A Review on Strength Properties of Fibre and Hybrid Fibre Reinforced Geopolymer Concrete

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Abstract - *Ordinary Portland Cement is the primary binder used in the production of conventional concrete. Due to the increasing ill-effects caused by portland cement production, there is a need to develop alternative binders to make concrete. The environmental threats include increased CO_2 emission and energy consumption. The development of Geopolymer concrete is an innovative step to address this problem. A lot of studies and researches are being carried out to explore the possibility of using geopolymer concrete as a green concrete in place of conventional cement concrete. Geopolymer binders are produced by polymeric reaction of alkaline liquid with alumino-silicate materials including the industrial wastes like fly ash, blast furnace slag, rice husk ash etc. Geopolymers are typically brittle and characterized by low tensile strength and fracture toughness. Fibres are added to reduce the brittle nature of geopolymer concrete. A brief review of research works done in the field of fibre and hybrid fibre reinforced geopolymer concrete is discussed in this paper.*

Key Words: Ordinary Portland cement, Geopolymer concrete, Blast furnace slag, Green binder, Brittle nature Hybrid fibre.

1. INTRODUCTION

Concrete is the most common, versatile, and reliable construction material in the world. The consumption of Ordinary Portland Cement (OPC) causes pollution to the environment due to the emission of CO_2 and to reduce the ill-effects to environmental due to OPC production, Geopolymer concrete (GPC) was introduced. Geopolymers are inorganic polymers synthesized via a chemical reaction between a highly alkaline solution and the Si–Al minerals present in the fly ash [17]. This process is termed geopolymerization. This results in a 3-D polymeric network consisting of Si–O–Al–O bonds with the formula of Mn−(SiO2)z−AlO2]·wH2O where M is an alkaline element, n is the degree of polymerization, z is a value between 1 and 32, and w is the hydration extent, which is a function of the type and amount of the alkaline solution used. Common aluminosilicate material used for producing geopolymer is fly ash and slag, which are both industrial byproducts and both of these materials have much lower carbon dioxide emission factor compared to cement [9]. The alkaline liquids 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].

Geopolymers in general emit less green-house gases due to their lower calciumcarbonate-based raw materials and production temperature. It was reported that the use of geopolymer could bring down the overall carbon dioxide emission by up to 64% in comparison with the use of cement [12]. Geopolymers exhibit high chemical and thermal stability, and have excellent adhesive behaviour, mechanical strength, and long-term durability [22]. The properties of geopolymer concrete includes high early strength, low shrinkage, sulphate resistance, freeze-thaw resistance and corrosion resistance [25]. The use of geopolymer technology not only helps in the reduction of CO_2 emissions by the cement industries, but also utilises the industrial wastes and by-products of alumino-silicate composition to produce added-value construction materials [5,12].

1.1 Fibre Reinforced Geopolymer Concrete

Fibre reinforced geopolymer concrete is relatively a new composite material where fibres are added in the matrix as micro reinforcement so as to improve the strength properties. Fibre reinforcement is the process by which fibrous materials are added in order to strengthen the matrix resulting in a product with increased performance specifications [26]. It is observed in concrete without fibres, there was development of the cracks due to plastic shrinkage, drying shrinkage and other reasons of changes in volume of Concrete [26]. The development of these micro cracks can induce elastic deformation of the concrete. The strong fibres pick up the load when the first crack occurs, thereby acting as the crack arresters. Fibres due to their lower price and excellent characteristics they impart to the concrete, makes them popular for its increased use in concrete in the recent years. The fibres which are usually used in geopolymer concrete are metallic fibres, synthetic fibres and natural fibres. They include glass, polypropylene, steel, basalt, carbon etc. The amount of fibres added to geopolymer mix is expressed as a percentage of the total volume of the composite which is same as in normal cement concrete [7]. The main factors affecting the properties of geopolymer fibre reinforced concrete are fibre matrix stiffness, aspect ratio of fibre, volume of fibres orientation of fibres, workability and compaction of concrete, size of coarse aggregate and mixing [1].

Fibres possessing lower modulus of elasticity are expected to enhance strain performance whereas fibres having higher modulus of elasticity are expected to enhance the strength performance [14].

1.2 Hybrid Fibre Reinforced Geopolymer Concrete

The use of a single type of fiber may improve the properties of geopolymer concrete only to a limited level. It has been observed that the concept of hybridization of two different fibres included in a common cement matrix can offer more attractive engineering properties because the presence of one fiber allows the more effective utilization of the potential properties for the other fiber [3]. Many studies using mono fibres such as steel, glass, polypropylene fibres, among others are being carried out. Hybrid Fibre Reinforced geopolymer Concrete (HFRGPC) is formed from different types of fibres, which differ in material properties. They remain bonded together when added in concrete and retain their identities and properties [18]. The hybridized fibres exhibits improvement in the compressive strength due to the better mechanical bond between the fibres and binding matrix which delays micro crack formation [7]. The hybridization of fibres may play key roles in arresting cracks and there by helps in gaining high performance of concrete.

The major factors to be considered upon selecting a type of fibre comprises fibre volume, fibre geometry, fibre orientation and fibre distribution. However, hybridization can proffer more attractive engineering properties as the presence of one fibre permits the more efficient utilization of the potential properties of the other fibre. The mixing of hybrid fibres makes the concrete homogeneous and isotropic and therefore it is transformed from brittle to more ductile material. The applications of hybrid fibre reinforced geopolymer concrete in various civil engineering include precast concrete pipe, highway pavement, airport runway, industrial flooring, etc.

The benefit of hybrid fibres system is to contribute a system in which one type of fibre, which is stronger and stiffer enhances the first crack stress and ultimate strength, while the second type, being flexible and ductile, assists in improved toughness and strain capacity in the post-cracking zone. Hybridization also reduces crack widths which leads to a higher tensile strength of the composites.

2. REVIEW OF LITERATURE

In recent years, many studies were conducted by various researchers on the field of geopolymer concrete. This paper reviews various researches done to evaluate the properties of fibre reinforced and hybrid fibre reinforced geopolymer concrete with emphasis on Polypropylene and Glass fibre. A comparative study on various results obtained is also presented.

2.1 Studies on Fibre Reinforced Geopolymer Concrete

Thamer Alomayri [22], introduced various amounts of glass microfibres into the geopolymer concrete, and investigated the influence of these microfibres on the performance of the geopolymer composites. The glass microfibre was at the dosages of 0%, 1%, 2% and 3% by weight. It is observed that the geopolymer composites displayed some non-linearity during fracture whereas a linear behaviour was observed for plain geopolymer. There is a rapid decline in the stress during the post-peak softening which indicates less toughness. The specimens reinforced with glass microfibre exhibited the ability to carry higher strain level especially addition of 2 % wt of glass fibre compared to the unreinforced geopolymer. But the addition of 3% wt of glass fibres gives the maximum value of stress. The crack arresting, bridging mechanisms and crack deflection results in non-linear stress-strain curves for the geopolymer composites. This implicits the feasibility of using glass microfibres to reduce the brittle failure in geopolymers. Glass microfibres may act as stoppers to crack growth by bridging the cracks.

Bhalchandra and Bhosle [4] experimentally investigated mechanical properties of glass fibre reinforced fly ash based geopolymer concrete with 28 days design strength. The effects of glass fibers on compressive strength, density, and flexural strength of hardened geopolymer concrete composite were studied. Glass fibers were added to the mix in 0.01%, 0.02%, 0.03% & 0.04% by volume of concrete. Compressive strength & flexural strength of glass fibre reinforced geopolymer concrete increases with respect to increase in percentage volume fraction of glass fibres from 0.01%,0.02%,0.03% & 0.04%. The addition of 0.03% volume fraction of glass fibres shows maximum increase in compressive strength and flexural strength. Also, it was observed that the glass fiber reinforced geopolymer concrete showed relatively higher strength in short curing time than that of geopolymer concrete and Ordinary Portland cement concrete.

Vijai et al. [25] discussed the mechanical properties of GPC composites, which contain fly ash, alkaline liquids and glass fibers with alkaline liquids to fly ash was fixed as 0.4. The glass fibers were mixed in the proportion of 0.01%, 0.02% and 0.03% of total volume of concrete. Addition of 0.03% volume fraction of glass fibers enhanced the compressive strength, split tensile strength and flexural strength of GPC.

Sathish et al. [19] in their experimental research find out the mechanical properties of glass fibre reinforced geopolymer concrete composites. Glass fibres were added to the mix in 0.01%, 0.02% and 0.03% by volume of concrete. With addition of 0.02% glass fiber, the increase in compressive strength and split tensile strength was 20%. The increase in compressive strength was about 10% for 0.01% and 20% for 0.02% with respect to GPC mix and decrease in compressive strength was about 5% for 0.03% with respect to 0.02% addition of glass fibre.

Table -1: Comparison of strength parameters of GPC with glass fibre

Author	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	With out fibre	With fibre	With out fibre	With fibre	With out fibre	With fibre

Vijay et al.[25]	28.49	38.28	1.33	3.02	5.4	6
Balachandra et al.[4]	36.33	43.67	-	-	4	5.96
Satish et al.[19]	24.26	28.74	1.93	2.5	-	-
Patil et al.[16]	35.88	38.72	3.65	4.05	10.28	12.10
Venugopal et al.[24]	25.03	26.43	3.93	4.37	3.52	4.06
Aswani[2]	38.47	39.2	3.41	3.51	3.3	3.7

Saradha & Rajasekhar [18] experimentally investigated the effect of polypropylene fibers on the mechanical properties of geopolymer concrete. Polypropylene fibers of dosage of 0.1%, 0.15%, 0.2%, and 0.25% by volume of concrete respectively is added. The mechanical properties were analysed for 28 days curing and there was a significant increase in compressive strength, flexural strength with the increase in percentage of polypropylene fiber from 0% to 0.2%. The improvement in mechanical properties mainly due to the blending of concrete with fibers by filling the voids and increases the compressive strength of the concrete, therby increasing the other mechanical properties.

Subbiah et al. [21] experimentally investigated geopolymer concrete mix with polypropylene fibres. They inferred that the low calcium fly ash based fibre geopolymer concrete had excellent compressive strength and was suitable for structural applications. 7.7% increase in compressive strength was noticed by the addition of PP fiber to the GPC. They concluded that the elastic properties of hardened fibre geopolymer concrete, the behaviour and the strength of fibre geopolymer concrete structural members are similar to those observed in the case of Portland cement concrete.

Patil et al. [16] conducted an experimental program to find out the mechanical properties of polypropylene fiber reinforced geopolymer concrete. The effects of inclusion of polypropylene fibers on mechanical properties 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. It was observed that the polypropylene fiber reinforced geopolymer concrete had relatively higher strength than GPC & OPC concrete.

Table -2: Comparison of strength parameters of GPC with polypropylene fibre.

Author	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	With out fibre	With fibre	With out fibre	With fibre	With out fibre	With fibre
Saradha et al. [18]	40.54	46.24	-	-	4.24	4.9

2.2 Studies on Hybrid Fibre Reinforced Geopolymer Concrete

Thaarrini et al. [23] experimentally investigated the addition of steel and polypropylene fibres in GPC and is to be added at the volume fractions upto 2%. Polypropylene fibre of 0.25% is kept constant and steel fibres of about 0.25%, 0.50% and 0.75% are varied. It was observed that the compressive strength, splitting tensile strength and flexural strength of hybrid fibre reinforced geopolymer concrete composites increases with respect to the increase in the percentage volume fraction of steel fibre from 0.25 to 0.75% and polypropylene fibre volume fraction as 0.25%.

Nisha Khamar et al. [15] analysed the properties of hybrid fibre reinforced geopolymer concrete under ambient curing crimped steel fibres with aspect ratio 60 were added in the mix at percentages of 0, 0.25, 0.5, 0.75 and 1. As the percentage of polypropylene increased, the fresh properties got decreased. From the compressive strength test, in comparing to GPC, hybrid fibre reinforced GPC has showed an increase in strength of 40% at 28 days and 37% at 56 days and comparing to steel fibre reinforced GPC, hybrid fibre reinforced GPC has showed an increase in strength of 20% at 28 days and 24% at 56 days. Percentage increase in flexural strength of hybrid fibre reinforced GPC was 49 % when compared to GPC and 23% compared to steel fibre reinforced GPC.

Devika et al. [6] investigated the impact of steel fibres and hybrid polypropylene- steel fibres on the mechanical flexural behavior of GPC. Crimped steel fibre with varying percentages (0%, 0.25%, 0.5%, 0.75% & 1%) is adopted in this study. And then polypropylene fibre is added to the optimum steel fibre mix with varying percentages (0%, 10%, 20%, 30% & 40%). The addition of fibres changes its brittle behavior to ductile with significant improvement in tensile strength, tensile strain, toughness and energy absorption capacities. The results of the experimental program reveal that mechanical properties of GPC are improved with the addition of fibres and also improve the load carrying capacity of beams. The workability of concrete had been found to decrease with increase of fibre content in concrete. It might be due to viscous nature of geopolymer concrete and uneven distribution of fibres in the mix.

Table -3: Comparison of strength properties of hybrid fibre (steel & polypropylene) reinforced concrete

Author	Compressive Strength (MPa)		Tensile Strength (MPa)		Flexural Strength (MPa)	
	With out fibre	With fibre	With out fibre	With fibre	With out fibre	With fibre
Devika et al. [6]	43.51	54.32	2.44	4.14	4.61	7.28
Nisha et al.[15]	40	52.5	2.5	4.1	4.9	6.6
Thaarini et al. [23]	32.05	38.91	1.28	2.19	4.2	5.36

3. CONCLUSIONS

Geopolymer concrete is an excellent alternative to OPC concrete. GPC is a better construction material and this will reduce the consumption of OPC which will help in reducing the consumption of natural resources, minimising the emission of CO_2 and other environmental threats associated with the production of OPC.

- Inclusion of fiber in GPC showed considerable increase in strength parameters as compared to GPC without fiber.
- Glass fibre reinforced geopolymer concrete exhibits more compressive strength, flexural strength and split tensile strength when compared to polypropylene fibre reinforced geopolymer concrete.
- With the addition of 0.03% volume of glass fibre, better result of compressive strength, flexural strength and split tensile strength was obtained from the literature studies.
- Addition of 1.5% volume fraction of polypropylene fibers of 20mm showed maximum increase in compressive strength, and flexural strength than the hybrid of 3 0.75% fiber of 12mm + 0.75% fiber of 20mm.
- The high strain capacity in the geopolymer composite is attributed to the contribution of the reinforcing glass microfibres to crack arresting and bridging. The presence of glass microfibres delays the formation of the first crack, enable the composites to accommodate large strains before failure.
- Unlike plain geopolymer the presence of microfibres imparts considerable energy absorption capacity to stretch and debond the microfibres before the complete fracture of the material occurs. This implies the feasibility of using glass microfibres to lessen the brittle failure in geopolymers.
- The hybrid combination of metallic and non-metallic fibres have significant effect on the compressive, tensile and flexural strength of GPC. Strength parameters are found to be increased with respect to increase in percentage volume fraction of metallic fibres in geopolymer fibre concrete.
- Improved tensile strength can be achieved by increasing the percentage of steel fibres. The higher number of fibres bridging the diametric ‘splitting’ crack, the higher would be the spilt tensile strength. The easy availability of PP fibres, combined with the high stiffness of steel fibres, resulted in the enhancement of the split tensile strength of GPC.

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