Performance of Geopolymer Concrete with Polypropylene Fibres

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Abstract- The purpose of this paper is to bring out the advantageous results of geopolymer concrete with polypropylene fibre. The geopolymer concrete mix with polypropylene fibres were prepared and the cylinders were heat cured in laboratory oven. Slump tests and compressive tests were done. Better workability and increase in compressive strength were noticed. Durability tests were conducted for sulphate and sulphuric acid resistance and the cylinders were durable to chemical environment. The work has been extended to the structural members like slab, beam, column and its behavior was studied.

Keywords – geopolymer concrete, polypropylene fibres.

I. INTRODUCTION

Geopolymers are formed when alumino silicates such as fly ash dissolve in strong alkaline solution, reorganize and precipitate in a hardened stage. The chemical reaction takes place in this case is a "GEOPOLYMER" represents this binder. Polypropylene fibres were added during mixing of the constituents to enhance the strength of matrix bonding.

Geopolymers are members of the family in inorganic polymers. The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, those results in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds (Davidovits, 1994).

II. LITERATUTE REVIEW

The study of the microstructure and the chemistry of hydration of the Portland cement, main hydraulic binder since the 19th century, have led to the development of novel cements with environmental sustainability (Moranville-Regourd, 1999; Roy, 1994; Roy, 1991). Cement has been partially replaced by active nano powders or supplementary cementing materials, such as ground granulated blast furnace slag (GBFS), silica fume (SF), rice husk ash (RHA), meta kaolin (MK) or fly ash (FA). These are examples of those new binders and constitute a significant contribution to the eco-efficiency of the global economy (Moranville- Regourd, 1999; Roy, 2003; Tailing, 1997; Van Loo, 2003). Other materials are those called the chemically bonded ceramics (CBC), the macro defect free cements (MDF) and the densified systems which contain homogeneously arranged ultrafine particles (DSP) (Moranville-Regourd, 1999; Roy, 1991; Roy, 1994). These new binders, which are alternative materials to traditional and blended cements and concretes, are obtained by the alkaline activation or geopolymerization of different industrial by-products (blast furnace slag and/or fly ashes). The provision of new types of cements is an ongoing research topic for the scientific community (Glukhovsky, 1983; Puertas, 1995; Roy, 1992; Shi, 2000; Wang, 1995b).

In this respect, the geopolymer technology proposed by Davidovits (1988) shows considerable promise for application in concrete industry as an alternative binder to the Portland cement (Duxsonet al, 2007). In terms of global warming, the geopolymer technology could significantly reduce the CO_2 emission to the atmosphere caused by the cement industries as shown by the detailed analyses of Gatner (2004).

In this project, attempts are made in order to increase the strength of geopolymer concrete. The use of polypropylene material increased the strength of the material through the matrix bonding between the materials.

III. CONSTITUENTS OF FIBRE GEOPOLYMER CONCRETE

Fibre geopolymer concrete was manufactured by using the low-calcium fly ash obtained from Thermal Power Plant. Polypropylene fibres were obtained from Reliance Industries. Coarse and fine aggregates used by the concrete industry are suitable to manufacture Fibre geopolymer concrete. The aggregate grading curves currently used in concrete practice are applicable in the case of Fibre geopolymer concrete.

A combination of sodium silicate solution and sodium hydroxide (NaOH) solution can be used as the alkaline liquid. It is recommended that the alkaline liquid is prepared by mixing both the solutions together at least 24 hours prior to use.

The Quantity of materials required for preparation of 1m^3 of Fibre Geopolymer concrete mixture is as follows:

Table 1: The quantity of materials required for the preparation of an m^3 of concrete using fly ash

MATERIALS	**For 1 m^3**
Fly ash	**408 Kg**
Polypropylene Fibre (Recron 3S)	**0.9 Kg**
Fine aggregate	**554 Kg**
Coarse aggregate	**1294 Kg**
Sodium silicate solution	**103 Kg**
Sodium hydroxide solution (8 Molar)	**41 Kg**
Super plasticizer	**6 Kg**
Extra water	**None**

The sodium silicate solution is commercially available in different grades. The sodium silicate solution with SiO_2 to Na_2O ratio by mass of approximately 2 i.e., SiO_2 – 29.4%, Na_2O – 14.7%, and water – 55.9% by mass, is recommended.

The sodium hydroxide with 97- 98% purity, in flake or pellet form is commercially available. The solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in the range between 8 molar and 16 molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 8 molar consists of 8 x 40=320 grams of NaOH solids per liter of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 262 grams per kg of NaOH solution with a concentration of 8 molar (Hardjito and Rangan, 2005), note that the mass of water is the major component in both the alkaline solutions.

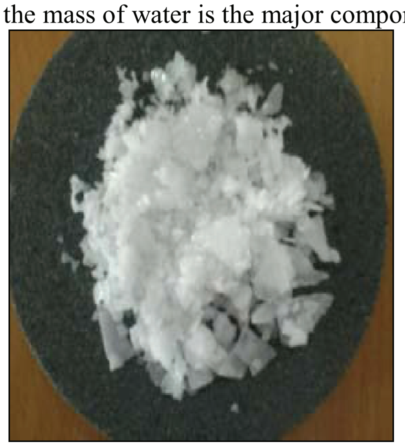

Figure 1: sodium hydroxide crystal

In order to improve the workability, a high range of water reducer super plasticizer and extra water may be added to the mixture.

A. Fly Ash –

- The fly ash was obtained from Tuticorin Thermal Power Station, Tamil Nadu, India.
- The reaction of fly ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.
- The specific gravity, fineness modulus, specific surface area and density of fly ash are 2.82, 1.375, 310 m^2/kg and 1.4 kg/ m^3 respectively.
- The properties of the fly ash used for the preparation of geopolymer concrete are given below.

Table 2: The fly ash sample sent to The Regional testing Laboratory, Madurai and the results were obtained as follows.

Sl. No.	CHARACTERISTICS	RESULTS
1	**Silicon di oxide (as SiO2) plus Aluminium Oxide (Al2O3) plus Iron Oxide (as Fe2O3), % by mass**	**85.94**
2	**Silica (as SiO2) % by mass**	**60.21**
3	**Magnesium oxide (as MgO), % by mass**	**1.99**
4	**Total Sulphur as Sulphur tri oxide (SO3), % by mass**	**2.19**
5	**Available alkali as Sodium oxide (Na2O), % by mass**	**0.39**
6	**Loss on Ignition, % by mass**	**2.05**
7	**Moisture content, % by mass**	**0.28**
8	**Calcium content (as CaO), % by mass**	**1.94**

B. Fibres –

The Fibres are polymeric synthetic Fibres (Recron 3S) within the following range of specifications:

- Effective diameter : 10 micron – 1.0 mm.
- Length : 6-48 mm.
- Specific gravity : more than 1.0.
- Suggested dosage : 0.6-2.0 kg/cumec (0.23-0.6 % by Weight of cement in mix). Usage will be regulated as stipulated in IRC- 44/456 or any other specialist literature.
- Water absorption : less than 0.45 percent.
- Melting point of this Fibre shall not be less than 160˚C.
- The aspect ratio generally varies from 200 to 2000.
- These synthetic Fibres will have good alkali and UV light resistance.

Figure 2: polypropylene fibre (recron 3s)

IV. MIXTURE PROPORTIONS OF FIBRE GEOPOLYMER CONCRETE

The primary difference between Fibre geopolymer concrete and Portland cement concrete is the binder. The silicon and aluminum oxides in the low-calcium fly ash reacts with the alkaline liquid to form the geopolymer paste that binds the loose coarse aggregates, fine aggregates, fibres and other un-reacted materials together to form the Fibre geopolymer concrete.

As in the case of Portland cement concrete, the coarse and fine aggregate occupy about 75 to 80% of the mass of Fibre geopolymer concrete. This component of Fibre geopolymer concrete mixtures can be designed using the tools currently available for Portland cement concrete.

The compressive strength and the workability of Fibre geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the Fibre geopolymer paste. Experimental results have shown the following:

- Higher concentration (in terms of molar) of sodium hydroxide solution and Fibre polypropylene results in higher compressive strength of Fibre geopolymer concrete.
- Higher the ratio of sodium silicate solution-to-sodium hydroxide solution ratio by mass, higher is the compressive strength of Fibre geopolymer concrete.
- The addition of naphthalene sulphonate-based super plasticizer, up to approximately 4% of fly ash by mass improves the workability of Fibre geopolymer concrete; however, there is a slight degradation in the compressive strength of hardened concrete when the super plasticizer dosage is greater than 2%.
- As the H_2O-to-Na_2O molar ratio increases, the compressive strength of Fibre geopolymer concrete decreases.
- The compressive strength of the concrete mix increased as a result of the addition of polypropylene Fibre material.

As can be seen from the above, the interaction of various parameters on the compressive strength and the workability of Fibre geopolymer concrete is a complex. In order to assist the design of low-calcium fly ash-based Fibre geopolymer concrete mixtures, a single parameter called water-to-Fibre geopolymer solids ratio by mass was devised. In this parameter, the total mass of water is the sum of the masses of water contained in the sodium silicate solution, the mass of water in the sodium hydroxide solution, and the mass of extra water if any, added to the mixture. The mass of Fibre geopolymer solids is the sum of the mass of fly ash, the mass of sodium hydroxide solids and the mass of the solids in the sodium silicate solution (i.e., the mass of Na_2O and SiO_2). Tests were performed to establish the effect of water-to-Fibre geopolymer solids ratio by mass on the compressive strength and the workability of Fibre geopolymer concrete. The test specimens were 150x300 mm cylinders, heat-cured in an oven at 64°C for 36 hours. This trend is ana logous to the well-known effect of water-to-cement ratio on the compressive strength of Portland cement concrete.

V. MIXING, CASTING, AND COMPACTION OF FIBRE GEOPOLYMER CONCRETE

Fibre geopolymer concrete was manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, initially the Fibre material is mixed with the fly ash. The aggregates were prepared in saturated-surface-dry (SSD) condition, and were kept in separate. The aggregates were first mixed together dry in 80-litre capacity mixer machine for about 5 minutes. The alkaline liquid was mixed with the super plasticizer. The liquid component of the mixture was then added to the dry materials and the mixing continued usually for another 10 minutes. The fresh concrete could be handled up to 30 minutes without any sign of setting. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete. Fresh fly ash-based Fibre geopolymer concrete was usually cohesive. The workability of the fresh concrete was measured by means of the conventional slump test. The compressive strength of Fibre geopolymer concrete is influenced by the wet-mixing time, as illustrated by the test data plotted.

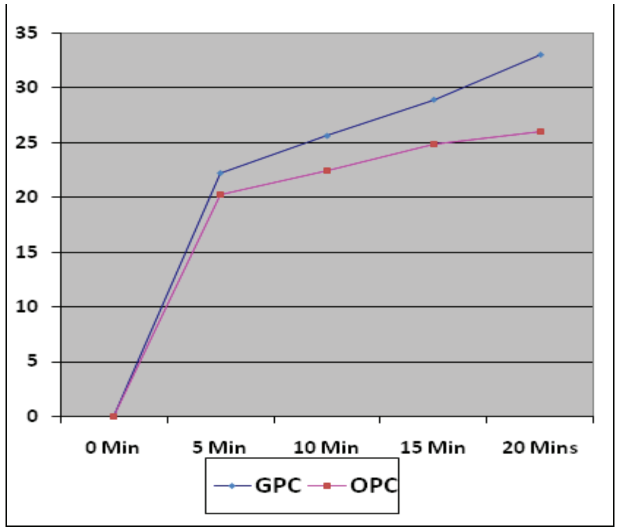

Figure 3: effect of wet-mixing time on compressive strength of fibre geopolymer concrete
GPC- geopolymer concrete, OPC-ordinary Portland cement concrete

VI. CURING OF FIBRE GEOPOLYMER CONCRETE

Heat-curing of low-calcium fly ash-based Fibre geopolymer concrete is generally recommended. Heat-curing substantially assist the chemical reaction that occurs in the Fibre geopolymer paste.

Heat curing time and heat curing temperature influence the compressive strength of Fibre geopolymer concrete. The effect of curing time is illustrated in Fig. The test specimens were 150x300mm cylinders heat-cured at 64˚C in an oven. The curing time period was 36 hours and the temperature was kept at a constant rate of 64̊C. The heat curing improved the polymerization process resulting in higher compressive strength.

Figure 4: heat curing of fibre geopolymer concrete cylindrical specimen.

VII COMPRESSIVE STRENGTH OF FIBRE GEOPOLYMER CONCRETE

The test specimen were 150 x300 mm cylinders, heat cured at 64̊C for 36 hours and tested in compres sion at an age of 14 and 28 days. The slump values of fresh concrete were also measured.

Numerous batches of Fibre geopolymer concrete mixture have been manufactured and tested in the laboratory over a period of two years. These test results have shown that the mean 7th day compressive strength was 28 MPa. The mean slump of the fresh Fibre geopolymer concrete was about 110mm.

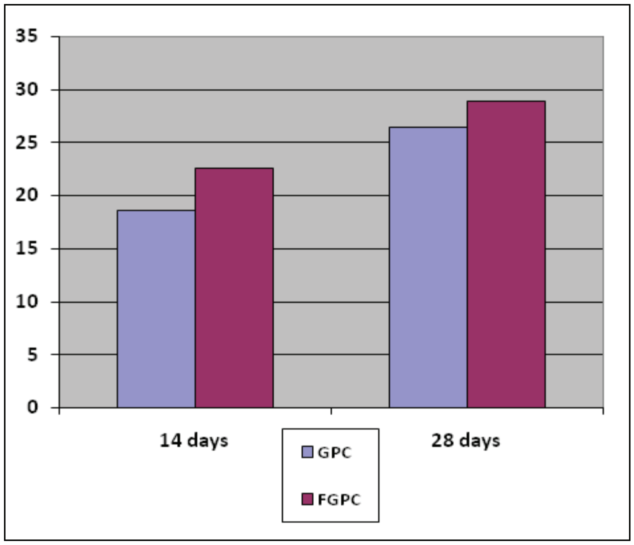

Figure 5:compressive strength comparision geopolymer concrete(gpc) and fibre geopolymer concrete(fgpc)

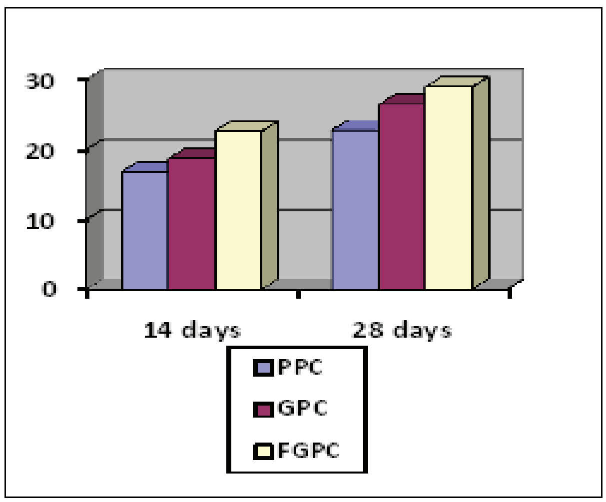

Figure 6: compressive strength comparision between portland pozzalona cement concrete(ppc), geopolymer concrete(gpc) and fibre geopolymer concrete(fgpc).

Figure 7: fibre geopolymer concrete specimens after failure

VIII. DURABILITY ANALYSIS FOR FIBRE GEOPOLYMER CONCRETE

A. Sulfate resistance –

Tests were performed to study the sulfate resistance of heat cured low calcium fly ash based Fibre geopolymer concrete. The test specimens were made using mixture and heat cured at 64'C for 36 hours after casting. They were immersed in 5% sodium sulfate solution for various periods of exposure up to one year. The sulfate resistance was evaluated based on the change in mass change in length and change in compressive strength of the specimens after sulfate exposure.

The results showed that heat cured low calcium fly ash based Fibre geopolymer concrete has an excellent resistance to sulfate attack. There was no damage to the surface of test specimens after exposure to sodium sulfate solution up to one year. The visual appearance of the test specimens after soaking in sodium sulfate solution up to one year revealed that there was no change in the appearance of the specimens compared to the condition before they were exposed. There was no sign of surface erosion. Cracking or spalling on the specimen. The specimens soaked in normal water also showed no change in the visual appearance. There were no significant changes in the mass and the compressive strength of test specimens after various periods of exposure up to one year. The change in length was extremely small and less than 0.015%.

B. Sulfuric Acid resistance –

Tests were performed to study the sulfate acid resistance of heat cured low calcium fly ash based Fibre geopolymer concrete. The concentration of sulfuric acid solution was 2%, 1% and 0.5%. The sulfuric acid resistance of Fibre geopolymer concrete was evaluated based on the mass loss and the residual compressive strength of the test specimens after acid exposure up to one year. The test specimen's 150 x 300mm cylinders were made using mixture and heat cured at 60'C for 24 hours after casing.

The visual appearance of specimen after exposure to sulfuric acid solution showed that acid attack slightly damaged the surface of the specimens. Compare the visual appearance of the Fibre geopolymer concrete specimens after soaking in various concentration of sulfuric acid solution for a period of one year with the specimen without acid exposure and left in ambient condition of the laboratory. It can be seen that the specimens exposed to sulfuric acid undergoes erosion of the surface the damage to the surface of the specimens increased as the concentration of the acid solution increased.

Figure 8: visual appearance heat cured fibre geopolymer concrete specimen after one month of exposure

IX. SUMMARY

Advantages of Fibre Geopolymer concrete:

- The Fly ash is an easily available material.
- Compared to cement it is of low capital cost.
- The chemical compounds used are easily available in the local market.
- The Fibre geopolymer concrete is a green concrete since there is no CO_2 emission.

X. CONCLUSION

The report presented information on heat cured fly ash based Fibre geopolymer concrete. Low calcium fly ash (ASTM class F) is used as the source material instead of the Portland cement to make concrete.

Low calcium fly ash based Fibre geopolymer concrete has excellent compressive strength and is suitable for structural applications. The salient factors that influence the properties of the fresh concrete and the hardened concrete have been identified.

The elastic properties of hardened Fibre geopolymer concrete and the behavior and the strength of Fibre geopolymer concrete structural members are similar to those observed in the case of Portland cement concrete. Therefore the design provisions contained in the cement standards and codes can be used to design reinforced low calcium fly ash based Fibre geopolymer concrete structural members.

Heat cured low calcium fly ash based Fibre geopolymer concrete also shows excellent resistance to sulfate attack, good acid resistance. Undergoes low creep and suffers very little drying shrinkage. The report has identified several economic benefits of using Fibre geopolymer concrete.

Innovations in engineering design and construction, which often call for new building materials, have made polypropylene Fibre-reinforced concrete applications. In the past several years, an increasing number of constructions have been taken place with concrete containing polypropylene fibres such as foundation piles, prestressed piles, piers, highways, industrial floors, bridge decks, facing panels, flotation units for walkways, heavyweight coatings for underwater pipe etc. This has also been used for controlling shrinkage & temperature cracking.

Due to enhance performances and effective cost-benefit ratio, the use of polypropylene Fibres is often recommended for concrete structures recently. The same advantage can be extended to Fibre geopolymer concrete also. The possibility of increased tensile strength and impact resistance offers potential reductions in the weight and thickness of structural components and should also reduce the damage resulting from shipping and handling.

The work can be further extended to slabs, beams, columns and its behavior will be discussed in future.

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