel Fiber, Slump Cone Test, Compaction Factor Test , Strength Parameter, Alkaline Solution .

1. INTRODUCTION

Demand for concrete as construction material is on the increase. In this concrete, the cement is primary binder material [1]. The demand of concrete as construction material leads to increase in production of cement. Production of 1 ton of cement requires about 2 tons of raw materials; shale and limestone and emits large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes greenhouse gas emission. The production of one tone cement liberates about 1tone of CO_2 to the atmosphere. Globally, the OPC production contributes about 7% of world's carbon dioxide. This is adding 1.6 billion tons of carbon dioxide to the atmosphere.[5] It is important to find an alternative binder material which has less carbon footprint than cement to produce the concrete. On the other hand, huge quantity of fly ash is generated around the globe from thermal power plants. The volume of fly ash would increase as the demand for thermal power increases. The fly ash is waste material from thermal power plant. And the disposal of fly ash is now a major problem. So we use fly ash as binder material in concreting. . The fly ash contains huge quantity of Al and Si material [2,3].

Davidovits (1988) proposed that an alkaline liquid could be used to react with the Silicon (Si) & Aluminum (Al) in source material of geological origin or in byproduct material such as Fly ash, there is polymerization process during the reaction so this is named as Geopolymer concrete [3].

The results of recent studies have shown the potential use of heat-cured fly ash based geopolymer concrete as a construction material. As a relatively new material, it is necessary to study the various properties of GPC as compared to the traditional OPC concrete in order to determine its suitability for structural applications. The ongoing research on fly ash-based geopolymer concrete studied several short-term and long-term properties. It was shown that heat-cured geopolymer concrete possesses the properties of high compressive strength, low drying shrinkage and creep, and good resistance to sulfate and acid. Geopolymer concrete was found to have higher bond strength with reinforcing steel and relatively higher splitting tensile strength than OPC concrete [11]. Heat-cured geopolymer concrete showed higher residual strength than OPC concrete cylinders after exposure to high temperature heat of up to 800 ^{0}C [12]. Therefore, heat-cured geopolymer concrete is considered as an ideal material for precast concrete structural members.

2. EXPERIMENTAL INVESTIGATION

2.1. *Materials*

2.1.1. *Fly Ash*

Low calcium, Class F (American Society for Testing and Materials 2001) dry fly ash collected from the JSW Energy Ltd. Jaigad through Ultratech Cement Limited, Unit: Narmada Cement, Ratnagiri, MH, India was used as the source material to make geopolymer concrete. It can be seen that this fly ash contained a very low percentage of carbon as indicated by the low Loss on Ignition (LOI) values.

2.1.2. *Alkaline Solution*

In this investigation, a mixture of sodium hydroxide (NaOH) solution and sodium silicate (Na_2SiO_3) solution was used as alkaline activators for geopolymerisation. The NaOH is available in pellets. For present study, the purity of NaOH pellets is 98% used. The sodium silicate is commercially available in liquid. The chemical composition of the sodium silicate solution was Na_2O=14.33%, SiO_2=33.10%, and water 52.57% by mass. The ratio of NaOH to Na_2SiO_3 was used as 2.5.

2.1.3. *Fine aggregate*

Fine aggregate (Sand) used is clean dry river sand. The sand is sieved using 4.75 mm sieve to remove all pebbles. The specific gravity of sand is 2.875 and the fineness modulus of 3.895 was used. The water absorption is of 1%.

2.1.4. *Coarse aggregate*

Locally available crushed aggregate was used. The coarse aggregate with maximum size of 20 mm having specific gravity of 3.03%. The water absorption of 0.55%.

2.1.5. *Fibers*

In this work steel fiber of size 0.50 mm diameter and 30 mm length having density of 7850 Kg/m3 were used. The steel fiber is of aspect ratio 60 and 100. And the type of steel fiber was crimped (Round).

2.2. *Mix design of steel fiber reinforced geopolymer concrete*

In the present study, method for mix design is the Indian Standard Method. The geopolymer consist primary binder as fly ash. The ratio of alkaline liquid to fly ash is 0.5.To obtain mass of sodium hydroxide and sodium silicate solution, the ratio of sodium hydroxide to sodium silicate was fixed at 2.5.

Table1. Mix Design.

ID Mix	Fly ash (Kg/m^3)	Fine aggregate (Kg/m^3)	Course aggregate (Kg/m^3)	NaoH Sol^n (Kg/m^3)	Na_2SiO_3 Sol^n (Kg/m^3)	Steel fibers (Kg/m^3)
GPC 0% fiber	368.91	581.03	1171.29	52.86	132.14	0
GPC1 1.5% Fiber of A.R. 60	368.91	581.03	1171.29	52.86	132.14	117.75
GPC2 1.5% fiber of A.R. 100	368.91	581.03	1171.29	52.86	132.14	117.75
GPC3 0.75% fiber of 60 + 0.75% fiber of 100	368.91	581.03	1171.29	52.86	132.14	58.88+ 58.88

2.3. *Preparation of Geopolymer concrete*

To prepare 10 molarity concentration of sodium hydroxide solution, 400 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the concrete to get the desired alkaline solution. The solids constituents of the GPC mix i.e. fly ash, fine aggregate and coarse aggregate were dry mixed in the pan mixer for about three minutes. After dry mixing, alkaline solution was added to the dry mix and wet mixing was done. In case of steel fiber reinforced GPC mixes fibers were added to the wet mix in three different proportions such as 1.5% of aspect ratio 60, 1.5% of aspect ratio 100 and hybridization of both i.e. 0.75% of aspect ratio 60 + 0.75% of aspect ratio 100 by volume of the concrete.

In this experimental work a total 36 no. of specimens were cast with and without steel fibers. The specimen consist of 150mm×150mm×150mm size cubes for compression test, 150mm diameter and 300mm length cylinders for split tensile test and 100mm×100mm×500mm size beams for flexural test.
After casting the specimens, they were kept in rest period for 24 hours and then they were demoulded. Afterword they were heat cured at 600c in hot air oven for 8 hours duration.
Then specimens were removed from oven & kept at room temperature. After 28 days, weight of specimens was taken to determine density & tests for compressive strength, Flexural strength & Split tensile

Strength were conducted. Workability is carried out by conducting the slump test and compaction factor test as per I.S. 1199-1959 on Fly ash based Geopolymer concrete and Geopolymer concrete with fiber.

3. RESULT AND DISCUSSION

All category samples are tested & analyzed for properties of Fresh concrete i.e. Slump, Compaction Factor & Density. These samples are also tested for properties of Hardened concrete i.e. Compressive Strength, Split tensile strength, Flexural Strength.

3.1. *Workability and Density*

The result of Slump Cone Test, Compaction Test, And Density of GPC & fiber reinforced GPC is shown in Table 2 and fig. 1, fig. 2, fig. 3.

Table -2: Workability and Density

Mix ID	Slump Value (mm)	Compaction Factor	Density of concrete (kg/m^3)
GPC 0% fiber	65	0.920	2472.69
GPC1 1.5% Fiber of12mm	27	0.880	2574.23
GPC2 1.5% fibre of 20mm	28.2	0.890	2622.22
GPC3 0.75% fiber of 12mm + 0.75% fiber of 20mm	27.5	0.910	2663.70

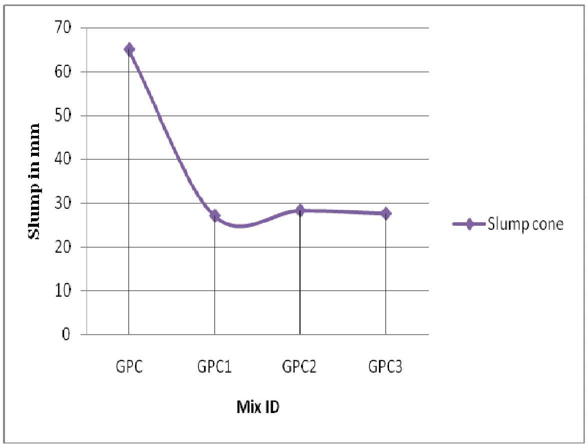

Fig. -1: Slump cone test

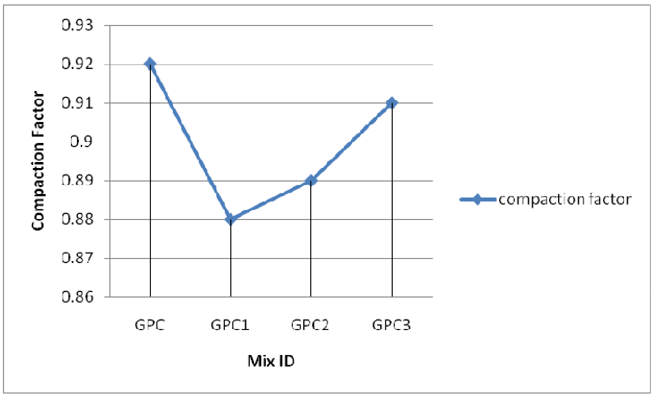

Fig. -2: compaction factor test

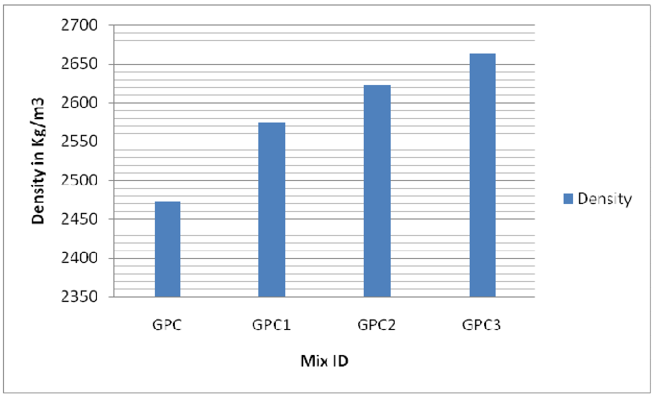

Fig. -3: Density of concrete

3.2. *Compressive Strength*

The result of compressive strength is shown in Table 3 and chart 4

Table -3: Compressive Strength of Geopolymer Concrete with and without fibers

Mix ID	**Avg. Comp. 'P' load in KN**	**Avg. Comp. strength in Mpa**	**% increase in strength**
GPC	807.37	35.88	-
GPC1	998.55	44.38	19.15%
GPC2	1046.47	46.21	22.35%
GPC3	1024.05	46.38	22.63%

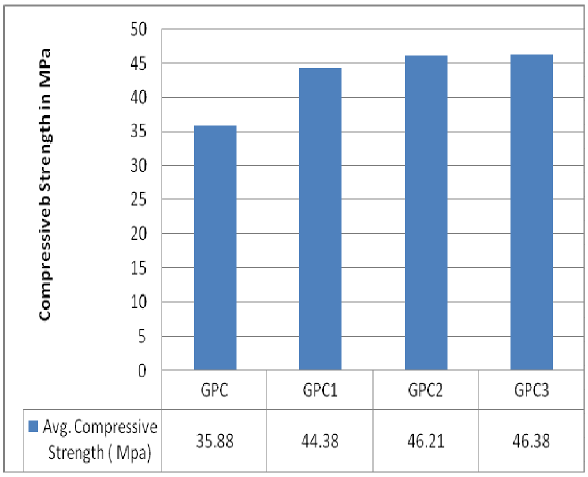

Fig. -4: Compressive strength

3.3. *Split Tensile Strength*

The result of Split Tensile Strength is shown in Table 4 and fig. 4

Table- 4: Split Tensile Strength of Geopolymer Concrete

Mix ID	Avg. Load 'P' in KN	Avg. Split Tensile strength in Mpa	% increase in strength
GPC	257.997	3.65	-
GPC1	336.58	4.76	23.31%
GPC2	340.70	4.82	24.27%
GPC3	337.88	4.78	23.64%

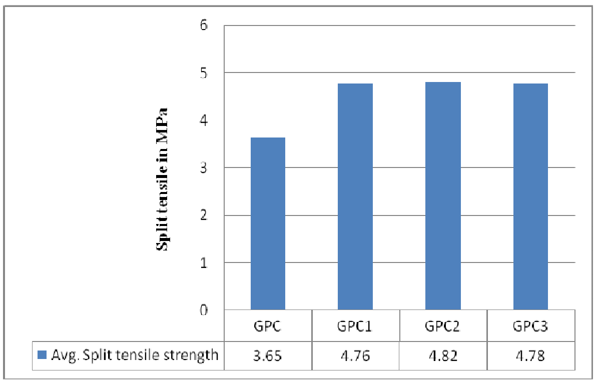

Fig. -5: Split tensile strength

3.3 Flexural Strength

The result of Flexural Strength is shown in Table 5 and
chart 6

Table-5: Flexural Strength of Geopolymer Concrete

Mix ID	Avg. load 'P' in KN	Avg. Flexural strength in Mpa	% increase in strength
GPC	24.49	10.28	-
GPC1	33.99	14.28	28.01%
GPC2	38.17	16.03	35.87%
GPC3	37.80	15.88	35.26%

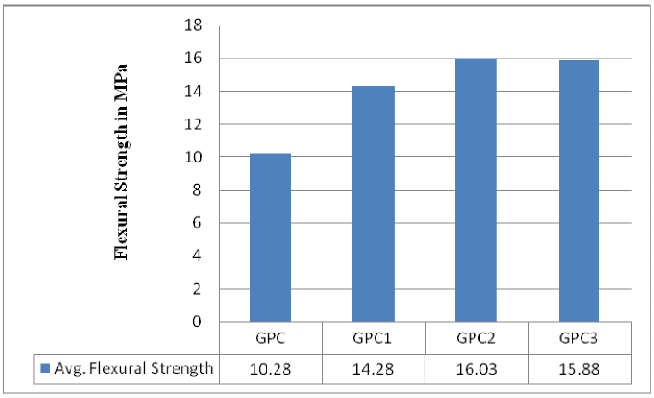

Fig. -6: Flexural Stength

3. CONCLUSIONS

1. Geopolymer concrete is an excellent alternative to Portland cement concrete.
2. The density of GPC with and without fiber is similar to the Ordinary Portland cement concrete.
3. The compressive, split tensile and flexural strength of Steel fiber reinforced geopolymer concrete is near about 20%, 23% and 28% respectively, higher than that of geopolymer concrete without fibers.
4. The Compressive strength, Split tensile strength, Flexural strength of 1.5% of steel fiber of aspect ratio 100 is 22.86%, 24.27%, 35.87% respectively, more than that of GPC without fiber, GPC1 with steel fiber of aspect ratio 60 and GPC3 with steel fiber of 0.75% of aspect ratio 60 and 0.75% of aspect ratio100.

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