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EFFECT OF INCLUSION OF STEEL FIBRES ON THE PROPERTIES OF GEOPOLYMER CONCRETE COMPOSITES

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ABSTRACT

This paper presents the results of an experimental investigation on the mechanical properties of Geopolymer Concrete Composites (GPCC) containing 90% Fly ash (FA), 10% Ordinary Portland Cement (OPC), alkaline liquids and steel fibers. The study analyses the impact of steel fibres on the mechanical properties such as density, Compressive Strength, Split Tensile strength and Flexural strength of hardened GPCC. Mixtures were prepared with alkaline liquid to fly ash ratio of 0.4 with 10% of fly ash replaced by OPC in mass basis. Steel fibers were added to the mix in the volume fractions of 0.25%, 0.5% and 0.75% 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, empirical expressions were developed to predict 28-day compressive strength, split tensile strength and flexural strength of Steel fiber reinforced GPCC in terms of volume fraction of steel fiber.

Keywords: Fly ash; geopolymer concrete composites; alkaline liquids; steel fibers; density; compressive strength; split tensile strength; flexural strength

1. INTRODUCTION

Demand for concrete as construction material is on the increase and so is the production of cement. The production of one ton of cement liberates about one ton of CO_2 to atmosphere [1]. In order to address environmental effects associated with Portland cement, there is need to develop alternative binders to make concrete. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass [2,3] is a significant development. Davidovits [4] proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or byproduct materials such as fly ash and rice husk ash. He termed these binders as geopolymers. Compared with ordinary Portland cement concrete,

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geopolymers show many advantages. Low-calcium fly ash-based geopolymer concrete has excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulfate attack, and good acid resistance [5]. Geopolymer concrete is suitable for structural applications and the design provisions contained in the current standards and codes can be used to design reinforced fly ash-based geopolymer concrete structural members [6]. Researches on concrete with more than 50% of fly ash are very rare since there is degradation in strength with higher percentages of fly ash. On the other hand, geopolymer concrete that is produced by a polymeric reaction of alkaline liquid with a byproduct material like fly ash with total replacement of cement by fly ash have several limitations such as necessity of heat curing and delay in setting time. In order to overcome these limitations efforts have been taken in the present investigation to develop Geopolymer Concrete Composites with Fly ash, OPC and alkaline liquids.

Also the concept of using fibers as reinforcement is not new. By the 1960s, steel, glass (GFRC), and synthetic fibers such as polypropylene fibers were used in concrete, and research into new FRCs continues today. Some types of fibers produce greater impact, abrasion, and shatter resistance in concrete. Concerning the structural applications, fiber concrete possesses many advantages compared to the traditional structural concrete. Yeol Choi et al. investigated the relationship between the splitting tensile strength and compressive strength of glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC). The splitting tensile strength and compressive strength of GFRC and PFRC at 7, 28 and 90 days were used an test results indicated that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20–50%, and the splitting tensile strength of GFRC and PFRC ranged from 9% to 13% of its compressive strength. Based on this investigation, a simple 0.5 power relationship between the splitting tensile strength and the compressive strength was derived for estimating the tensile strength of GFRC and PFRC [7].

Mazaheripour et al. analyzes the impact of polypropylene fibers on the performance of light weight self compacting concrete at its fresh condition as well as its mechanical properties at the hardened condition and they found that applying 0.3% volume fractions of polypropylene fiber to the light weight self compacting concrete resulted in 40% reduction in the slump flow (from 720 mm to 430 mm Polypropylene fibers did not influence the compressive strength and elastic modulus of light weight self compacting concrete, however applying these fibers at their maximum percentage volume determined through this study, increased the tensile strength by 14.4% in the splitting tensile strength test, and 10.7% in the flexural strength [8].

Okan Karahan et al. studied the durability properties of concrete containing polypropylene fiber and fly ash. The laboratory results showed that inclusion of fly ash either into Portland cement concrete or fly ash concrete did not improve the compressive strength and elastic modulus. The positive interactions between polypropylene fibers and fly ash lead to the lowest drying shrinkage of fibrous concrete with fly ash. Freeze–thaw resistance of polypropylene fiber concrete was found to slightly increase when compared to concrete without fibers. Moreover, fly ash increased the freeze–thaw resistance more than the polypropylene fibers did [9]. Songa et al. investigated the strength potential of nylon-fiber-reinforced concrete versus that of the polypropylene-fiber-reinforced concrete, at a fiber content of 0.6 kg/m^3. The compressive and splitting tensile strengths and modulus of rupture of the nylon fiber concrete improved by 6.3%, 6.7%, and 4.3%, respectively, over those of the polypropylene fiber concrete. On the impact resistance, the first-crack and failure strengths and the percentage increase in the post first-crack blows improved more for the nylon fiber concrete than for its polypropylene counterpart. In addition, the shrinkage crack reduction potential also improved more for the nylon-fiber-reinforced mortar. The above-listed improvements stemmed from the nylon fibers registering a higher tensile strength and possibly due to its better distribution in concrete [10].

Literatures indicated that several researchers have investigated the effect of inclusion of fibers in concrete consisting of either 100% cement or partial replacement of cement by fly ash. The present investigation is designed to evaluate the mechanical properties of steel fibre reinforced Geopolymer Concrete Composites consisting of 90% Fly ash, 10% Cement and alkaline liquids.

2. EXPERIMENTAL INVESTIGATION

2.1 Materials

Low calcium fly ash (ASTM class F) collected from Mettur thermal power station was used as the source material to make geopolymer concrete in the laboratory. Ordinary Portland cement with a specific gravity of 3.15 was used in casting the specimens. Fine Aggregate (sand) used is clean dry river sand. The sand is sieved using 4.75 mm sieve to remove all the pebbles. Fine aggregate having a specific gravity of 2.81, bulk density of 1693 kg/m^3 and fineness modulus of 2.75 was used. Coarse aggregates of 19 mm maximum size having a fineness modulus of 6.64, bulk density of 1527 kg/m^3 and specific gravity of 2.73 were used. Water conforming to the requirements of water for concreting and curing was used throughout.

In this investigation, a combination of Sodium hydroxide solution and sodium silicate solution was used as alkaline activators for geopolymerisation. Sodium hydroxide is available commercially in flakes or pellets form. For the present study, sodium hydroxide flakes with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used as such. The chemical composition of sodium silicate is: Na_2O-14.7%, SiO_2-29.4% and Water -55.9% by mass. In this work hooked-end steel fibers made with low carbon steel were used. These steel fibers have a length of 35 mm, nominal diameter of 0.5 mm and an aspect ratio of 70.

2.2 Mix Design of geopolymer concrete composite

In the design of geopolymer concrete (GPC mix), coarse and fine aggregates together were taken as 77% of entire mixture 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 mixture by mass. Fine aggregate was taken as 30% of the total aggregates. From the past literatures it is clear that the average density of fly ash-based geopolymer concrete is similar to that of OPC concrete (2400kg/m^3).Knowing the density of concrete, the combined mass of alkaline liquid and fly ash can be arrived. By assuming the ratios of alkaline liquid to fly ash as 0.4, mass of fly ash 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. Extra water (other than the water used for the preparation of alkaline solutions) and super plasticizer Conplast SP 430 based on Sulphonated Napthalene Polymers were added to the mix by 10% and 3% by weight of fly ash respectively to achieve workable concrete. This GPC mix has two limitations such as delay in setting time and necessity of heat curing to gain strength. In order to overcome these two limitations of GPC mix, 10% of fly ash was replaced by OPC and the mix design was altered accordingly which results in Geopolymer Concrete Composite (GPCC mix). The mix proportions of GPC and GPCC are given in Table 1.

Table 1: Mix proportions

Mix ID	Fly Ash kg/m^3	OPC kg/m^3	Fine Aggregate kg/m^3	Coarse Aggregate kg/m^3	NaOH Solution kg/m^3	Na_2SiO_3 Solution kg/m^3	Extra Water kg/m^3	Super plasticizer kg/m^3	Steel Fibers kg/m^3
GPC	394.3	--	554.4	1293.4	45.1	112.6	39.43	11.83	-
GPCC	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	-
GPCC 1	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	19.63
GPCC 2	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	39.25
GPCC 3	354.87	39.43	554.4	1293.4	40.56	101.39	55.18	11.83	58.88

2.3 Preparation of GPCC

To prepare 12 molarity concentration of sodium hydroxide solution, 480 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup to one liter. The mass of NaOH solids was measured as 354.45 grams per kg of NaOH solution of 12M concentration. 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 GPCC mix i.e. fly ash, OPC and the aggregates 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 for 4 minutes. Finally extra water along with super plasticizer was added to achieve workable GPCC mix. In case of steel fiber reinforced GPCC mixes fibers were added to the wet mix in three different proportions such as 0.25%, 0.5% and 0.75% volume of the concrete.

In this experimental work a total of 90 numbers of concrete specimens were cast with and without steel fibers. The specimens considered in this study consisted of 30 numbers of 150mm side cubes, 30 numbers of 150mm diameter and 300mm long cylinders and 30 numbers of 100 mm X 100mm X 500mm size prisms.

Before casting machine oil was smeared on the inner surfaces of the cast iron mould. Concrete was poured into the moulds and compacted thoroughly using a table vibrator. The top surface was finished using a trowel. The GPC specimens were removed from the mould after 4 days while the GPCC specimens were removed from the mould immediately after 24 hours since they set in a similar fashion as that of conventional concrete. All the specimens were left at room temperature till the day of testing. Tests for compressive and split tensile strengths were conducted using a 2000kN Digital Compression testing machine and the test for flexural strength was conducted using a 100kN Flexural testing machine. These tests were conducted as per the relevant Indian standard specifications [11,12].

3. RESULTS AND DISCUSSION

3.1 Density

Density of geopolymer concrete composites is presented in Figure 1. Average Density values of Geopolymer concrete composites ranges from 2347 to 2448 kg/m^3 as shown in Table 2. As the age of concrete increases, there is a slight increase in the average density. The density of geopolymer concrete composites was found approximately equivalent to that of conventional concrete.

Table 2: Average density of geopolymer concrete composites

Mix ID	Average density in kg/m^3	
	7 Days	**28 Days**
GPC	2347.16	2384.20
GPCC	2378.77	2385.88
GPCC 1	2396.05	2425.68
GPCC 2	2408.89	2428.64
GPCC 3	2443.45	2447.90

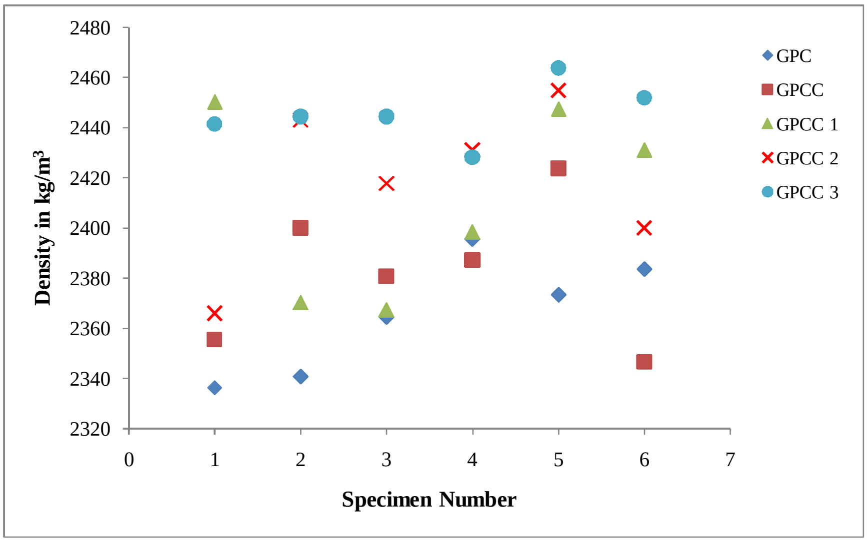

Figure 1. Density of specimens

3.2 Compressive Strength

The compressive strength of different mixes at 7 days and 28 days are represented in Figure

2. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength. Compressive strength of GPCC increases by about 73% with reference to GPC mix. As the age of concrete increases from 7 days to 28 days, compressive strength also increases for all the mixes. From the test results it can be seen that, average compressive strengths of Geopolymer Concrete Composites containing steel fibers were higher than those of Geopolymer concrete composites without steel fibers. As the volume fraction increases from 0.25 to 0.75%, compressive strength increases with respect to the control mix. The increase in compressive strength was about 11%, 13% and 24% for GPCC1, GPCC2 and GPCC3 respectively with reference to GPCC mix. Based on the test results, using least square regression analysis the equation for predicting the 28 days compressive strength of steel fibre reinforced Geopolymer Concrete Composites in terms of percentage volume fraction of fibers (V_f) is obtained and given in Equation 1.

$$f_{cs} = f_{co} + 11.08\ V_f \tag{1}$$

where,

f_{cs} = 28 days Compressive Strength of steel fibre reinforced Geopolymer Concrete Composites

f_{co} = 28 days Compressive Strength of Geopolymer Concrete Composites

V_f = Percentage Volume fraction of steel fibres.

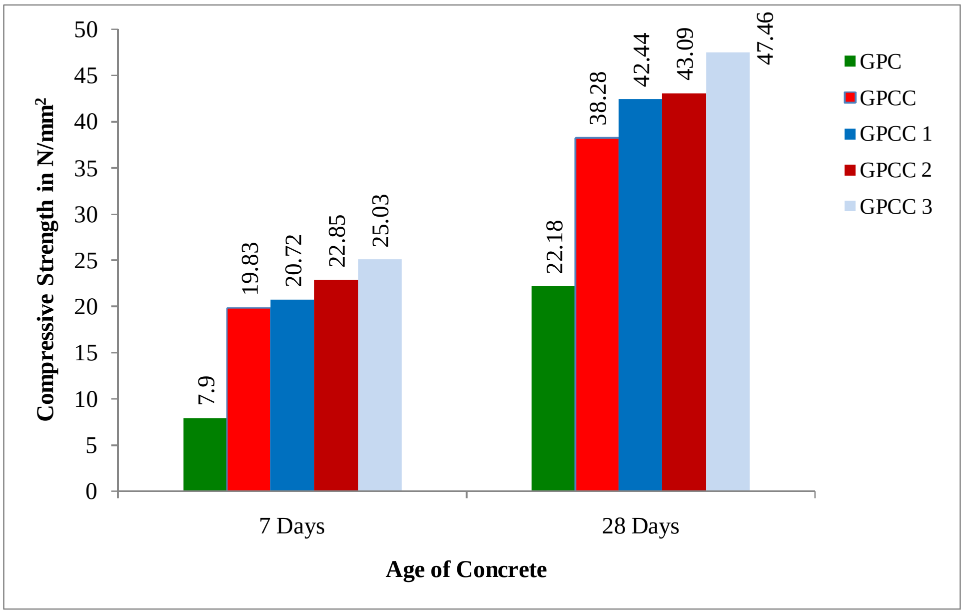

Figure 2. Effect of addition of steel fibres on compressive strength

3.3 Split tensile strength

The split tensile strength of different mixes at 7 days and 28 days are represented in Figure 3. Replacement of 10% of fly ash by OPC in GPC mix resulted in an improved split tensile strength. Split tensile strength of GPCC increases by about 128% with reference to GPC mix. As the age of concrete increases from 7 days to 28 days, split tensile strength also increases for all the mixes. From the test results it can be seen that, average tensile strengths of Geopolymer Concrete Composites containing steel fibers were higher than those of Geopolymer concrete composites without steel fibers. As the volume fraction increases from 0.25 to 0.75%, split tensile strength increases with respect to the control mix. The increase in tensile strength was about 1%, 18% and 24% for GPCC1, GPCC2 and GPCC3 respectively with reference to GPCC mix. Based on the test results of this investigation, using least square regression analysis the equation for predicting the 28 days split tensile strength of steel fiber reinforced Geopolymer Concrete Composites in terms of percentage volume fraction of fibers (V_f) is obtained and given in Equation 2.

$$f_{ts} = f_{to} + 0.834\ V_f \qquad (2)$$

where,

f_{ts} = 28 days Split tensile strength of steel fibre reinforced Geopolymer Concrete Composites

f_{to} = 28 days Split tensile Strength of Geopolymer Concrete Composites

V_f = Percentage Volume fraction of steel fibres.

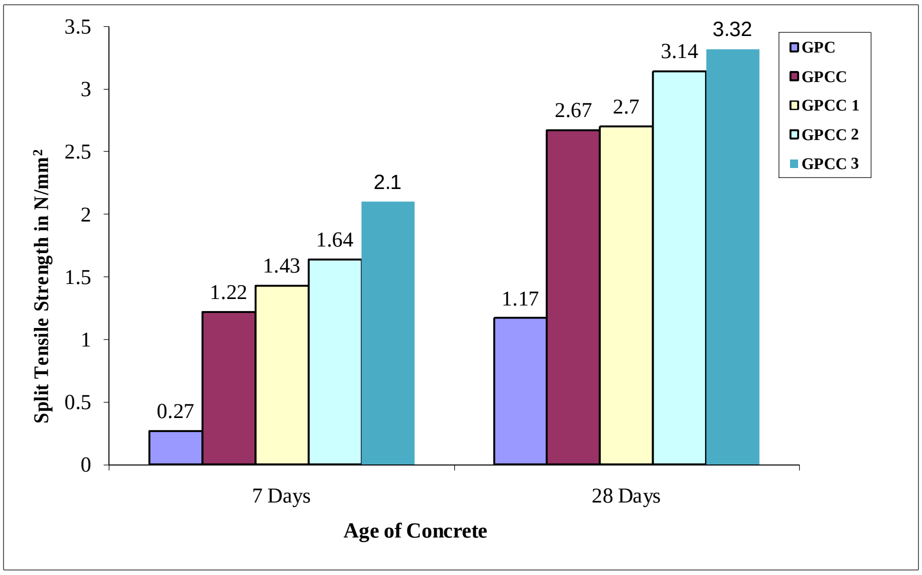

Figure 3. Effect of addition of steel fibres on split tensile strength

3.4 Flexural strength

The Modulus of rupture of different mixes at 7 days and 28 days are represented in Figure 4. Replacement of 10% of fly ash by OPC in GPC mix resulted in an improved flexural strength. Flexural strength of GPCC increases by about 17% with reference to GPC mix. As the age of concrete increases from 7 days to 28 days, flexural strength also increases for all the mixes. From the test results it can be seen that, average flexural strengths of Geopolymer Concrete Composites containing steel fibers were higher than those of Geopolymer concrete composites without steel fibers. As the volume fraction increases from 0.25 to 0.75%, flexural strength increases with respect to the control mix. The increase in modulus of rupture was about 3%, 34% and 44% for GPCC1, GPCC2 and GPCC3 respectively with reference to GPCC mix. Based on the test results of this investigation, using least square regression analysis the equation for predicting the 28 days flexural strength of steel fiber reinforced Geopolymer Concrete Composites in terms of percentage volume fraction of fibers (V_f) is obtained as

$$f_{fs} = f_{fo} + 3.36\ V_f \tag{3}$$

where,

f_{fs} = 28 days flexural strength of steel fibre reinforced Geopolymer Concrete Composites
f_{fo} = 28 days flexural Strength of Geopolymer Concrete Composites
V_f = Percentage Volume fraction of steel fibres.

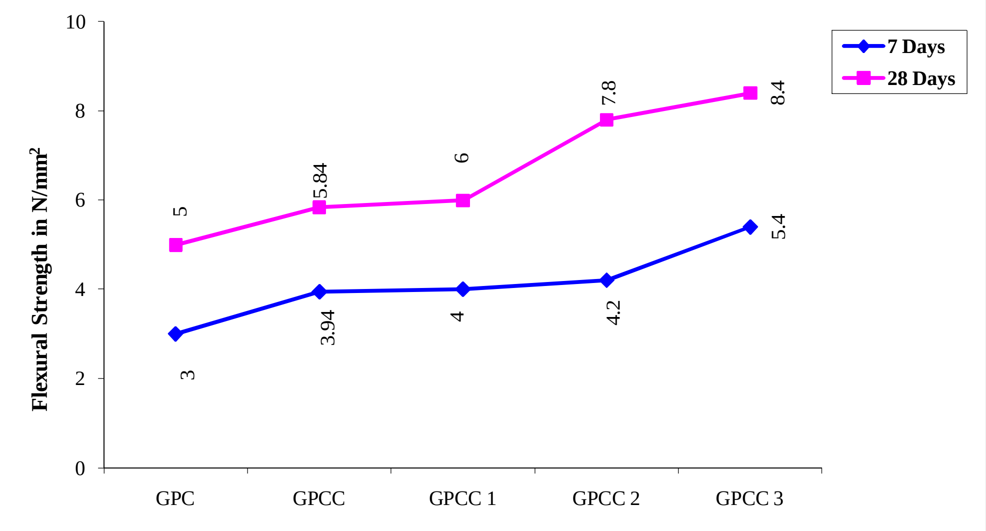

Figure 4. Effect of addition of Steel fibres on flexural strength

4. CONCLUSIONS

Geopolymer Concrete (GPC mix) has two limitations such as delay in setting time and necessity of heat curing to gain strength. These two limitations of GPC mix was eliminated by replacing 10% of fly ash by OPC which results in Geopolymer Concrete Composite (GPCC mix). Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength, split tensile strength and flexural strength by 73%, 128% and 17% respectively with reference to GPC mix. Addition of steel fibers in Geopolymer concrete composites enhanced its mechanical properties. Compressive strength, split tensile strength and flexural strength of steel fiber reinforced Geopolymer concrete composites increases with respect to the increase in the percentage volume fraction from 0.25 to 0.75. Addition of 0.25% volume fraction of steel fibers resulted in an enhanced compressive strength, split tensile strength and flexural strength by 11%, 1% and 3% respectively with reference to GPCC mix. For addition of 0.5% volume fraction of steel fibers the compressive strength, split tensile strength and flexural strength is increased by 13%, 18% and 34% respectively with reference to GPCC mix. Similarly addition of 0.75% volume fraction of steel fibers resulted in an enhanced compressive strength, split tensile strength and flexural strength by 24%, 24% and 44% respectively with reference to GPCC mix. Equations for predicting the 28 days compressive strength, split tensile strength and flexural strength of steel fiber reinforced Geopolymer Concrete Composites in terms of percentage volume fraction of fibers (V_f) are obtained by using least square regression analysis from the test results of these investigations.

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