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EXPERIMENTAL INVESTIGATIONS ON MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE COMPOSITES

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ABSTRACT

Due to growing environmental concerns of the cement industry, alternative cement technologies have become an area of increasing interest. It is now believed that new binders are indispensable for enhanced environmental and durability performance. Geopolymer concrete (GPC) is an innovative method and is produced by complete elimination of ordinary Portland cement by fly ash. Geopolymer concrete has two limitations such as delay in setting time and necessity of heat curing to gain strength. Present research aimed to rectify these two limitations of GPC by replacing 10% of fly ash by OPC on mass basis. 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) and alkaline liquids. The study analyses the impact of replacement of 10% of fly ash by OPC in the GPC mix on the mechanical properties such as density, Compressive Strength, Split Tensile strength and Flexural strength both in ambient curing at room temperature and heat curing at 60^{o} C for 24 hours in hot air oven. Mixtures were prepared with alkaline liquid to fly ash ratio of 0.4. Based on the test results, empirical expressions were developed to predict split tensile strength and flexural strength of GPC as well as GPCC in terms of their compressive strength.

Keywords: Fly ash; geopolymer concrete composite; alkaline liquid; compressive strength; split tensile strength; flexural strength

1. INTRODUCTION

Concrete is one of the most far used construction materials in the world. Portland cement, an essential constituent of concrete is not an environmentally friendly material. The production of Portland Cement not only depletes significant amount of natural resources but also

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liberates a considerable amount of Carbon dioxide (CO_2) and other greenhouse gases. 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 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 [4]. Compared with ordinary Portland cement concrete, 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 (GPCC) with 90% Fly ash, 10% OPC and alkaline liquids. The present investigation is designed to evaluate the mechanical properties of Geopolymer Concrete Composites.

2. EXPERIMENTAL PROGRAM

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.

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: Details of 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**
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

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 this experimental work a total of 72 numbers of Geopolymer concrete specimens were cast with and without OPC. The specimens considered in this study consisted of 24 numbers of 150 mm side cubes for compressive strength, 24 numbers of 150 mm diameter and 300 mm long cylinders for split tensile strength and 24 numbers of 100 mm X 100 mm X 500 mm size prisms for flexural strength. 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. Half of the total number of specimens was left at room temperature for ambient curing (A.C) till the day of testing while the remaining specimens were kept in hot air oven for heat curing (H.C) at 60^{o} C for 24 hours. 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 [7, 8].

3. RESULTS AND DISCUSSION

3.1 Density

Density of GPC ranges from 2336 to 2413 kg/m^3 and density of GPCC ranges from 2356 to 2424 kg/m^3 as shown in Figure 1. As the age of concrete increases, there is a slight increase in the average density of GPC as well as GPCC. The density of geopolymer concrete and geopolymer concrete composite was found approximately equivalent to that of conventional concrete.

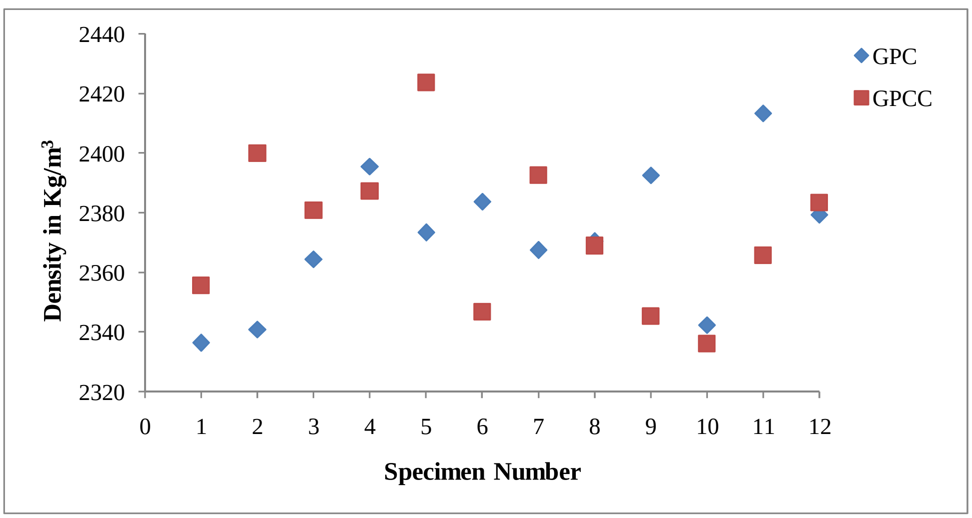

Figure 1. Density of GPC and GPCC specimens

3.2 Compressive Strength

The compressive strength of GPC and GPCC mixes at the age of 7 days and 28 days for both ambient curing and heat curing is presented in Figure 2. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced compressive strength. In ambient curing, the compressive strength of GPCC increases by about 151% and 73% at the age of 7 days and 28 days respectively with reference to GPC mix. In heat curing, the compressive strength of GPCC increases by about 64% and 39% with reference to GPC mix at the age of 7 days and

28 days respectively. The percentage increase in compressive strength is higher in ambient curing than the heat curing. This may be due to the reason that at ambient curing the heat evolved by hydration of 10% of OPC stimulates the polymerization of 90% of fly ash present in the GPCC mixes. The 28 days compressive strength of ambient cured GPCC specimens is very much higher than the 28 days compressive strength of heat cured GPC specimens. This may be due to the reason that sufficient heat is evolved for the polymerization process by just replacing 10% of fly ash by OPC in GPC mix. Due to heat curing the compressive strength increases by 171% and 77% at the age of 7 days in GPC and GPCC mixes respectively while at the age of 28 days it is 28% and 3% respectively. The percentage increase in compressive strength due to heat curing is less in GPCC than GPC in both 7 days and 28 days age of concrete. The 28 days compressive strength of GPC in ambient curing is 2.81 times that of 7 days compressive strength while in heat curing it is only 1.33 times. Similarly the 28 days compressive strength of GPCC in ambient curing is 1.93 times that of 7 days compressive strength while in heat curing it is only 1.12 times. As the age of concrete increases the compressive strength increases both in GPC and GPCC mixes but the rate of increase is more in ambient curing than heat curing.

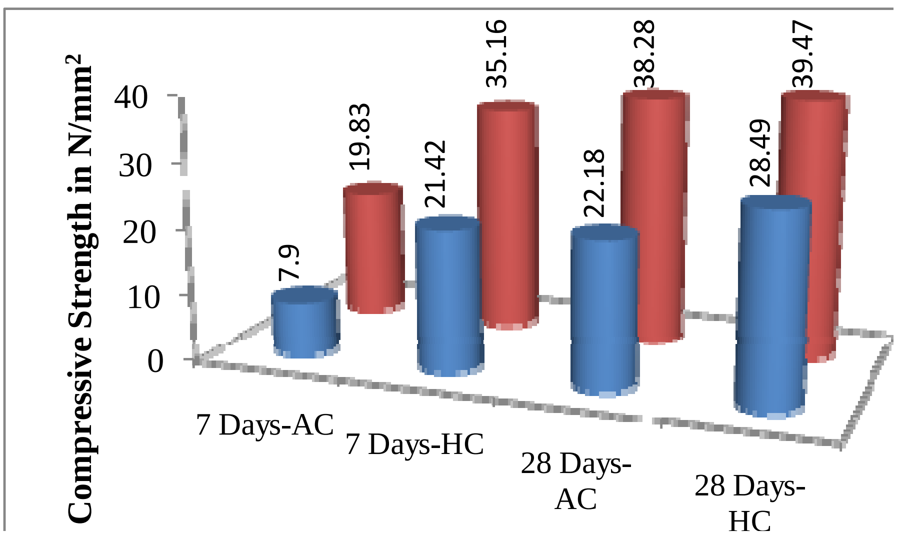

Figure 2. Compressive strength of GPC and GPCC specimens

3.3 Split Tensile Strength

The split tensile strength of GPC and GPCC mixes at the age of 7 days and 28 days for both ambient curing and heat curing is presented in Figure 3. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced split tensile strength. In ambient curing, the split tensile strength of GPCC increases by about 352% and 128% at the age of 7 days and 28 days respectively with reference to GPC mix. In heat curing, the split tensile strength of GPCC increases by about 175% and 127% with reference to GPC mix at the age of 7 days and 28 days respectively. The percentage increase in split tensile strength is higher in ambient curing than the heat curing. At the age of 28 days, the split tensile strength of ambient cured GPCC specimens is more than the split tensile strength of heat cured GPC specimens. Due to heat curing the split tensile strength increases by 304% and 146% at the age of 7 days in GPC and GPCC mixes respectively while at the age of 28 days it is 14% and 13% respectively. The percentage increase in split tensile strength due to heat curing is less in GPCC than GPC in both 7 days and 28 days age of concrete. The 28 days split tensile strength of GPC in ambient curing is 4.33 times that of 7 days split tensile strength while in heat curing it is only 1.22 times. Similarly the 28 days split tensile strength of GPCC in ambient curing is 2.19 times that of 7 days split tensile strength while in heat curing it is only 1.1 times. As the age of concrete increases the split tensile strength increases both in GPC and GPCC mixes but the rate of increase is more in ambient curing than heat curing. In this study, the split tensile strengths of GPC and GPCC are assumed to be proportional to the square root of their compressive strength. Based on the test results, using regression analysis relationship between the splitting tensile strength and compressive strength of GPC and GPCC at all ages have been derived and given in Equation 1 and Equation 2 respectively.

$$f_{st} = 0.230\sqrt{f_{ck}} \tag{1}$$

$$f_{st} = 0.442\sqrt{f_{ck}} \tag{2}$$

where, f_{st} = Split tensile strength and f_{ck} = Compressive strength

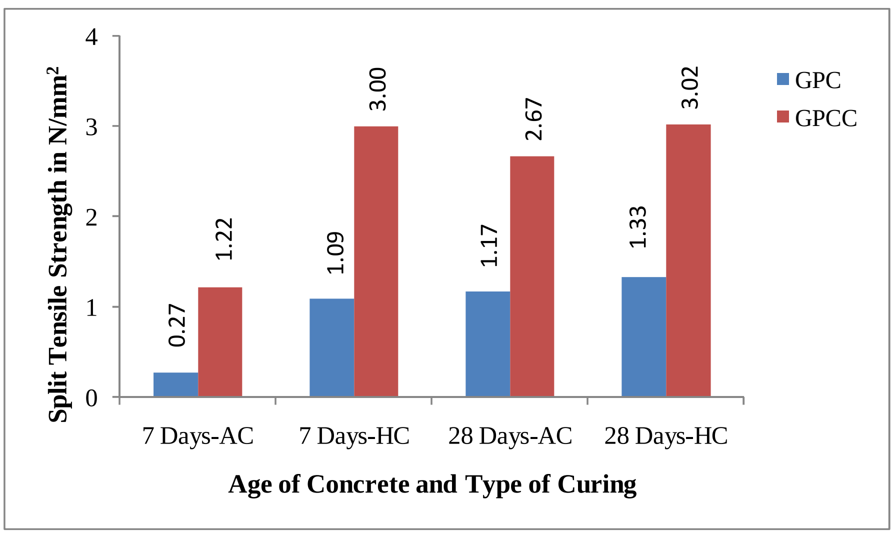

Figure 3. Split tensile strength of GPC and GPCC specimens

3.4 Flexural Strength

The flexural strength of GPC and GPCC mixes at the age of 7 days and 28 days for both ambient curing and heat curing is presented in Figure 4. Replacement of 10% of fly ash by OPC in GPC mix resulted in an enhanced flexural strength. In ambient curing, the flexural strength of GPCC increases by about 31% and 17% at the age of 7 days and 28 days respectively with reference to GPC mix. In heat curing, the flexural strength of GPCC increases by about 18% and 11% with reference to GPC mix at the age of 7 days and 28 days respectively. The percentage increase in flexural strength is higher in ambient curing than the heat curing. At the age of 28 days, the flexural strength of ambient cured GPCC specimens is more than the flexural strength of heat cured GPC specimens. Due to heat curing the flexural strength increases by 47% and 32% at the age of 7 days in GPC and GPCC mixes respectively while at the age of 28 days it is 8% and 3% respectively. The percentage increase in flexural strength due to heat curing is less in GPCC than GPC in both 7 days and 28 days age of concrete. The 28 days flexural strength of GPC in ambient curing is 1.67 times that of 7 days flexural strength while in heat curing it is only 1.23 times. Similarly the 28 days flexural strength of GPCC in ambient curing is 1.48 times that of 7 days flexural strength while in heat curing it is only 1.15 times. As the age of concrete increases the flexural strength increases both in GPC and GPCC mixes but the rate of increase is more in ambient curing than heat curing. In this study, the flexural strengths of GPC and GPCC are assumed to be proportional to the square root of their compressive strength. Based on the test results, using regression analysis relationship between the flexural strength and compressive strength of GPC and GPCC at all ages have been derived and given in Equation 3 and Equation 4 respectively.

$$f_{fs} = 1.104\sqrt{f_{ck}} \qquad (3)$$

$$f_{fs} = 0.920\sqrt{f_{ck}} \qquad (4)$$

where, f_{fs} = flexural Strength and f_{ck} = Compressive Strength

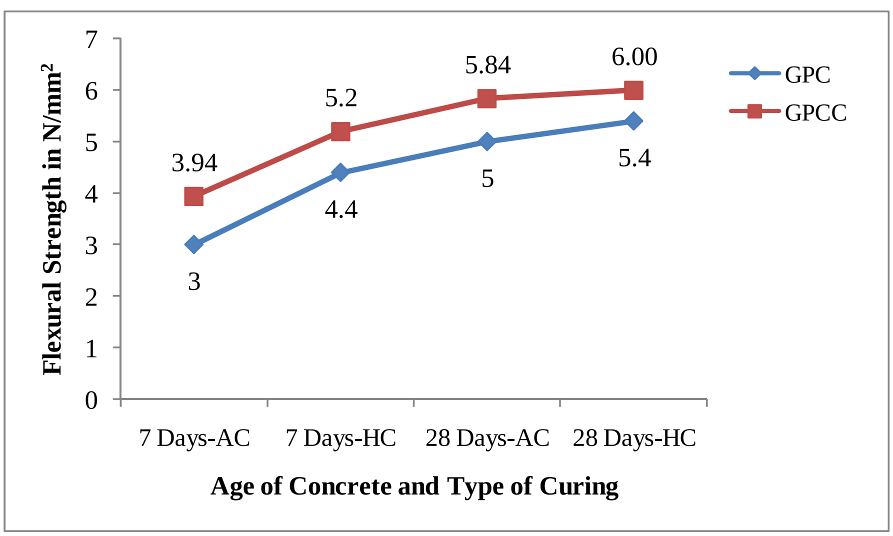

Figure 4. Flexural strength of GPC and GPCC specimens

4. CONCLUSION

Geopolymer Concrete has two limitations such as delay in setting time and necessity of heat curing to gain strength. In this study these two limitations of GPC mix was eliminated by replacing 10% of fly ash by OPC which resulted 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 in ambient curing at the age of 28 days. Similarly in heat curing the compressive strength, split tensile strength and flexural strength are enhanced by 39%, 127% and 11% respectively with reference to GPC mix at the age of 28 days. At the age of 28 days, the compressive strength, split tensile strength and flexural strength of GPCC in ambient curing itself is more than that of GPC in heat curing. This may be due to the reason that sufficient heat is evolved during the hydration of cement which is utilized for the polymerization process of fly ash by just replacing 10% of fly ash by OPC in Geopolymer Concrete which resulted in Geopolymer Concrete Composite.

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