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REVIEW ARTICLE

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FIBRE AND HYBRID FIBRE REINFORCED GEOPOLYMER CONCRETE– A REVIEW

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ABSTRACT

In The utilization of cementing material such as silica fume, flyash, granulated blast furnace slag, rice-husk ash and metakaolin are new trend in concrete studies. Ordinary Portland cement utilizes significant amount of natural resources and pollutes the atmosphere by emitting large amount of carbondioxide.so to reduce this ill effect, a new research field is developed in concrete called geopolymer concrete. In geopolymer composite products, the inorganic alumina silicate polymer gel is synthesized from source material which is rich in silicon and aluminum, which has low calcium (class F) flyash, which binds the loose aggregate, and other unreacted materials in the produced geopolymer mix. Fibres play a vital role in geopolymer concrete, mainly due to their low price, easy availability, excellent characteristics in improving tensile strength, flexural strength, resistance to plastic shrinkage during curing and crack propagation by controlling the crack widths tightly, thus improving durability. This paper briefly reviews the various research work done in the area of fibre and hybrid fibre reinforced geopolymer concrete and its strength properties.

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INTRODUCTION

The two main problem faced by construction industry are global warming and waste disposal. The waste effluents sludge and by products such as large quantities of flyashthat are produced during the combustion of coal is used for electricity generation. Most of this ash is disposed in landfills at suitable sites. The disposal of such waste must meet at least two conditions (DivyaKhale and Rubina Chaudhary, 2007).

- Safe chemical encapsulation - control their release into ground water and seepage water.
- Structural stability with respect to adverse environmental condition.

At the same time Global warming is also one of the biggest social, political, economic and environmental issues which is caused by the emission of greenhouse gases such as carbon dioxide, methane and nitrous oxide into the atmosphere.

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It is reported that the production of cement imparts about 5-7 % of carbon dioxide emissions globally and about 5 -10% of dusts as a result of decarbonation of lime in kiln to atmosphere (Korniejenko *et al*., 2016). In order to reduce environmental effects related with cement, the need to develop alternative binders to make concrete is essential. One way to produce an eco-friendly concrete is to replace the quantity of Portland cement partially or fully with by-product materials such as fly ash, blast furnace slag, rice husk etc. For that geopolymer emerged as a possible solution. Geopolymer based materials are environmental friendly and need only moderate energy to produce. Carbon dioxide emission can be reduced upto 80% compared to that of ordinary Portland cement. A polymeric structure, Al – O – Si bond formed during depolymerisation constitutes the main building block of geopolymeric structure. Geopolymers possesses excellent mechanical strength due to high degree of polycondensation (DivyaKhale and Rubina Chaudhary, 2007). Strength of Geopolymer concrete decreases as the ratio of water-to-geopolymer solid by mass increases; this trend corresponds to the water-to-cement ratio in the compressive strength of OPC. Fresh geopolymeric material is readily workable even at a very low liquid/solid ratio i.e. below 0.4. The strength depends on both the Si:Al and Na:Al ratios of the material. pH range in 13–14 is the most suitable for the formation of the geopolymers with good mechanical strength. Alkali concentration in the range of 5–10 M plays a vital role in the formation of geopolymer. Geopolymer concrete support low creep and verylittle drying shrinkage. Young's modulus, Poisson's ratio and Tensile strength of low calcium fly ash based geopolymer concretes acquires the characteristics similar to Portland cement concrete (DivyaKhale and Rubina Chaudhary, 2007). Fibres are small piece of reinforcing material used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They also reduce the permeability of concrete and thus reduce bleeding of water. Geopolymer Fibre reinforced concrete is the composite material containing fibres in the geopolymer matrix in an orderly manner or randomly distributed manner. Its properties certainly depends upon the efficient transfer of stress between matrix and the fibres (Enther Thanon Dawood and Mahynddin Ramli, 2011).

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 (Aswani and LathiKarthi, 2017). 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 (Enther Thanon Dawood and Mahynddin Ramli, 2011). Usually used fibres in geopolymer concrete are metallic fibres, synthetic fibres and natural fibres. This paper reviews various researches done to test 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.

Fibre Reinforced Geopolymer Concrete

Steel reinforcement is the common method of reinforcing the tensile strength of geopolymer concrete, but it is expensive (8). The addition of fibres to geopolymer material works on a similar theory whereby fibres act to transmit tensile forces across a crack (Divya Khale and Rubina Chaudhary, 2007). Fibres to reinforce can be placed into two categories based on the elastic moduli of fibres:

- Fibres with lower elastic moduli than the cement matrix (such as cellulose, nylon, polypropylene)
- Fibres with higher moduli than the cement matrix (such as asbestos, glass, steel etc.)

Fibres having lower modulus of elasticity to enhance strain performance whereas fibres having higher modulus of elasticity are expected to enhance the strength performance (Navid Ranjbar *et al.*, 2016). The modulus of elasticity of matrix must be much lower than that of fibre for efficient stress transfer (Mahyuddin Ramli and Eether Thanam Dawood, 2011). Fibres are also able to control the propagation of shrinkage crack in fresh concrete, suppresses all brittle behaviour, enhances the ductility and the post crack strength of concrete (Enther Thanon Dawood and MahynddinRamli, 2011). The performance of fibres in geopolymer matrices depends on the inherent properties of fibres, fibre content, geopolymer precursor, the dispersion ,contact of fibre and geopolymer matrix, curing condition and age of concrete (NavidRanjbar *et al.,* 2016). Studies on fibre reinforced geopolymer conforms that curing temperature and curing time significantly influences the strength parameters. Curing temperature is an important factor in the setting of the geopolymer but curing at higher temperature for more than a couple of hours greatly affect the development of strength. Increase in strength for curing periods beyond 48 h was not very significant (Divya Khale and Rubina Chaudhary, 2007). In this review polypropylene fibre and glass fibre is used for comparative study. Glass fibre is made up from 200-400 individual filaments which are lightly bonded to make up a stand. These stands can be chopped into various lengths, or combined to make cloth mat or tape (Navid Ranjbar *et al.*, 2016). The commonly used glass fibres are e-glass. Polypropylene is one of the cheapest and abundantly available polymers polypropylene fibres are resistant to most chemical.

Comparison of Strength Parameters on Fibre Reinforced Geopolymer Concrete on 28 days

Based on the above comparison, it was observed that Compressive strength, flexural strength and split tensile strength was found to be more for glass fibre reinforced geopolymer concrete as compared to polypropylene fibre reinforced geopolymer concrete. Heat cured fibre reinforced geopolymer concrete had high strength parameters than ambient cured fibre reinforced geopolymer concrete.

Hybrid fibre reinforced geopolymer concrete

Different types of fibres are used in geopolymer concrete mixes for obtaining favourable advantage from the concept of hybridization of fibres. There are many studies using mono fibres such as steel, glass, polypropylene fibres, among others. The effect of hybrid fibres on geopolymer concrete have gained popularity due to the decrease in compressive strength. Moreover, the use of a single type of fibre may improve the properties of GFRC (geopolymer fibre reinforced concrete) to a limited level (Enther Thanon Dawood and Mahynddin Ramli, 2011). Hybrid geopolymer Fibre Reinforced Concrete (HGFRC) 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 (Selina Ruby *et al.*, 2014). The hybridized fibres can show enhancement in the compressive strength due to the better mechanical bond between the fibres and binding matrix which delays micro crack formation (Enther Thanon Dawood and Mahynddin Ramli, 2011). The hybridization of fibres may play important roles in arresting cracks and thus can achieve high performance of concrete. The main disadvantage of incorporating a fibre in concrete is the loss of workability and difficulty in casting. As a result high volumes of air is entrapped in concrete which results in reduction of strength and durability. Nowadays concrete can be designed to have a high workability that allows the concrete to have required flow in the congested reinforcement areas and fill complicated formwork without segregation. The main factors to consider while selecting a type of fibre incudes fibre volume, fibre geometry, fibre orientation and fibre distribution. However, the concept of hybridization can offer more attractive engineering properties as the presence of one fibre enables the more efficient utilization of the potential properties of the other fibre. This leads to an improved flexural rigidity and has great potential for crack control, although the volumetric density is high (Enther Thanon Dawood and Mahynddin Ramli, 2011). The hybrid combination of metallic and non-metallic fibres can offer potential advantages in improving concrete

Table 1. Comparison of compressive strength on fibre reinforced geopolymer concrete

Author and year	Type of GPC	Fibres used	Compressive strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	Without fibres	With fibres	Without fibres
Bhalachandra and bhosle (2010)	100 % flyash	Glass fibre	43.67	36.33	No results	No results
Thomas et al. (2012)	100 % flyash	Glass fibre	24.26	28.74	-	-
Patil et al. (2015)	100 % flyash	*PP fibre	39.20	3588	-	-
Subbiah et al. (2013)	100 % flyash	*PP fibre	28.5	26.5	-	-
Vijay et al. (2012)	90% flyash and 10% OPC	Glass fibre	39.47	28.49	38.28	22.18

* PP – Polypropylene fibre

Table 2. Comparison of split tensile strength on fibre reinforced geopolymer concrete

Author and year	Type of GPC	Fibres used	Split tensile strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	Without fibres	With fibres	Without fibres
Thomas et al. (2012)	100 % fly ash	Glass fibre	2.5	1.93	-	-
Vijay et al. (2012)	90% flyash and 10% OPC	Glass fibre	3.02	1.33	2.67	1.17
Patil et al. (2015)	100 % fly ash	*PP Fibre	4.16	3.65	-	-

PP – Polypropylene fibre

Table 3. Comparison of flexural strength on fibre reinforced concrete

Author and year	Type of GPC	Fibres used	Flexural strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	With-out fibres	With fibres	With-out fibres
Vijay et al. (2012)	90% flyash and 10% OPC	Glass fibre	6	5.4	5.84	5
Thameralomayri (2017)	100 % fly ash	Glass fibre	-	-	7.8	3.2
Bhala-chandra and bhosle (2010)	100 % fly ash	* PP fibre	6.28	4	-	-
Patil et al. (2015)	100 % fly ash	* PP fibre	12.73	10.28	-	-

Table 4. Comparison of compressive strength on hybrid fibre reinforced concrete

Author and year	Type of GPC	Hybrid fibres	Compressive strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	Without fibres	With fibres	Without fibres
Devika and deepthi (2013)	100 % fly ash	Steel and *PP Fibres	-	-	54.32	43.51
Nisha and reshmi (2013)	100 % fly ash	Steel and *PP Fibres	-	-	52.5	40
Thaarini et al. (2015)	100 % fly ash	Steel and PP fibres	42.08	21	38.91	32.05
Venkata subramani (2015)	100 % fly ash	Steel and glass fibre	30.08	25.09	29.17	24.75

* PP – Polypropylene fibre

Table 5. Comparison of split tensile strength on hybrid fibre reinforced concrete

Author and year	Type of GPC	Hybrid fibres	Split tensile strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	Without fibres	With fibres	Without fibres
Devika and deepthi (2013)	100 % fly ash	Steel and *PP fibre	-	-	4.14	2.44
Nisha an reshmi (2013)	100 % fly ash	Steel And *PP fibre	-	-	4.1	2.5
Thaarini et al. (2015)	100 % fly ash	Steel and *PP fibre	3.76	1.57	2.19	1.28
Venkatasubramani (2015)	100 % fly ash	Steel and glass fibre	2.78	1.53	2.68	1.42

* PP – Polypropylene fibre

Table 6. Comparison of flexural strength onhybrid fibre reinforced concrete

Author and year	Type of GPC	Hybrid fibres	Flexural strength (MPa)			
			Heat curing		Ambient curing	
			With fibres	Without fibres	With fibres	Without fibres
Devika and deepthi (2013)	100 % fly ash	Steel and *PP fibre	-	-	7.28	4.61
Nisha an reshmi (2013)	100 % fly ash	Steel and *PP fibre	-	-	6.6	4.9
Thaarini et al. (2015)	100 % fly ash	Steel and *PP fibre	5.73	4.85	5.36	4.2
Venkatasubramani (2015)	100 % fly ash	Steel and glass fibre	5.07	3.47	4.31	3.34

* PP – Polypropylene fibre

properties as well as reducing the overall cost of concrete production. The mixing of hybrid fibres makes the concrete homogeneous and isotropic. Itconvert material behavior from brittle to ductile and is utilized for various applications (Selina Ruby *et al.*, 2014).

The advantage of hybrid fibres system is to provides a system in which one type of fibre, which is stronger and stiffer. It improves the first crack stress and ultimate strength, whereas the second type of fibre, which is more flexible and ductile, leads to the improved toughness and strain capacity in the post-cracking zone. It also contributes to a hybrid reinforcement to reduce crack widths. This leads to a higher tensile strength of the composite. In this review blend of polypropylene fibre and glass fibre on steel fibres is used for comparative study.

Comparison of Strength Parameters on Hybrid Fibre Reinforced Concrete on 28 days

Majority of the studies were conducted with a combination of metallic fibre with non-metallic fibres. From tables 4-6, it is evident that hybrid combination of metallic and non-metallic fibres have significant effect on the compressive, tensile and flexural strength. Strength parameters are found to increase with respect to increase in percentage volume fraction of steel fibres in both geopolymer and geopolymer fibre concrete. The combination of steel and polypropylene fibre has better performance than combination of steel with glass fibresbecause of the high elastic modulus of steel fibre and the low elastic modulus of polypropylene fibre. 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 (6). Heat cured hybrid fibre reinforced geopolymer concrete had high strength parameters than ambient cured hybrid fibre reinforced geopolymer concrete.

Conclusion

From the literatures reviewed, it is clear that fibres can play a vital role in modifying the strength properties of geopolymer concrete and the following conclusions can be derived,

- Compressive strength, flexural strength and split tensile strength was found to be more for glass fibre reinforced geopolymer concrete as compared to polypropylene fibre reinforced geopolymer concrete.
- Heat cured fibre reinforced geopolymer concrete had high strength parameters than ambient cured fibre reinforced geopolymer concrete.
- The hybrid combination of metallic and non-metallic fibres have significant effect on the compressive, tensile and flexural strength. Strength parameters are found to be increased with respect to increase in percentage volume fraction of steel fibres in both geopolymer and geopolymer fibre concrete.
- Heat cured hybrid fibre reinforced geopolymer concrete had high strength parameters than ambient cured hybrid fibre reinforced geopolymer concrete

Studies show that the inclusion of fibre on geopolymer concrete exhibited higher compressive, flexural and tensile strength. Most of the researchers were conducted either with glass fibre or polypropylene fibre or with the combination of other fibres like natural fibres, metallic fibres etc., in conventional and geopolymer concrete. The above reviewed studies shows that hybrid fibre gopolymer concrete can make significant change in strength properties. Reviews on Hybrid fibre geopolymer concrete using glass fibre and polypropylene fibres are comparatively lesser in number and study on the same might produce high strength geopolymer concrete with much less expenses when compared with the commonly used metallic fibres.

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