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Mechanical and Micro-Structural Properties of Fly Ash Based Geopolymer Concrete

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ABSTRACT: Replacement in concrete material has been a wide concept accepted by all researchers to reduce the emission of CO₂, which leads to various environmental problems. Among various replacements, polymeric based concrete, which always scored a greater output from that of conventional concrete. Fly ash based Geopolymer concrete is one type of special concrete, produced by the polymerization process of silicon and aluminium rich material in presence of alkaline activator such as sodium hydroxide and sodium silicate or potassium hydroxide and potassium silicate are reacted to form a gel under ambient condition. By adding secondary reinforcements namely fibers, along with this type of concrete facilitate bond strength efficiently. Secondary reinforcements did the role of determinants to mechanical and durable resistance, it also enables the effective utilization of intrinsic tensile and flexural strength. In this paper, the constituents of geopolymer concrete and its mechanical properties and micro-structural study is carried out by SEM analysis by dispersing polypropylene fibres in various percentages such as 0, 0.5%, 1%, 1.5%

KEYWORDS: Geopolymer, fly ash, Polypropylene fibre, mechanical properties, micro-structure, SEM

I. INTRODUCTION

Concrete is the widely used construction material that makes best foundations, architectural structures, bridges, roads, block wall, fences and poles. Usage of concrete structures is increased day-to-day life, which leads to the production of large amount of cement and increased in CO₂ emission. Among the greenhouse gases, CO₂ contributes about 65% of global warming and causes various environmental issues. To overcome this above problem, the production and usage of cement content is reduced which, can be done by adding other source material. The development of alternative binders to Portland cement has a rapid application towards construction industry. The outcome industrial wastes can be used as source materials. Waste materials such as Fly ash, GGBS, Rice husk ash, silica fume etc. Geopolymer concrete is one of the special concrete in which the cement content is fully replaced with source (industrial waste) material, which shows, considerable promise application in concrete industry without environmental hazards.

Geo-polymer concrete was discovered by Joseph Davidovits. It's an inorganic alumina-silicate polymer, synthesised from silicon and aluminium rich materials like fly ash. The chemical composition of geopolymer material is same as natural zeolite but the micro-structural property of zeolite is amorphous instead of crystalline. Geo-polymerisation process involves a substantially fast chemical reaction under alkaline condition on silica and alumina material.

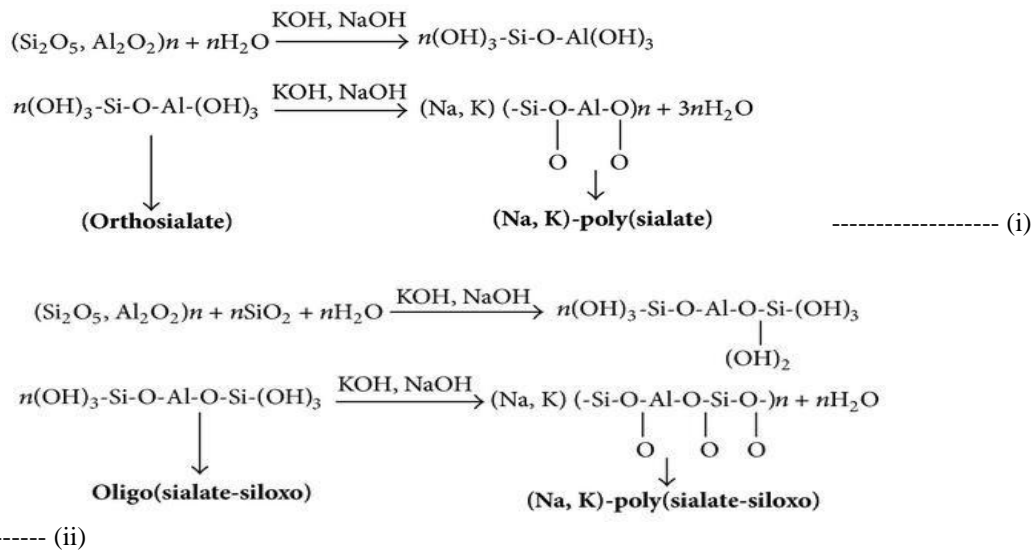
The reaction of FA with an alkaline solution contains sodium hydroxide and sodium silicate in their mass ratio, which results 3D polymeric chain material and ring structure consisting of Si-O-Al-O bonds. The schematic formation of geopolymer material is in equations (i) and (ii).

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The last term $n\text{H}_2\text{O}$ in the above equation reveals that water released during the chemical reaction that occurs in the formation of geopolymers. The water present in the geopolymer concrete matrix was expelled out during curing and further drying periods, this leaves discontinuous Nano-pores in the matrix mix, which provide benefits to the performance of geopolymer concrete. The water in the geopolymer mix doesn't play any role during chemical reaction, it provides only workability to the mixture during handling. This is merely contrast to the chemical reaction, which takes place in Portland cement mixture during hydration process.

II. CONSTITUENT MATERIALS AND ITS PROPERTIES

1. **Fly ash:** Fly ash is a fine powder that is a by-product of burning pulverized coal in electric generation power plants and they are collected by electrostatic precipitation. In this paper, class F fly ash was used which is obtained from Mettur Thermal Power Station, Salem. Specific Gravity of fly ash is 3.14, Colour-grey, Moisture content-nil.
2. **Fine aggregate:** The particles of granular materials are so fine that they pass through a 4.75mm sieve. It is essential material in concrete consist of natural sand. The purpose of fine aggregate is to fill the voids, on coarse aggregate and to act as workability agent. It was screened to remove deleterious materials and tested as per procedure given in IS: 2386-1963. Specific gravity of fine aggregate is 2.34, Grading zone -Zone II, Water absorption-0.5%, Bulk density-1.60 g/cc, Moisture content-nil.
3. **Coarse aggregate:** Aggregate, which retained in 4.75 mm sieve is known to be coarse aggregate. Locally available coarse aggregate having the maximum size of 10mm were used in this experiment. Testing of coarse aggregate was done as per IS:383-1970. Specific gravity of coarse aggregate is 2.77, water absorption-0.3%, Impact value-20%, Crushing value-18%.
4. **Sodium hydroxide:** Sodium hydroxide looks like pellets or flakes, which is colourless and soluble in water, ethanol and methanol. It is also known as caustic soda. It is available with different purity content. Cost of sodium hydroxide varies with the purity of the substance. Since the nature of geopolymer concrete is homogenous So, the material NaOH used in this should be homogenous which contains 94% to 96% of purity level. The main work of NaOH is to activate the sodium silicate. Specific gravity-1.47, Purity-97%, Na_2CO_3 -2.0%, Cl-0.01%, SO_4 -0.01%, SiO_2 -0.02%.
5. **Sodium-Silicate:** It is gel like liquid, which is also known as water glass or liquid glass. The strength of geopolymer concrete varies with different percentage of Na_2O . Generally, it is composed of oxygen-silicon polymer. A dark pale yellow colored viscous gel used in this experimental work. Density of the solution is 1720 Kg/m^3 , Specific gravity-1.6, Na_2O -15.9%, SiO_2 -31.4%, H_2O -52.7%

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6. **Polypropylene fibre:** The Specific Gravity of polypropylene fibres is 0.90 – 0.91 gm/cm³. Because of its low specific gravity, polypropylene yields the greatest volume of fibre for a given weight. Polypropylene fibre provides good bulk and cover, while being lighter in weight. Polypropylene is the lightest of all fibres and is lighter than water. It is 34% lighter than polyester and 20% lighter than nylon. It has lowest thermal conductivity than any natural or synthetic fibre. Polypropylene fibres retain more heat for a longer period of time and have excellent insulative properties. Melting point of polypropylene is about 165°C and the maximum processing temperature of the fibre is approximately 140°C. The water absorption of polypropylene fibre is about 0.3% after 24 hours immersion in water. It shows excellent resistance to most acids except chlorosulfonic acid and concentrated sulphuric acid.

III. EXPERIMENTAL INVESTIGATION

The following tests were conducted on the geopolymer concrete specimens are

1. **Compression test (conforming to IS 516):** This test was performed on 150 mm x 150 mm x 150 mm sized geopolymer concrete cubes casted for M35 grade with 12 molarity to determine the compressive strength of the mix. This test was performed on normal GPC specimens and polypropylene fibre reinforced GPC specimens. The percentage of polypropylene fibres were varied from 0 to 1.5% with 0.5% intervals. The compression test on cube specimens was performed in the compression testing machine.
2. **Split tensile test (conforming to IS 5816-1999):** To determine the tensile strength of geopolymer concrete mix for M35 with 12M, split tensile test was done on the cylindrical test specimens of 150mm x 300mm using the compression testing machine. This method consists of applying a diametric compressive force along the length of a cylindrical specimen.
3. **Flexure test (conforming to IS 516):** Flexural strength of a concrete is a measure of its ability to resist bending. Flexural strength can be expressed in terms of ‘modulus of rupture’. Concrete specimens having 100 mm x 100 mm cross section and 500 mm length are prepared for flexural test. They were supported on two rollers in the flexure testing machine. The specimens were placed on the supports such as the distance between the rollers equals to 400 mm. The load was applied on the concrete specimen through the third roller at the middle of the specimen. The distance between the loading point and any of the bottom support was maintained as 200 mm. The specimen is subjected to bending, using three-point loading until it fails.
4. **SEM analysis (Scanning Electron Microscope):** Detailed study on microstructure and molecular level interaction are to be studied by SEM. Microstructural study in concrete help us to understand better about the reactions and bond between the elements. Rather than mechanical and durable aspects which are considered as the surface and volumetric resistance, this type of microstructural investigation provide us the information and relation about the molecules formed and present inside the concrete.



(a)



(b)



(c)

Fig.1 Testing of Mechanical Properties (a) Compressive strength test (b) Split Tensile test (c) Flexural Strength test

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IV. RESULTS AND DISCUSSION

1. COMPRESSIVE STRENGTH

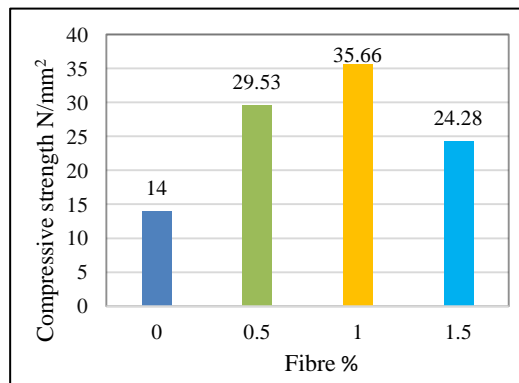


Fig.2 Compression strength at 3 days for various fibre fraction

Fig.1. shows 3days compression strength of geopolymer concrete specimen with different fibre fraction. From the chart it can be clearly seen that fibre fraction of 1% showed the optimum compressive strength of 35.66 MPa. Optimum fibre fraction showed a greater difference with other fibre fraction. 0.5% and 1.5 % of fibre fraction found to have a decrease in strength then that of optimum fibre fraction. Still it can be also seen that the optimum fibre dosage attained the design mix compressive strength at the 3 days itself. From the test results it can be concluded that addition of fibres in the geopolymer concrete increases the strength at the earliest to perform even better than that of normal geopolymer concrete.

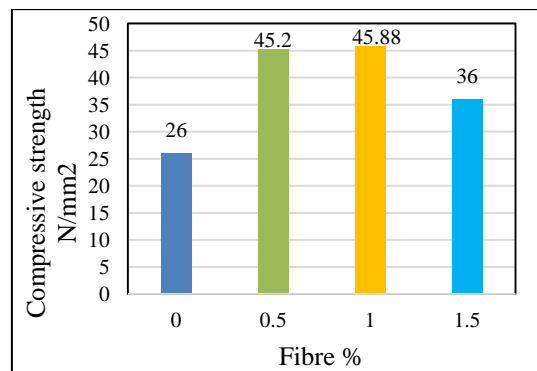


Fig.3Compression strength at 7 days for various fibre fraction

Fig.2. shows 7 days compression strength of geopolymer concrete specimen with different fibre fraction. From the chart it can be easily understood that fibre fraction of 1% showed the optimum compressive strength of 45.88 MPa. Optimum fibre fraction showed a higher compressive strength with other fibre fraction. 0% of fibre fraction found to have a least strength when compared to optimum fibre fraction. Still it can be also seen that the optimum fibre dosage shows an increase in compressive strength when compared to the compressive strength at 3 days. From the test results it can be concluded that though GPC without fibres shows lower compressive strength when compared to the fibre reinforced geopolymer concrete.

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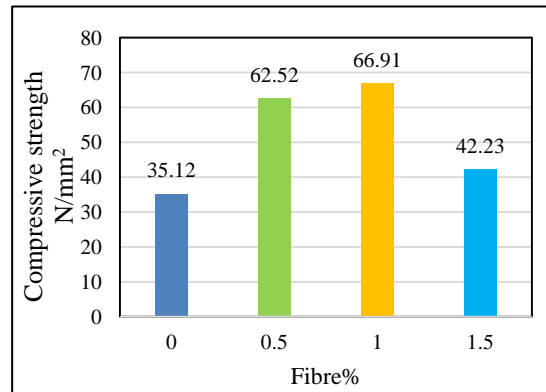


Fig.4 Compression strength at 28 days for various fibre fraction

Fig.8.3. shows the compression strength of geopolymer concrete specimen with different fibre fraction at 28 days. The chart indicates that fibre fraction of 1% showed the optimum compressive strength of 66.91MPa. The compressive strength at 28 days shows that the compressive strength increases with increase in fibre fraction up to 1%. Beyond this percentage of the fibre fraction the value of the compressive strength is found to be decreasing. From the test results it can be concluded that addition of fibres in the geopolymer concrete helps in increasing the compressive strength as well as to gain strength at the earlier stage itself.

2. Split Tensile test

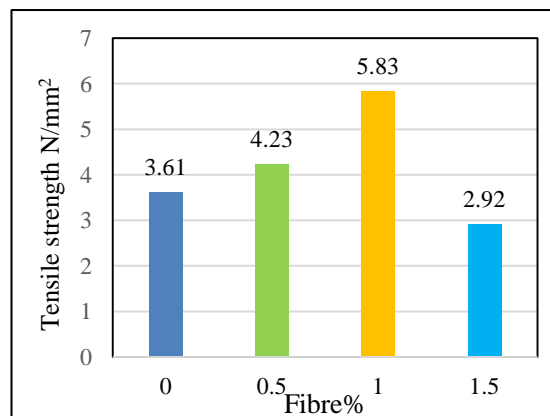


Fig.5 Split tensile strength at 7 days for various fibre fraction

Fig.4. shows the split tensile strength of geopolymer concrete specimen with different fibre fraction. From the chart it can be clearly seen that fibre fraction of 1% showed the optimum tensile strength of 5.83MPa. Optimum fibre fraction showed a greater difference with other fibre fraction. 0.5% and 1.5% of fibre fraction found to have a decrease in strength than that of optimum fibre fraction. While 1.5% of fibre fraction showed a decrease of 53.18% from the optimum fibre fraction. Still it can be also seen that the optimum fibre dosage attained the nearly full tensile strength at the 3 days itself. From the test results it can be concluded that addition of fibres in the geopolymer concrete increases the tensile strength at the earliest even more than that of the compressive strength.

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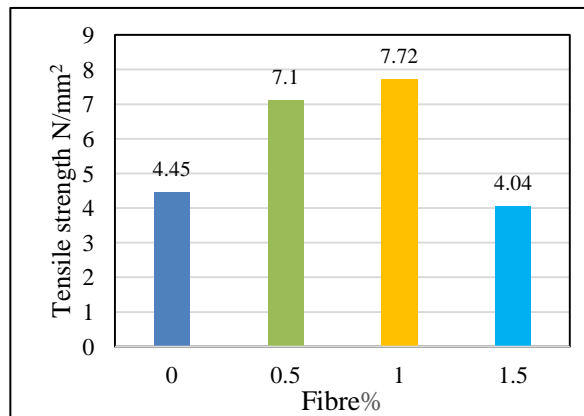


Fig.6 Split tensile strength at 28 days for various fibre fraction

Fig.5. shows the split tensile strength of geopolymer concrete specimen with different fibre fraction at the age of 28 days. The chart shows that fibre fraction of 1% showed the optimum tensile strength of 7.72 MPa. Optimum fibre fraction showed a greater difference with other fibre fraction.. Still it can be also seen that if the fibre fraction exceeds the optimum dosage it may lead to decrease in the tensile strength of the specimen. It also showed a decrease in strength, when compared to the geopolymer concrete specimens without fibre. From the test results it can be concluded that addition of fibres in the geopolymer concrete increases the tensile strength till the optimum fibre dosage.

3. Flexure Test result

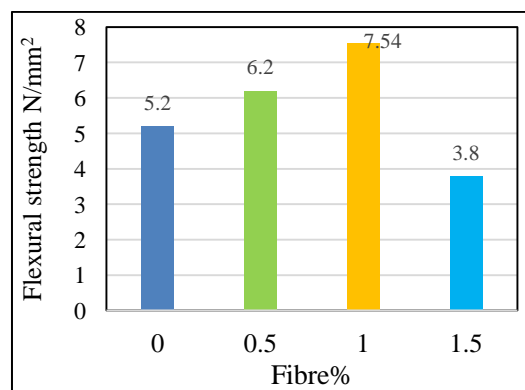


Fig.7 Flexural strength at 7 days for various fibre fraction

Fig.8.6. shows the flexural strength of geopolymer concrete specimen with different fibre fraction at 7 days. From the chart it can be clearly seen that fibre fraction of 1% showed the optimum flexural strength of 7.54 MPa. Optimum fibre fraction showed a greater difference with other fibre fraction. 0.5% of fibre fraction found to have a decrease in strength to 21% from optimum fibre fraction. While 1.5% of fibre fraction showed a decrease of 28.49% from the optimum fibre fraction. Still it can be also seen that the optimum fibre dosage attained the design mix flexural strength at the 7 days itself. From the test results it can be concluded that addition of fibres in the geopolymer concrete increases the flexural strength at the earliest. But the flexural strength reaches the peak value at 1% and falls rapidly when the percentage of fibres are increased a little higher.

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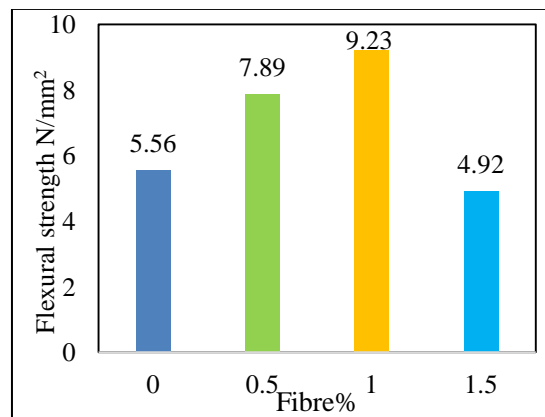


Fig.8 Flexural strength at 28 days for various fibre fraction

Fig.7. shows the flexural strength of geopolymer concrete specimen with different fibre fraction at the age of 28 days. From the chart it can be clearly seen that fibre fraction of 1% showed the optimum flexural strength of 9.23 MPa. 0.5% of fibre fraction found to have a decrease in strength to 14.43% from optimum fibre fraction. While 1.5% of fibre fraction showed a decrease of 47.80% from the optimum fibre fraction. The optimum fibre fraction shows an increase in the flexural strength of 60.69% in comparison to that of the geopolymer concrete specimen without fibre. With increase in the fibre dosage of 0.5% the flexural strength increases by 32.54%. From the test results it can be concluded that addition of fibres in the geopolymer concrete increases the strength at the earliest and increase in the flexural strength is only 13.66% higher after the seven days of curing at the optimum fibre fraction.

4. SEM test

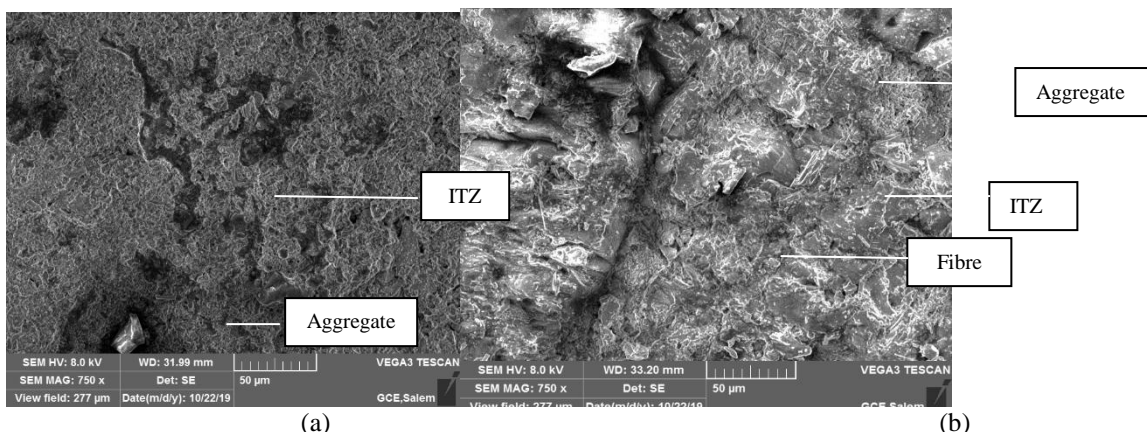


Fig.9 SEM images (a) 0% , (b) 1% of fibre fraction

SEM images were obtained to know the microstructure behaviour for geopolymer concrete. The result which is obtained from the mechanical property i.e. by adding 1% of fibre gives higher strength compared to other fibre fraction. So SEM images were taken for 0% and 1% of fibre fraction, comparing these images Fig.(a),(b) shows clear variation Fig.(a) shows lesser formation of Interfacial Transition Zone (ITZ), it indicates weak bond strength of geopolymer paste. This weak ITZ will be connected to another micro cracks path within paste matrix, when the geopolymer concrete sample loaded for testing it get premature failure. But in Fig, (b) addition of polypropylene fibre increases the bond

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strength effectively. In this bond between Si-O-Al were strong and make the concrete denser to yield higher strength compared to 0% fibre fraction.

V. CONCLUSION

From the above mentioned experimental investigation following conclusions has been determined

- Polypropylene fibre with 1% fraction proved the maximum compressive strength of 35.6 MPa at 3days, 45.88 MPa at 7days, 66.91 MPa at 28days. These values are found to be optimum than other percentages of fibre fraction added to the concrete.
- Split tensile strength results shows that fibre based geopolymer concrete specimens with 1% recorded 5.83 MPa at 7days, 7.72 MPa at 28 days found optimum than other fractions.
- Flexural strength results imply the fibre fraction of 1% produced an optimum value of 7.54 MPa at 7days, 9.23 MPa at 28days than other fractions.
- Microstructural behaviour of geopolymer fibre reinforced concrete shows higher bond strength, better Interfacial Transition Zone these are the responsible for the strength properties of geopolymer concrete. In which the SEM image gives the reason for premature failure while loading.

From all the above conclusion it may be concluded that 1% of polypropylene fibre based concrete found to be optimum in all results.

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