Review on Effect of Basalt Fiber and Hooked Steel Fiber on GGBS Based Geopolymer Concrete

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Abstract- *Geopolymer cement concrete (GPCC) are inorganic polymer composites, with the potential to form an environmentally sustainable construction material. Geopolymer concrete can be used for replacing or supplementing the conventional concrete. Geopolymer concrete can be manufactured using industrial waste products such as fly ash, GGBS (Ground Granulated Blast Furnace Slag) etc. It is considered as an ecofriendly alternative to the ordinary portland cement(OPC) based concrete. The addition of fibers to a brittle matrix is a well known method to improve the flexural strength. In this paper, various fiber reinforced geopolymer concrete related literatures are reviewed. Durability studies on fiber reinforced geopolymer concrete were also reviewed.*

Keywords*-* GGBS based geopolymer, Hybrid fibers, mechanical properties, durability study

I. INTRODUCTION

The portland cement is used as binding material in conventional concrete. Production of cement uses high amount of energy and resources. Production of 1 tonne cement liberates 1 tonne of CO_2 to the atmosphere. Due to these problems many attempts were made to reduce the use of portland cement as binder. The binder in concrete can be replaced by the use of source material containing high amount of silica and alumina. Geopolymer concrete was invented by Davidovits. The term is used to describe a amorphous alkali aluminosilicate composite and is commonly termed as inorganic polymers. Geopolymerization involves the chemical reaction of aluminosilicate oxides with alkali polysilicates yielding polymeric Si-O-Al bonds. Concrete exhibits brittle behaviour due to low tensile strength. The addition of fibers changes its brittle behavior to ductile. Inclusion of fibers increases tensile and toughness properties of concrete. Many studies proved that addition of different types of fibers improves the strength parameters of geopolymer concrete. Durability is an important factor to be analyzed in order to evaluate the life of concrete. Many studies had done through sulphate resistance test, acid resistance test, corrosion and chloride penetration etc shows good performance of geopolymer concrete than Portland cement composites.

II. GEOPOLYMER CONCRETE

Geopolymers are obtained by the reaction of solid aluminosilicate powder with alkali hydroxide or alkali silicate. A schematic representation of formation of geopolymer concrete is shown below.

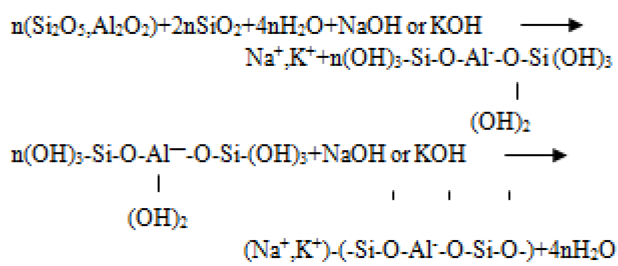

Figure1. Schematic Formation of geopolymer concrete [1]

The solution dissolved and releases [SiO_4] and [AlO_4] tetrahedral units and these units are linked to the polymeric precursor by sharing oxygen atoms to form the amorphous geopolymer with Si-O-Al-O bonds. This process release water that is consumed during dissolution. This expelled water helps in workability of geopolymer concrete during mixing and placing. Components of geopolymer concrete consists of a base material, alkaline activators, coarse aggregate, fine aggregate and admixture. The base material is usually fly ash , GGBS, rice husk ash, construction wastes etc.

2.1 Features of Geopolymer concrete.

Geopolymer concrete has many structural and physical properties. Some of its features are listed below

1. The geopolymer technology showed a considerable promise as a alternative binder to the portland cement
2. The mechanical behavior of geopolymer concrete is more reliable than nominal concrete mix

3. Durability property of geopolymer concrete is better than nominal concrete
4. The geopolymer concrete has two limitations such as delay in setting time is difficult and heat curing is must to get the desired strength[2]

III. REVIEW OF LITERATURE

3.1 LITERATURE ON STEEL FIBER REINFORCED GEOPOLYMER CONCRETE.

Navid et al. conducted a study on geopolymer composite using copper coated micro steel fiber. Different properties of the composite was studied with fresh and hardened properties. The addition of steel fiber indicated an increase in flexural strength at a high rate until 28 day and continued at a lower rate. 2%fiber content by volume fraction led to increase in second day flexural strength to ultimate strength .The addition of 3% and 4% steel fiber showed increase in flexural strength up to 7days and after which strength remained unchanged. 3% steel fiber was found as optimum. Inclusion of steel fiber enhances early compressive strength of the composite. It has a limited effect on the ultimate compressive strength. Fig 2 showed below indicates the compressive strength of steel fiber reinforced geopolymer concrete.

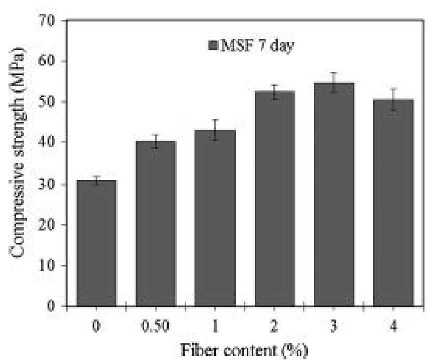

Fig 2, Compressive strength of steel fiber reinforced GPC (Source: Navid et.al 2015)

Surya et al. studied the effect of hooked steel fiber on mechanical properties on geopolymer concrete and is compared with conventional concrete. Steel fiber was added to the concrete mix in volume fraction of 0.5% to 1.5% with 0.5% increment. Normal GeoPolymer Concrete (GPC) attained a compressive strength of 31.6 MPa where as 1% hooked steel fiber showed highest compressive strength of 39.8MPa which is 25.9% increment. Increase in split tensile strength was about 26.9% and 57.4% for 0.5% and1% hooked steel fiber with respect to normal GPC .Increase in hooked steel fiber reduced the tensile strength further up to 44.2% when 1.5% fiber was added.

Rekha et al. studied the effect of round crimped steel fibers with 0.25%, 0.5%, 0.75% and 1% volume fraction of steel fibers. Mechanical and durability properties were also studied .It was observed that workability values were reduced gradually when fibers are added. Increase in steel fiber content increased the compressive strength.GPC and fiber reinforced GPC showed about 93% strength development within 3 days. 98% of compressive strength was obtained at 7^{th} day. 1% addition of crimped steel fiber resulted in maximum compressive strength. Flexural strength increased (up to 42.45 %.) as the fiber fraction increased in the GPC Maximum flexural strength obtained was 5MPa with 1% steel fiber.

Arya et al. studied mechanical properties of geopolymer concrete reinforced with steel fibers. This study involved finding compressive and split tensile strength of geopolymer concrete by varying fly ash to chemical ratio as 0.3, 0.35, 0.4 and steel fiber content as 0, 0.5 and 1%. Increase in the percentage of steel fiber, increased the compressive as well as the tensile strength of geopolymer concrete. Increase in strength occurred at curing temperature ranging from 30^0C to 90^0C. The optimum percentage obtained was 1% with compressive strength of 26.8MPa and split tensile strength of 3.5MPa

Ramkumar et al. developed a geopolymer concrete reinforced with crimped mild steel and crimped stainless steel. Three mixes were studied with no fiber, stainless steel fiber and mild steel fiber. Three mixes contained 50%GGBS and 50% fly ash. The strength properties were compared with ordinary Portland cement mix. Results showed increased strength properties than normal concrete. Addition of crimped mild steel shows gradual increase in compressive strength, split tensile strength and flexural strength. Crimped mild steel showed better result on mechanical properties than crimped stainless steel. Compressive strength was increased by 2.25% when steel fibers were added to normal geopolymer.

Vijay et al. studied the effect of inclusion of steel fibers on the properties of geopolymer concrete. The composite consisted of 90% flyash and 10% ordinary portland cement. Impact of steel fiber was studied with mechanical property analysis. Steel fiber were added to the concrete in volume fractions of 0.25, 0.5 and 0.75%. Based on the results empirical expressions were developed to predict 28 day strength parameters. As the volume fraction increases the compressive strength also increases to about 24% with 0.75% of steel fibers. Using least square regression analysis, the equation for predicting the 28 days compressive strength of steel fiber reinforced Geopolymer Concrete Composites in terms of percentage volume fraction of fibers (*Vf*) is

$$fcs = fco + 11.08\ Vf$$

where *fcs* = 28 days Compressive Strength of steel fiber reinforced Geopolymer Concrete Composites, *fco* = 28 days Compressive Strength of Geopolymer Concrete Composites, *Vf* = Percentage Volume fraction of steel fibers.

The equation for tensile strength is

$$fts = fto + 0.834\ Vf$$

where *fts* = 28 days Split tensile strength of steel fiber reinforced Geopolymer Concrete composites, *fto* = 28 days Split tensile Strength of Geopolymer Concrete composites
The equation for flexural strength is

$$ffs = ffo + 3.36\ Vf$$

where *ffs* = 28 days flexural strength of steel fiber reinforced Geopolymer Concrete Composites. *ffo* = 28 days flexural Strength of Geopolymer Concrete composites.

3.2 LITERATURE REVIEW ON BASALT FIBER REINFORCED GEOPOLYMER CONCRETE

Arunagiri et al. conducted a study on basalt fiber based geopolymer concrete. Experiment was conducted with various proportions of basalt fiber as 0.5%, 1%, 1.5%, 2%, and 2.5%. Mechanical properties of GPC were compared with and without basalt fibers. With the addition of basalt fiber, there was a sudden increase in compressive strength of about 10%for 0.5% fiber content. After the addition of basalt fiber, the compressive strength increased gradually to 40MPa for 2% basalt fiber. 2.5% addition of basalt fiber showed a decrease in compressive strength. Split tensile strength was also increased with increase in basalt fiber content. With 2% basalt fiber, the maximum tensile strength obtained was 3.3MPa at 7 day and 3.7 MPa at 28 day.2% basalt fiber gave a maximum flexural strength of 6.8MPa.

Anil et al. studied basalt fiber reinforced concrete with percentage of basalt fibr from 0.5% to 2.5% with 0.5% increment. Compressive and tensile strength were compared with reference mix which had 0% basalt fiber. Increase in basalt fiber percentage increased the compressive strength gradually up to 40MPa. Beyond 2% fiber content compressive strength decreased rapidly. Split tensile strength also showed the same trend as increase in basalt fiber content increased the tensile strength up to 3.5MPa at 28 day. Above 2% the addition of basalt fiber decreased the tensile strength.

Anil et al. studied flexural behavior of basalt fiber reinforced GPC with 0.5% to 2.5% basalt fiber .The results showed an increase in flexural strength for basalt fiber reinforced GPC than normal geopolymer concrete. Maximum increase of flexural strength (67.88%) was obtained for an optimum fiber content of 2%. Higher basalt content resulted in decreased flexural strength.

Kumutha et al. investigated the properties of basalt fiber reinforced geopolymer concrete. Investigation used fly ash and GGBS for making geopolymer concrete. Fibers were added to the concrete at 0.5 to 2.5% with 0.5% increment. Strength parameters of different percentage were compared with geopolymer concrete without basalt fiber. With increase in basalt fiber content the strength parameters were also increased gradually.2% addition of basalt fiber was taken as optimum and beyond this percentage of fiber content the strength reduced.

3.3 LITERATURE REVIEW ON HYBRID FIBER REINFORCED GEOPOLYMER CONCRETE.

Navid Ranjbar et al. studied interfacial bond in steel and polypropylene fiber reinforced geopolymer concrete. Fibers were added to the geopolymer concrete by 0.5, 1 ,2, 3and 4%. Results showed that independent of fiber type, the increase in fiber content reduced the workability of concrete. Maximum flexural strength of 27MPa and 35MPa was obtained at 3% of steel fibers on 7 and 28 day respectively. Beyond 3% the flexural strength reduced to 20Mpa at 7 day. The flexural strength enhancement by polypropylene was very small at early stages. But it showed an increased strength at 56 day. Steel fiber showed an improvement in early compressive strength. Polypropylene had no effect on early strength attainment but had long term adverse effect on compressive strength.

Aamer Bhutta et al. studied the flexural behavior of GPC with different types of steel and deformed polypropylene fibers 0.5% volume fraction was considered for the study. Mechanical properties were checked and the results showed that strength parameters were affected by curing temperature, concentration of activator etc. The compressive strength increased to 106% when heat cured (60^0C for 24 hrs) .Tensile and flexural strength also increased when heat curing was done. The heat curing provided significant increase in strength parameters. The end deformed steel fiber showed the improvement in strength characteristics. Change in activator concentration has less importance.

Damu.et.al. examined the effect of steel and polypropylene fiber on geopolymer concrete by strength properties. The steel and polypropylene fibers were added at the volume fractions up to 2%. Steel fiber content was varied as 0.25%, 0.50% and 0.75% and polypropylene fiber of 0.25% was kept constant for all the three mixes. Samples were cured at ambient and heat conditions. Workability of hybrid fiber geopolymer concrete reduces as the percentage of steel fiber increased.

Nisha et al. experimented the properties of hybrid fiber reinforced geopolymer concrete under ambient curing. Hybrid fiber was made with cribbed steel and polypropylene fibers. Steel fibers were added in the mix at varying percentages of 0, 0.25, 0.5, 0.75, and 1. Optimum percentage of steel fiber was replaced with polypropylene fiber in various percentages as 0, 10, 20, 30 and 40.strength properties were determined. Results showed that 0.5% steel fiber and 20% polypropylene fiber in steel fiber gave the maximum strength.

Elavarasan et al. studied the strength parameters on geopolymer concrete using steel and glass fibers. Steel fibers were added at 0.25, 0.5 and 0.75% and glass fiber content was kept constant at 0.03%. Mechanical properties of both ambient cured and heat cured samples were studied. Results showed an increase in compressive, tensile and flexural strength with increase in percentage of steel fibers.0.75% of steel fiber and 0.03% of glass fiber gave maximum compressive, tensile and flexural strength.

3.4 LITERATURE REVIEW ON DURABILITY STUDIES ON GEOPOLYMER CONCRETE

Ganesan et al. studied the durability characteristics of steel fiber reinforce geopolymer concrete and were compared with that of plain GPC and also with Portland based conventional concrete. Durability parameters considered included water absorption, abrasion resistance, resistance to chemical attack, effect of alternate drying and wetting and resistance against chloride. The steel fibers were added in volume fractions 0.25%, 0.5%, 0.75% and 1%. M30 conventional concrete were used for durability comparison. Micro structure properties such as water absorption, effective porosity and sorptivity were lower than Ordinary Portland Cement (OPC) concrete. The abration resistance obtained for steel reinforced GPC was 65%less than that for OPC concrete and GPC. Fiber reinforced geopolymer concrete and OPC concrete showed excellent acid and sulphate resistance when exposed to 3% H_2SO_4 solution. Chloride iron penetration was almost same for GPC and OPC concrete.

David et al. assessed durability parameters for geopolymer concrete made from class F fly ash. Durability study included water sorptivity, carbonation, chloride diffusion and Rapid Chloride ion Penetration Test (RCPT). The results were compared with durability of ordinary Portland and blended cement concrete. Sorptivity curve showed a non linearity in the initial stages and was due to high bleeding. Chloride diffusion of GPC showed favourable result than OPC and blended cement concrete. Initial carbonation resulted in low pH for GPC but pH increased after carbonation test. Sorptovity result obtained during the test shown in Fig 3.

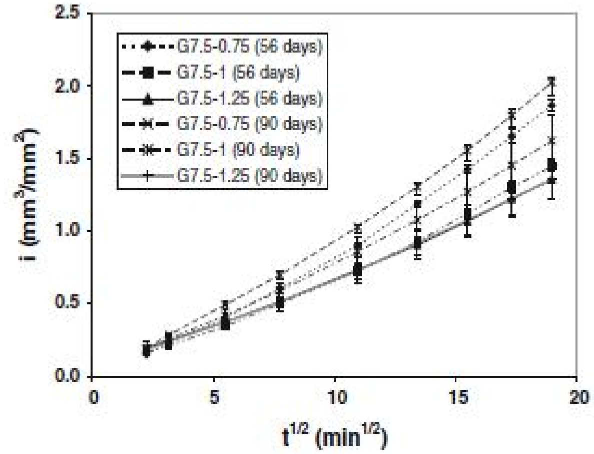

Fig 3.Sorptivity result,Absorption(i) versus square root of time for GPC at 56 and 90 days(Source: David.et.al 2014)

Prasanna et al. investigated the durability properties of geopolymer concrete made with GGBS and rice husk ash. Durability performance under sorptivity, RCPT and accelerated corrosion were studied. The test results showed that addition of rice husk ash reduced the sorptivity to a minimum at 10% replacement with rice husk ash and sortivity increased as its percentage was increased to 30%. 28 day RCPT showed minimum value for 10% rice husk ash and got increased gradually when percentage of rice husk ash increased. Higher corrosion initiation was observed at 20% replacement of rice husk ash. Sorptivity and RCPT results are shown in Fig 4 and Fig 5.

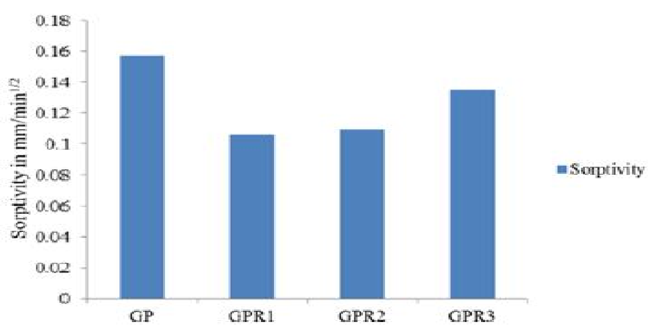

Fig 4.Sorptivity of GPC
Source (Prasanna.et.al.2015)

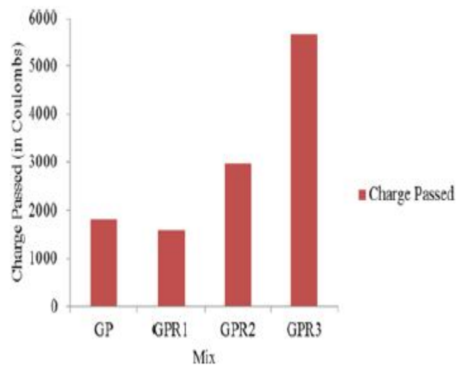

Fig 5.RCPT of GPC
Source (Prasanna.et.al.2015)

Prinya et al. assessed the resistance to acid and sulphate solution of high calcium fly ash concrete. Durability of GPC was evaluated in terms of strength after immersion for 3 and 6 months in 3% H_2SO_4 and 5% $MgSO_4$ and the results were compared with durability parameters of control mix. The compressive strength got reduced after sulphate resistance test due to deterioration of materials.

IV.CONCLUSION

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

- The compressive strength, tensile strength and flexural strength parameters were improved by the incorporation of steel and basalt fiber.
- Strength parameters were found to be more for addition of 1% steel fiber by volume of concrete.
- Mechanical properties of geopolymer concrete can be improved by adding hybrid fibers.
- Study reveals that GPC has good durability characteristics when compared to conventional concrete.

To explore more in this field study on the effect of steel and basalt hybrid fiber on the strength properties of geopolymer concrete to be studied.

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