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A Literature Review on Fiber Reinforced Geopolymer Concrete

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Abstract— As the infrastructure development growing worldwide, the demand for Ordinary Portland Cement (OPC) increases exponentially. Studies revealed that the production of one ton cement releases around one ton of CO_2 to the atmosphere due to the calcinations of lime stone and combustion of fossil fuel. The production of cement is highly energy intensive and it consumes a substantial amount of natural resources. Davidovits (1978) proposed that binders can be produced by polymeric reaction of alkaline liquid with alumino-silicate materials such as fly ash, blast furnace slag, rice husk ash etc. Geopolymer also has the ability to form a strong chemical bond with rock based aggregates. Fiber reinforced geopolymer concrete is relatively a new composite material in which fibers are introduced in the matrix as micro reinforcement to improve the strength properties. This paper presents a review on various research works done in the area of geopolymer concrete and the effect of fiber on their mechanical properties.

Index Terms — Alumino-Silicate mateial, Fly ash, Geopolymer concrete, Glass fiber, Micro reinforcement, OPC, Polypropylene fiber (PP).

1 INTRODUCTION

The demand for concrete as a construction material increases exponentially and thereby, there is an increase in the demand for the production of OPC. The environmental issues associated with the production of cement are well known. The production of one ton cement releases around one ton of carbon dioxide to the atmosphere due to the calcinations of lime stone and combustion of fossil fuel and causes the global warming condition [12]. In addition, the production of cement is highly energy intensive and it consumes a large amount of natural resources.

To reduce these problems, it is necessary to find out an alternative material for cement. Many researches were carried out to find a replacement for cement. Partial replacement and high volume replacement of OPC with materials having binding property were studied [10], [11]. In 1978, Davidovits proposed that binders can be produced by polymeric reaction of alkaline liquid with alumino-silicate materials such as fly ash, rice husk ash, blast furnace slag etc and termed these binders as Geopolymers. Geopolymers can be considered as a green material, because it relies on minimally processed natural materials or industrial byproducts, thus reducing its carbon foot print. Geopolymers have gained considerable attention for their rapid strength attainment, corrosion resistance, chemical stability, low rate of shrinkage and freeze thaw resistance.

The existing Portland cement standards are not adopted for mix design of geopolymer concrete, presently the findings based on different experimental investigations on geopolymer concrete have been considered as reference. To produce geopolymer concrete of desired strength, various mix proportioning by trial and error methods are being used on the basis of type of work, availability and properties of materials, field conditions and also workability and durability requirements.

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Even though the geopolymers possess many advantages over OPC, they also show tension failure behavior similar to that of OPC [12], [13], [17]. Incorporation of fibers in concrete has been found to improve several properties of concrete like cracking resistance, ductility and fatigue resistance, impact and wear resistance [5], [12], [16].

2 GEOPOLYMER CONCRETE

The term geopolymer was coined by Davidovits to represent a broad range of materials characterized by chains or networks of inorganic molecules. The schematic representation of geopolymer concrete is shown in Fig. 1 as described by equations (A) and (B).

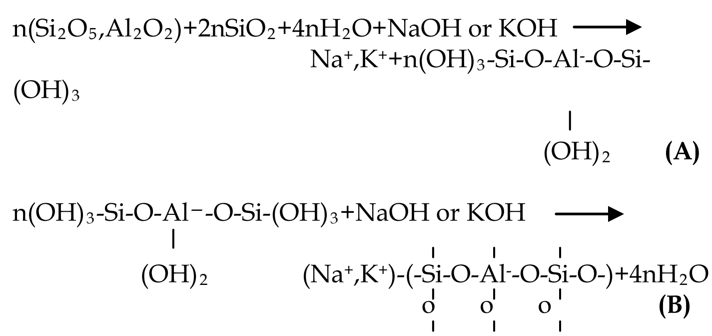

Figure 1. Schematic Formation of geopolymer concrete [1]

These geopolymer materials represent an innovative technology generating considerable interest in the construction industry, particularly in light of the ongoing emphasis on sustainability. In contrast to OPC, the geopolymer system consumes minimum natural materials or industrial byproducts to act as the binding agent. One ton of low calcium fly ash can be utilized to manufacture around $3m^3$ of high quality fly ash based geopolymer concrete, and hence earn benefits through carbon-credit trade [11].

There are two main constituents of geopolymers, namely the base material and the alkaline liquids. The base material for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al). These could be natural minerals such as kaolinite, clays, etc. Alternatively, byproduct materials such as fly ash, silica fume, slag, rice-husk ash, red mud, etc could be used as base material. The choice of the base material for making geopolymers depends on factors such as availability, cost, type of application, and specific demand of the end users. Zeng s et al. [18] showed that similar chemical composition in the base material did not produce similar compressive strength and high content of calcium did not always lead to high compressive strength. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based. The most common alkaline liquid used in geopolymerization is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate [10]. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds viz;

$Mn [-(SiO_2) z–AlO_2] n. wH_2O$

where M is a monovalent cation such as potassium or Sodium, the symbol '–' indicates the presence of a bond, n is the degree of polycondensation or polymerization and z is 1, 2,3 or higher [1].

The electrical resistance of fresh geopolymers remains unchanged in the first two hours of the delay time which was suggested as the introduction period of geopolymerization and major portion of geopolymerization gets over within a period of 24h [18]. Similar to hydration in Portland cement, the geopolymerization of fly ash based geopolymer may take longer period because of the slow diffusion of reactive ions from the fly ash after fast reaction period at the early age. Slow geopolymerization process can consume free ions and reduce porosity in the geopolymer specimens [18].

The chemical reaction comprises the following steps [23]:

- Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- Orientation or condensation of precursor ions into monomers.
- Setting or polycondensation or polymerization of monomers into polymeric structures.

3 MIX DESIGN

The primary difference between the geopolymer concrete and the Portland cement concrete is the binder. The silicon and aluminium 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 and other unreacted materials together to form the geopolymer concrete.

To produce geopolymer concrete of desired strength, various mix proportioning methods were used on the basis of nature of work, type, availability and properties of material, field conditions and workability and durability requirements. Rangan et al. [11] proposed the mix design procedure for production of fly ash based geopolymer concrete whereas Anuradha et al. [4] had presented modified guidelines for mix design of geopolymer concrete using Indian standard code (IS 10262-2009).

As in the case of normal concrete, the coarse and fine aggregates occupy about 75 to 80% of the mass of geopolymer concrete. The influence of aggregates, such as grading, angularity and strength are considered to be the same as in the case of normal concrete [11].

Studies carried out on fly ash-based geopolymer concrete showed that the compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Abhishek et al. and Patankar et al.[2], [21] proposed the guidelines for the design of fly ash based geopolymer concrete of ordinary and standard grade on the basis of quantity and fineness of fly ash, quantity of water and grading of fine aggregate by maintaining water- to-geopolymer binder ratio of 0.40, solution-to-fly ash ratio of 0.35 and sodium silicate-to-sodium hydroxide ratio of 2 with concentration of sodium hydroxide as 13 M. Heat curing was done at 60 °C for duration of 24 h and tested after 7 days after oven heating. Experimental results of geopolymer concrete mixes equivalent to M20, M25, M30, M35 and M40 grades showed promising results of workability and compressive strength. Research results have shown the following [21]:

- Higher fineness of fly ash results in higher strength and workability with early duration of heating.
- Compressive strength increases with increase in concentration of sodium hydroxide solution and or sodium silicate solution with increased viscosity of fresh mix.
- Compressive strength reduces with increase in water to geopolymer binder ratio.
- As solution to fly ash ratio increases, strength is also increases but the rate of gain of strength is not much significant beyond solution to fly ash ratio of 0.35.

4 FIBER REINFORCED GEOPOLYMER CONCRETE

Incorporation of fiber into the cementitiuos matrix can enhance the flexural properties and control the crack propagation and widening under different types of mechanical loading or shrinkage [14]. Fibers of different materials and geometric properties are used in construction applications. The compressive strength and workability of fiber reinforced geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the composite [20]. Ilamvazhuthi et al. studied mainly on the effects of polypropylene (PP) and glass fiber on the mechanical properties of geopolymer concrete. PP fibers have gained popularity in recent years for use in concrete, mainly owing to their low price and excellent characteristics in improving tensile strength, flexural strength and crack resistance [12]. Since the surface of PP fiber is hydrophobic, it will not be affected by wet geopolymer matrix and this helps to prevent chopped fibers from balling effect during mixing. Alkali resistant glass fiber reinforcement is relatively a new addition to the family of fibers and are available in continuous or chopped lengths. They impart high tensile strength, high stiffness, high chemical resistance and con-

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siderable durability to fiber reinforced concrete [19].

Eswaramoorthi et al. and Venugopal et al. [7], [22] conducted an experimental study on the effects of polypropylene fiber on low calcium fly ash based geopolymer concrete. Compressive strength test, split tensile strength test and load deflection test were carried out. They compared the results of geopolymer concretes with polypropylene fiber and without polypropylene fiber. Subbiah et al. [20] investigated strength properties of geopolymer concrete with polypropylene fiber by mixing polypropylene fibers in geopolymer concrete and the cylinder samples were heat cured in laboratory oven. Slump tests and compressive tests were conducted the results showed better workability and increase in compressive strength. Durability tests were conducted for sulphate and sulphuric acid resistance and the cylinders were resistant to chemical environment. Patil et al. [16] had done an experimental program to determine mechanical properties of polypropylene fiber reinforced geopolymer concrete. The effects of inclusion of polypropylene fibers on compressive strength, split tensile strength and flexural strength of hardened geopolymer concrete composite were studied. Polypropylene fibers were added to the mix in two different lengths of 12mm and 20mm and also the hybridization of both polypropylene fibers was mixed in volume of concrete. Based on the test results, it was observed that the polypropylene fiber reinforced geopolymer concrete had relatively higher strength than GPC & OPC concrete. Reed et al. [12] investigated the effects of polypropylene fibers in geopolymer concrete using 0.05 and 0.15 % fibers (by weight) under ambient curing. Compressive strength and ductility were analyzed. Ranjbar et al. [14] evaluated the effects of wettability, chemical characterization and nanometric roughness of polypropylene and micro steel fibers, on fly ash based geopolymer binder. The fiber incorporation in geopolymer matrix was performed by 0.5, 1, 2, 3 and 4% of the total volume of each type of fibers. Nisha et al [15] studied the effect of combination of steel fiber and polypropylene fiber on the strength properties of geopolymer concrete under ambient curing.

Sathish et al. [17] did experimental research to determine the mechanical properties of geopolymer concrete composites with glass fibers. Glass fibers were added to the mix in 0.01%, 0.02% and 0.03% by volume of concrete. Based on the test results, it was observed that the Geopolymer concrete composites have relatively higher strength in short curing time (one day) than the geopolymer concrete and ordinary Portland cement concrete. Balachandra et al. [5] investigated experimental by the mechanical properties of glass fiber reinforced geopolymer concrete. Glass fibers were added to the mix in 0.01%, 0.02%, 0.03% & 0.04% by volume of concrete. Based on the test results it was observed that the glass fibers reinforced geopolymer concrete have relatively higher strength in short curing time (3 days) than geopolymer concrete & Ordinary Portland cement concrete. Vijay et al. [24] investigated the impact of glass fibers on the mechanical properties of hardened GPC both in ambient curing and in heat curing at 60°C for 24 in hot air oven. Glass fibers were added in the volume fractions of 0.01%, 0.02% and 0.03% volume of concrete. It was observed that addition of 0.03% volume fraction of glass fiber in geopolymer concrete composites enhanced its mechanical properties.

5 COMPARISION OF RESULTS

The strength parameters obtained in various research works are presented in Table I and Table II.

TABLE I.
COMPARISON OF STRENGTH PARAMETERS OF GPC WITH POLYPROPYLENE FIBER

Author	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	Without fiber	With fiber	Without fiber	With fiber	Without fiber	With fiber
Eswaramoorthi et al. [7]	35.6	38.6	3.94	5.28	No result	No result
Patil et al. [16]	35.88	38.72	3.65	4.05	10.28	12.10
Subbiah et al. [20]	26	29	No result	No result	No result	No result
Venugopal et al. [22]	25.03	26.43	3.93	4.37	3.52	4.06

TABLE II.
COMPARISON OF STRENGTH PARAMETERS OF GPC WITH GLASS FIBER

Author	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	With out fiber	With fiber	Without fiber	With fiber	Without fiber	With fiber
Sathish et al. [17]	28.74	24.26	1.93	2.5	No result	No result
Vijay et al. [24]	35.88	38.72	3.02	1.83	5.4	5.31
Balachandra et al. [5]	36.33	43.67	No result	No result	4	5.96

The results obtained from various studies showed that the polypropylene and glass fiber have significant effect on the compression, split tensile and flexural strength. The incorporation of fibers not always resulted in an increase in the strength parameter

6 CONCLUSION

In this paper, review of various investigations on geopolymer concrete and fiber reinforced geopolymer concrete is presented. A detailed review revealed that:

- The mix proportion of geopolymer concrete depends up on fineness of fly ash, grading of fine aggregate, concentration of the alkaline liquid, ratio between the alkaline liquids, ratio between the fly ash and alkaline liquid.

- The tensile strength parameters improved by the incorporation of polypropylene and glass fiber.
- Compressive strength, split tensile strength and flexural strength was found to be more for addition of 0.03% glass fiber by volume of concrete.
- Some technical studies showed a result of increase in compressive strength [7] by the incorporation of polypropylene fiber while some other showed a decrease in compressive strength due to the hydrophobic characteristics of polypropylene fiber [14].

A study on the effect of polypropylene fiber on the compressive strength is in progress by the authors along with experimental investigations on the strength parameters of low calcium fly ash based geopolymer concrete with the addition of a combination of polypropylene fiber and glass fiber.

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