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A Literature Review on Fiber Reinforced Geopolymer Concrete – Glass and Steel Fibers

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Abstract **:- The production of Ordinary Portland Cement requires large amount of energy consumption, also leading to an enormous emission of carbon di-oxide to the atmosphere, which is being a great challenge to the sustainable development. Efforts are needed to develop an environmental friendly civil engineering construction material for minimizing emission of green-house gases to the atmosphere. A review summary of the extensive literature survey conducted to know about one such environmental friendly concrete named geopolymer concrete is presented in this paper. It is found to be an excellent alternative construction material to the concrete produced using Ordinary Portland Cement. This paper briefly reviews the constituents of geopolymer concrete, its strength and potential applications. The Cement is totally replaced by the pozzolanic material that is rich in Silicon and Aluminum like fly ash referred to as "Geopolymer concrete" which is a contemporary material. Geopolymer concrete is manufactured by reusing and recycling of byproducts obtained worldwide from Thermal Plant known as Fly Ash and use of alkaline activators (NaOH and Na_2SiO_3). Use of these ingredients in concrete enhances the properties of concrete. Utilization of fly ash is helpful for reduction of environmental pollution. This paper also presents a review of usage of various types of fibers in geopolymer concrete such as glass and steel fibers.**

Keywords: Fly ash, alkaline activators, geopolymer concrete, fibers, compressive strength

1. INTRODUCTION

Construction is one of the fast growing fields worldwide. As per the present world statistics, annual global production of Ordinary Portland Cement (OPC) is over 4.1 Billion Metric tons. This quantity will increase by more than 25% within the next 10 years. The main source material for the production of Ordinary Portland Cement (OPC) is Lime stone. Availability of Lime stone might end within the next 40 years. Production of one ton of OPC, utilizes a huge quantity of energy, with approximately one ton of Carbon dioxide (CO_2) emission to the atmosphere as a by-product, which is a major challenge for sustainable development. Hence it is essential to find an alternative binder. The waste output of various industries such as Fly Ash, Slags and Rice Husk Ash etc. can be used as cement replacement material. Since Geopolymer concrete doesn't use any OPC, the production of cement shall be reduced and hence the pollution of atmosphere by the emission of carbon dioxide (CO_2) shall also be minimized, also utilizing the Industrial wastes. GPC is being studied extensively and shows promise as a substitute to Portland cement concrete.

A French Professor Joseph Davidovits (Geopolymer Institute, Saint-Quentin, France) first proposed that an alkaline activating solution could be used to react with the silicon (Si) and the aluminum (Al) in materials such as fly ash and rice husk ash to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he used the term "Geopolymer" in the year 1978 to represent these binders. These Geopolymer depend on thermally activated natural materials like Meta kaolinite or industrial by products like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). The existing Portland cement standards cannot be adopted for mix design of geopolymer concrete. 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 the material, field conditions and also workability and durability requirements. Even though the geopolymer possess many advantages over OPC, they also show tension failure behavior similar to that of OPC. 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.

2. MATERIALS USED

Geopolymer concrete is generally a mix of binder and alkali solution with fine aggregate and coarse aggregate, where the role of binder plays by mainly Fly Ash, but with a replacement of some percentage of fly-ash with Ground Granulated Blast Furnace Slag (GGBS) shows a good result. The alkali solution is the mixture of Sodium Hydroxide (or Potassium Hydroxide) and Sodium Silicate (or Potassium Silicate) to a different ratio. In addition to above mentioned major ingredients, Research results suggest that the use of materials such as Naphthalene Based Super Plasticizer, glass powder, micro silicates etc., improves the fresh and hardened properties of Geopolymer Concrete.

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2.1 Fly Ash

Fly Ash is a waste product obtained from pulverized coal in thermal plants. Fly ash is most commonly in dark grey color. They are spherical and finer than Ordinary Portland Cement. Depending upon the source and composition of the coal being burned, the components of fly ash vary considerably, but all fly ash includes substantial amounts of silicon dioxide (SiO_2) both amorphous and crystalline), aluminum oxide (Al_2O_3) and calcium oxide (CaO).

Fly ash plays the role of an artificial pozzolanic material; its silicon dioxide content reacts with the calcium hydroxide from the cement hydration process to form the calcium silicate hydrate (CS-H) gel. The use of High Volume Fly Ash (HVFA) in the place of ordinary Portland cement in concrete shows excellent mechanical property, durability and performance. The Indian Standard code for Fly ash is IS 3812-1 (2003): Specification for Pulverized Fuel Ash, Part 1: For Use as Pozzolana in Cement, Cement Mortar and Concrete.

2.2 Fine Aggregate

River Sand is a granular material composed of finely divided rock and mineral particles. The most common constituent of sand is silica (silicon dioxide SiO_2). Sand particles are that which passes through sieves of size between 0.074 mm and 4.75 mm. Manufactured sand (M sand) is sand made from rock by artificial processes, usually for construction purposes in cement or concrete. It differs from river sand by being more angular, and has some different properties.

2.3 Coarse Aggregate

Coarse aggregate (broken stone) is produced by mining rock deposits. It is also known as blue metals. Aggregate serves as reinforcement to add strength to the overall composite material. Waste slag from the manufacture of iron and steel, recycling of concrete, e-waste etc. can be used in the place of coarse aggregate. The Indian Standard code for Fine and Coarse Aggregate is IS 383 (1970): Specification for Coarse and Fine Aggregates from Natural Sources for Concrete.

2.4 Alkaline Activators

Mixture of sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) is used as alkaline activators to produce geopolymer concrete. Mixing the fly ash with the alkaline activator creates a binder that is generally known as alkali-activated fly ash-based geopolymer paste. The Na_2SiO_3 solution to NaOH solution ratio affects the mechanical strength of the geopolymer concrete. Ratios in the range of 0.4 to 2.5 provide good mechanical properties. Another factor is molarity of the NaOH solution and to produce good geopolymer concrete it should be between 8M and 16M.

2.5 Fibers

Glass fibers are made of silicon oxide with addition of small amount of other oxides. Glass fibers have high strength, good temperature resistance, corrosion resistance and are available at low price.

Steel fibers have short, discrete lengths and an aspect ratio in the range of 20-100, with any cross section that are sufficiently small to be randomly dispersed in an unhardened concrete mixture using usual mixing procedures.

3. MIX DESIGN

The primary difference between the geopolymer concrete and the 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 and other unreacted materials together to form the geopolymer concrete, to produce geopolymer concrete of desired strength, on the basis of nature of work, type, availability, properties of material, field conditions, workability and durability requirements.

Rangan et al. proposed a mix design procedure for production of fly ash based geopolymer concrete. Anuradha et al. has presented modified guidelines for mix design of geopolymer concrete using Indian standard code IS 10262-2009. 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. 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. 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:

- 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 GEO-POLYMER CONCRETE

Incorporation of fiber into the cementitious matrix can enhance the flexural properties and control the crack propagation and widening under different types of mechanical loading or shrinkage. 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.

Dr. Mrs. S. A. Bhalchandra et al studied the effects of inclusion of glass fibers on density, compressive strength & flexural strength of hardened geopolymer concrete composite (GPCC). Alkaline liquids to fly ash ratio were fixed as 0.35 with 100% replacement of OPC with Fly ash. For alkaline liquid combination ratio of Sodium hydroxide solution to Sodium silicate solution was fixed as 1.00. Glass fibers were added to the mix in 0.01%, 0.02%, 0.03% & 0.04% by volume of concrete.

J. Asanammal Saral et al studied the mechanical properties of geopolymer concrete composites with Glass fiber and Copper Slag. Compressive strength test, split tensile test and water absorption test in heat curing at 60˚C for 24 hours in hot air oven are done. Glass fibers were added in the mix in the volume fraction of 0.5%, 1.0%, 1.5% and 2.0% volume of the concrete. In this study the replacement of sand with copper slag in geopolymer concrete varying the percentage of 0%, 10%, 20%, 30%, 40%. The concentration of sodium hydroxide solution is 14M.

A. Alekhya et al studied the strength of M30 grade Glass Fiber Reinforced Geopolymer Concrete Composites (GFRGPCC) with partly addition of Ground Granulated Blast Furnace Slag (GGBS) and Ordinary Portland Cement (OPC). Glass Fibers in the volume fractions of 0.01%, 0.02% and 0.03% of concrete are added. The ratio of sodium silicate to sodium hydroxide is 2.5. The ratio of alkaline liquids to fly ash is 0.4. The amount of Super plasticizer used is 3% of fly ash.

V. Kishore Kumar et al studied the effects of glass fiber on strength and durability properties of Geopolymer concrete. Sodium silicate and sodium hydroxide were used as alkali activators and its ratio is kept as 2.7. Alkali solution to fly ash ratio as 0.35 and glass fibers was added with the variation of 0.005% to 0.035% by volume of concrete. A 12M molarity of sodium silicate and sodium hydroxide was used as alkali activator.

G. Ramkumar et al studied the load carrying capacity and deflections at peak load and service loads in Steel Fiber Reinforced Geopolymer Concrete. Three GPC mixes of fly ash (50%) and GGBS (50%) in the binder stage were considered. 0.75% Stainless steel fiber and 0.75% mild steel fibers were added in the concrete. Ratio between $Na_2SiO_3/NaOH$ used in the production of alkaline activator was 2.2.

Meor Ahmad Faris et al studied the Performance of steel wool fiber reinforced geopolymer concrete and were tested in terms of density, workability, and compression. Steel wool fiber of high quality, low carbon steel were added into the geopolymer concrete as reinforcement with different weight percentage vary from 0 % - 5 %. Ratio between $Na_2SiO_3/NaOH$ used in the production of alkaline activator was 2.5. The ratio of fly ash to alkaline activator that has been used in this research was 2.0. The molarity of the solution used in this research is 12M.

Tadepalli Naga Srinu et al studied the Mechanical Properties of Steel Fiber Reinforced Geopolymer Concrete incorporated with Fly-Ash & GGBS. Steel fibers are added maximum up to 2% taken by weight of binder of diameter 0.5mm. The ratio of sodium silicate to sodium hydroxide is 2.5. The ratio of alkaline liquids to fly ash is taken as 0.35.

5. Comparisons of Results

The strength parameters obtained in each research work are given as follows:

TABLE 1
COMPARISON OF STRENGTH OF GLASS FIBER REINFORCED GPC

AUTHOR	COMPRESSIVE STRENGTH (N/mm^2)		TENSILE STRENGTH (N/mm^2)		FLEXURAL STRENGTH (N/mm^2)	
	WITHOUT FIBER	WITH FIBER	WITHOUT FIBER	WITH FIBER	WITHOUT FIBER	WITH FIBER
S. A. Bhalchandra	36.33	43.67	NA	NA	4.00	6.28
J. Asanammal Saral	41.56	59.26	4.15	6.18	NA	NA
A. Alekhya	33.61	37.34	2.393	3.00	5.6	6.44
V. Kishore Kumar	48.72	52.28	2.36	3.16	5.12	7.99

TABLE 2
COMPARISON OF STRENGTH OF STEEL FIBER REINFORCED GPC

AUTHOR	COMPRESSIVE STRENGTH (N/mm^2)		TENSILE STRENGTH (N/mm^2)		FLEXURAL STRENGTH (N/mm^2)	
	WITHOUT FIBER	WITH FIBER	WITHOUT FIBER	WITH FIBER	WITHOUT FIBER	WITH FIBER
G. Ramkumar	44.16	53.13	3.372	5.91	6.61	8.19
Meor Ahmad Faris	55.42	65.72	NA	NA	NA	NA
Tadepalli Naga Srinu	43.15	56.54	2.56	5.50	2.28	4.62

The results obtained from various studies show that the addition of glass and steel fiber has significant effect on the compression, split tensile and flexural strength of the GPC.

6. CONCLUSIONS

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

- The mix proportion of geopolymer concrete depends up on fineness of fly ash, concentration of the alkaline liquid, alkaline solution ratio and Fly-Ash and alkaline solution ratio.
- Addition of various types of Glass and steel fibers significantly increase the strength properties of the geopolymer concrete.
- Results show that the addition of up to 3% of Glass and Steel fiber increases compression, split tensile and flexural strength of concrete.

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