Jr. of Industrial Pollution Control 28(1)(2012) pp 35-40

FEASIBILITY STUDY ON EFFECTIVE UTILISATION OF FLY ASH FROM TWO THERMAL POWER STATIONS ON THE DEVELOPMENT OF GEOPOLYMER CONCRETE

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Key words : Fly ash, Geopolymer concrete, Alkaline liquid, Density, Compressive strength, Split tensile strength,

(Received 19 October 2011; accepted 10 December 2011)

ABSTRACT

In order to address environmental effects associated with Portland cement, there is a need to develop alternative binders to make concrete. An effort in this regard is the development of geopolymer concrete, synthesized from the materials of geological origin or by product materials such as fly ash, which are rich in silicon and aluminum. This paper presents results of an experimental program on the mechanical properties such as density, compressive strength, split tensile strength and flexural strength of geopolymer concrete using fly ash collected from Mettur and Tuticorin thermal power stations. The various parameters of study for this investigation were i) Source of fly ash ii) Concentration of NaOH (8M, 12M and 16M) iii) Type of Curing (Ambient Curing at room temperature and Heat curing at 60°C for 24 Hours in Hot air Oven) iv) Age of Concrete (7 days and 28 days). The test results indicated that for both the sources of fly ash, there was an increase in compressive strength, split tensile strength and flexural strength of geopolymer concrete with increase in age, concentration of NaOH and also due to heat curing.

INTRODUCTION

Geopolymer is a type of amorphous alumino-silicate product that exhibits the ideal properties of rock-forming elements, i.e., hardness, chemical stability and longevity. The properties of geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance. These high-alkali binders do not generate any alkali-aggregate reaction (Davidovits, 1994). The geopolymer binder is a low-CO_2 cementious material. It does not rely on the calcination of limestone that generates CO_2. This technology can save up to 80% of CO_2 emissions caused by the cement and aggregate industries (Davidovits, 1994).

It is reported that the worldwide cement industry contributes around 1.65 billion tons of the greenhouse gas emissions annually (Malhotra, 2002; Hardjito *et al.* 2004). Due to the production of Portland cement, it is estimated that by the year 2020, the CO_2 emissions will rise by about 50% from the current levels (Naik,

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2005; Tarek Salloum, 2007). Therefore, to preserve the global environment from the impact of cement production, it is now believed that new binders are indispensable to replace Portland cement. In this regard, the geopolymer concrete is one of the revolutionary developments related to novel materials resulting in low-cost and environmental friendly material as an alternative to the Portland cement (Davidovits, 1991; Temuujin *et al*. 2010). Geopolymer Concrete is an innovative binder material and is produced by totally replacing the Portland cement. It is demonstrated that the geopolymeric cement generates 5–6 times less CO_2 than Portland cement (Davidovits, 2005). Therefore, the use of geopolymer technology not only significantly reduces the CO_2 emissions by the cement industries, but also utilises the industrial wastes and/or by-products of alumino-silicate composition to produce value added construction materials (Malhotra, 2002; Davidovits, 1990).

Hardjito *et al*. (2002; 2004 ;2003) studied different short and long term properties of fly ash based geopolymers using the West Australian fly ashes. The physical and chemical properties of fly ash vary in a wide range depending on the type of coal used and the furnace temperature. Therefore, the properties of geopolymer concrete may vary depending on the type of fly ash used to make it.

In this paper an attempt has been made to make geopolymer concrete in the laboratory using the fly ash produced by the power plants in Mettur and Turticorin of South India. Some observations in making the geopolymer concrete and its strength characteristics are discussed in this paper.

EXPERIMENTAL PROGRAMME

Parameters and Materials

The various parameters of this investigation are i) source of fly ash (Mettur and Tuticorin thermal power stations) ii) Concentration of NaOH (8M, 12M, and 16M) iii) Type of Curing (Ambient Curing at room temperature and Heat curing at 60 °C for 24 Hours in Hot air Oven) iv) Age of Concrete 7 days and 28 days. Low calcium fly ash (ASTM class F) collected from Mettur and Tuticorin thermal power stations was used as the source material to make geopolymer concrete in the laboratory. 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/m³ 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/m³ and specific gravity of 2.73 were used. Water conforming to the requirements of water for concreting and curing was used through out.

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. To prepare sodium hydroxide solution of 8 molarity (8M), 320 grams (8 x 40 i.e., molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and made up to one liter. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molarity, M. The mass of NaOH solids was measured as 255 grams per kg of NaOH solution of 8M concentration, 354.45 grams per kg of NaOH solution of 12M concentration, 444.6 grams per kg of NaOH solution of 16M concentration. 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

Mix Design of Geopolymer Concrete

In the design of geopolymer concrete 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/m³).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. Using the above procedure the mix was designed and the mix proportions are given in Table 1.

Table 1. Details of mix proportions

Alkaline Liquid to Fly Ash Ratio	Fly Ash Kg/m³	Fine Aggregate Kg/m³	Coarse Aggregate Kg/m3	NaOH Solution Kg/m³	Na_2SiO_3 Solution Kg/m³	Extra Water Kg/m³	Super plasticizer Kg/m³
0.4	394.3	554.4	1293.4	45.1	112.6	39.43	11.83

Preparation of Geopolymer Concrete

The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before making the geopolymer concrete to get the desired alkaline solution. The solids constituents of the fly ash-based geopolymer concrete, i.e. the aggregates and the fly ash, 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. 72 cubes of size 150mm x 150mm x 150mm for compressive strength, 72 cylinders of size 150mm x 300 mm for split tensile strength and 36 prisms of size 100mm x 100mm x 500mm for flexural strength were cast and compaction was done by mechanical vibration using a table vibrator.

Curing of Geopolymer Concrete

After casting the specimens, they were kept in rest period for five days and then they were demoulded. The term 'Rest Period' was coined to indicate the time taken from the completion of casting of test specimens to the start of curing at an elevated temperature. This may be important in certain practical applications. For instance, when fly ash-based geopolymer concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber. At the end of the Rest Period, 36 cubes, 36 cylinders and 18 prisms were kept under ambient conditions for curing at room temperature. Remaining specimens were heat cured at 60°C in hot air oven for 24 hours.

RESULT AND DISCUSSION

Density of Geopolymer Concrete

Density of geopolymer concrete for the two sources of flyash is presented in Figure 1. Average Density values of Geopolymer concrete ranges from 2337 kg/m³ to 2405 kg/m³ and 2316 kg/m³ to 2397 kg/m³ for Mettur fly ash and Tuticorin fly ash respectively. Variation of density is not much significant with respect to source of fly ash, concentration of NaOH solution, type of curing and age of concrete. The density of geopolymer concrete was found approximately equivalent to that of conventional concrete.

Compressive Strength

The compressive strength of geopolymer concrete made using two sources of fly ash is presented in Figures 2 and 3. In case of ambient curing, the com-

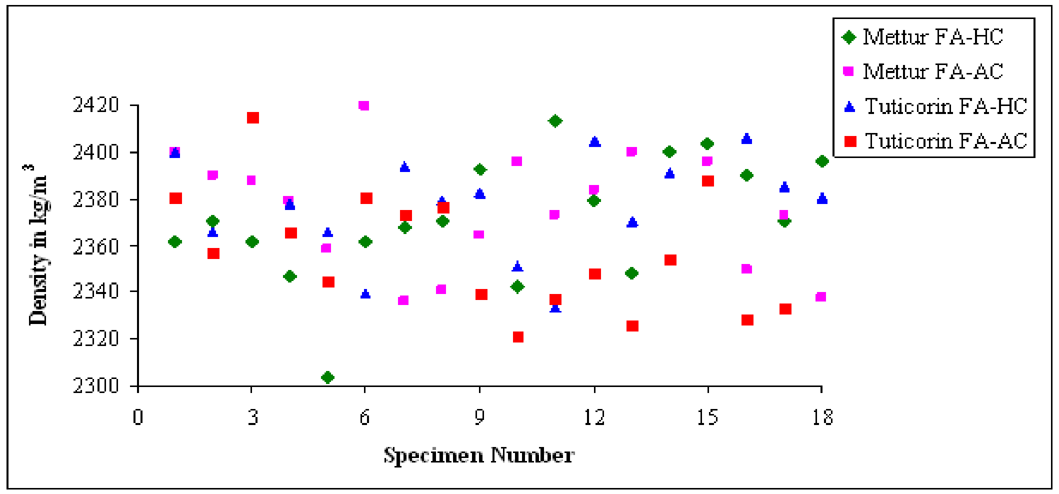

Fig. 1 Density of Geopolymer concrete

pressive strength of geopolymer concrete using Mettur fly ash is more than the compressive strength of concrete made using Tuticorin fly ash for both 7 and 28 days. In heat curing, the difference in compressive strength of Geopolymer concrete using Mettur fly ash and Tuticorin fly ash is not significant. Due to increase in the concentration of NaOH, compressive strength of geopolymer concrete increases for both the sources of fly ash. In ambient curing, the 28 days compressive strength is about 2.8 to 4.6 times of 7 days compressive strength but in heat curing it is only about 1.2 to 1.4 times which reveals that the rate of gain in compressive strength after 7 days in heat curing is less than that of ambient curing. Similarly in 7 days the heat cured compressive strength is 2.51 to 5.04 times ambient cured compressive strength but in 28 days the heat cured compressive strength ranges about 1.08 to 1.57 times ambient cured compressive strength which shows that heat curing results only in compressive strength development at early ages.

Split Tensile Strength

The split tensile strength of geopolymer concrete made using two sources of fly ash is presented in Figure 4 and Figure 5. The split tensile strength of geopolymer concrete using mettur fly ash is more than the split tensile strength of concrete made using tuticorin fly ash in most of the cases. Due to increase in the concentration of NaOH, split tensile strength of geopolymer concrete increases for both the sources of fly ash. In ambient curing, the 28 days split tensile strength is about 3.5 to 6.8 times of 7 days split tensile strength but in heat curing it is only about 1.05 to 1.7 times which reveals that the rate of gain in split tensile strength after 7 days in heat curing is less than that of ambient curing. Similarly in 7 days the heat cured split tensile strength is 4.04 to 6.25 times ambient cured split tensile strength but in 28 days the heat cured split tensile strength ranges about 1.1 to 2.1times ambient cured split tensile strength which shows that heat curing results only in split tensile strength development at early ages. In this study, the split tensile strength of geopolymer concrete is assumed to be proportional to the square root of their compressive strength. From regression analysis as shown in Figure 6, a relationship between the splitting tensile and compressive strength of geopolymer concrete for all the parameters of study has been derived and it is given in equation 1.

$$f_{st} = 0.25\sqrt{f_{ck}} \quad (1)$$

Flexural Strength

The Flexural strength of geopolymer concrete made using two sources of fly ash is presented in Figure 7. The flexural strength of geopolymer concrete using mettur fly ash is more than the flexural strength of concrete made using tuticorin fly ash. Due to increase in the concentration of NaOH, flexural strength of geopolymer concrete increases for both the sources of fly ash. For mettur flyash, the flexural strength of geopolymer concrete increased by 8% to 27% due to heat curing. Similarly for tuticorin flyash, flexural strength of geopolymer concrete increased by 12% to 29% due to heat curing. In this study, the flexural strength of geopolymer concrete is assumed to be proportional to the square root of their compressive strength. From regression analysis as shown in Figure 8, a relationship between the flexural and compressive strength of geopolymer concrete for all the parameters of study has been derived and it is given in equation 2.

$$f_b = 1.08\sqrt{f_{ck}} \quad (2)$$

CONCLUSION

The compressive, split tensile and flexural strength of geopolymer concrete using mettur flyash is greater than that of geopolymer concrete using tuticorin flyash in most of the cases. The increase in the concentration of NaOH in the alkaline activator results in increase in compressive, split tensile and flexural strength of geopolymer concrete. The compressive, split tensile and flexural strength of heat cured geopolymer concrete is much higher than that of ambient cured geopolymer concrete. In ambient curing, the strength increases as the age of concrete increases from 7 days to 28 days. The strength of heat cured geopolymer concrete does not increase substantially after 7 days. The average density of fly ash based geopolymer concrete is similar to that of OPC concrete.

NOMENCLATURE

Fck - Compressive strength of geopolymer concrete
Fst - Split tensile strength of geopolymer concrete
Fb - Flexural strength of geopolymer concrete
AC - Ambient Curing
HC - Heat Curing
FA - Fly Ash

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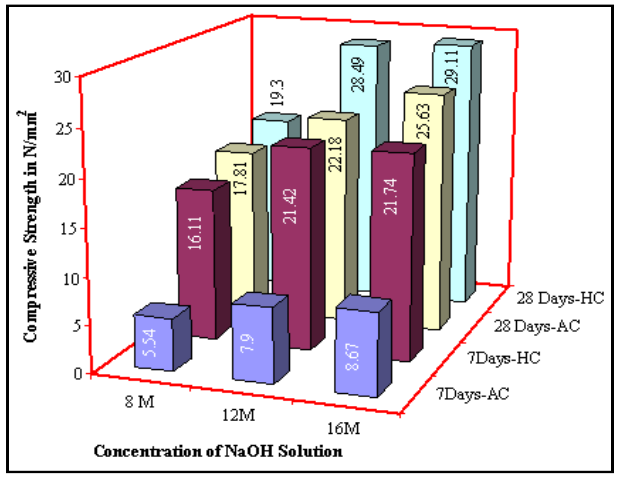

Fig. 2 Compressive strength of Mettur Fly ash based Geopolymer Concrete

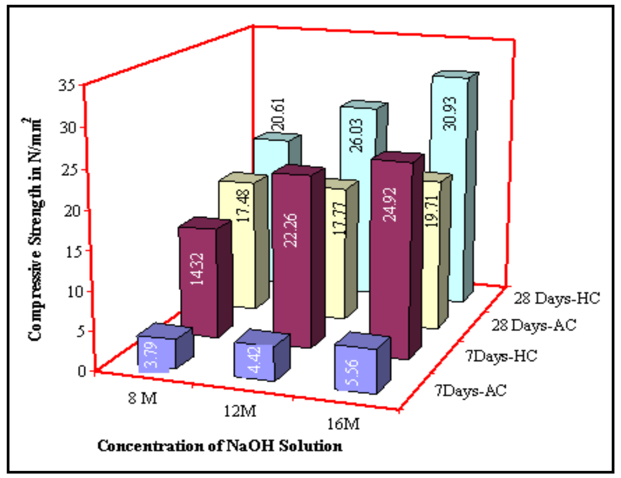

Fig. 3 Compressive strength of Tuticorin Fly ash based Geopolymer Concrete

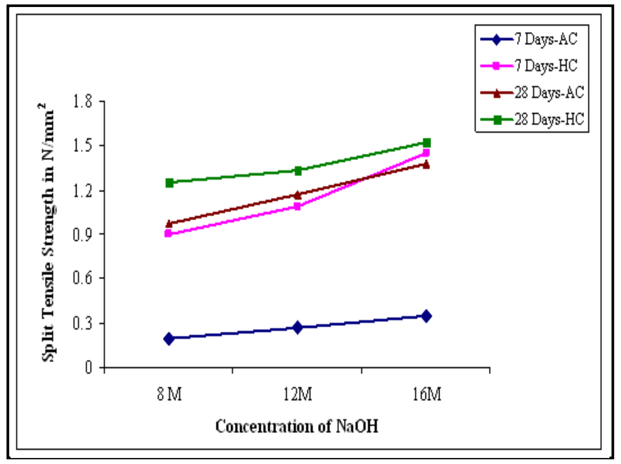

Fig. 4 Split tensile strength of Mettur Fly ash based Geopolymer Concrete

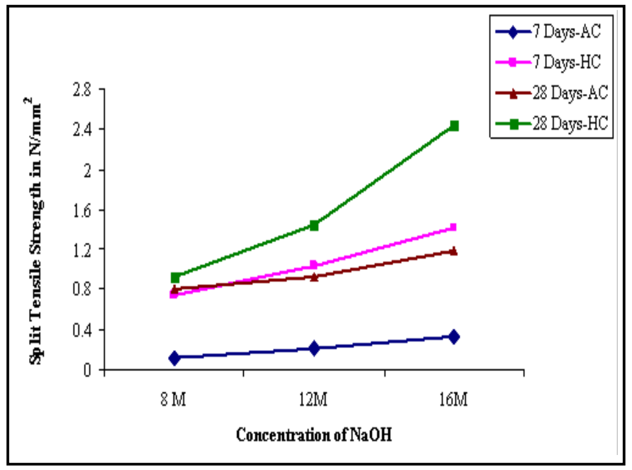

Fig. 5 Split tensile strength of Tuticorin Fly ash based Geopolymer Concrete

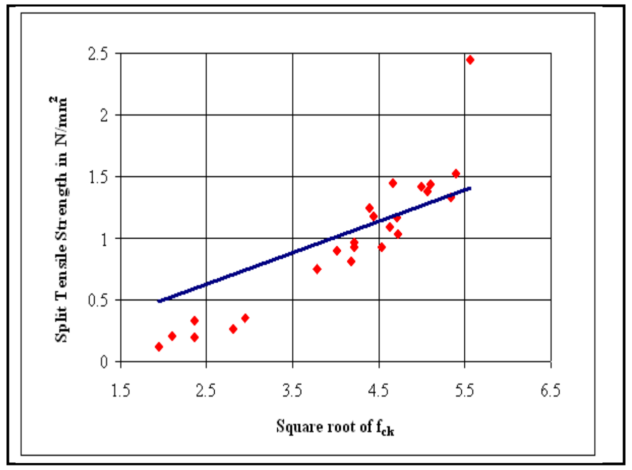

Fig. 6 Split tensile strength Versus Square root of Compressive Strength

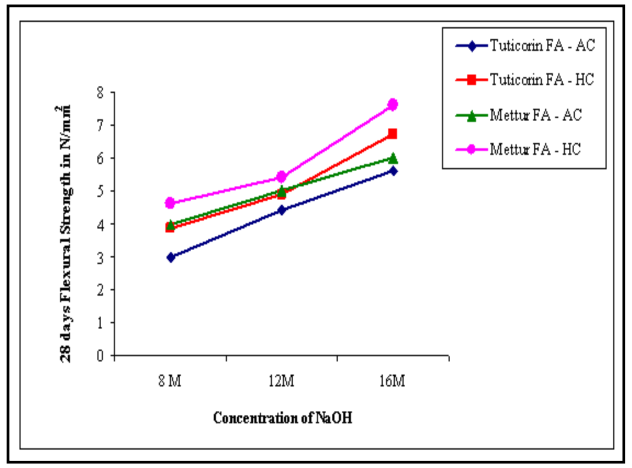

Fig. 7 Flexural strength of Geopolymer Concrete

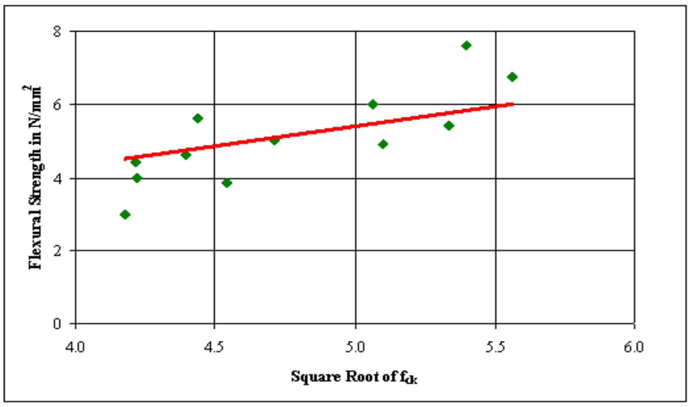

Fig. 8 Flexural strength Versus Square root of Compressive Strength

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