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Glass Fibre Concrete: Investigation on Strength and Fire Resistant Properties

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Abstract: *Over the decades, there has been a significant increase in the use of fibres in concrete for improving its properties such as tensile strength and ductility. The fibre concrete is also used in retrofitting existing concrete structures. Among many different types of fibres available today, glass fibre is a recent introduction in the field of concrete technology. Glass fibre has the advantages of having higher tensile strength and fire resistant properties, thus reducing the loss of damage during fire accident of concrete structures. In this investigation glass fibres of 450 mm length are added to the concrete by volume fraction of up to 1% to determine its strength and fire resistant characteristics. Comparison of the strength and fire-resistance performance of conventional concrete and glass fibre concrete was made. The paper presents the details of the experimental investigations and the conclusions drawn there from.*
Key words*: Concrete, Glass fibre, Volume Fraction, Strength properties, Fire resistant characteristics.*

I. Introduction

Generally, concrete is strong in compression and weak in tension. Concrete is brittle and will crack with the application of increasing tensile force. Once concrete cracks it can no longer carry tensile loads. In order to make concrete capable of carrying tension at strains greater than those at which cracking initiates, it is necessary to increase the tensile strength. To increase the tensile and flexural strength, fibres are added in concrete. The addition of fibres to concrete will result in a composite material that has properties different from those of un-reinforced concrete. The extent of this variation depends not only on the type of fibres, but also on the fibre dosage.

The incorporation of fibres into a brittle concrete can have the effect of controlling the growth and propagation of micro cracks as the tensile strain in the concrete increases. Care is needed in using fibre as additive in concrete. The use of fibres in concrete has increased with the development of fast-track construction. In fact, nearly 65 per cent of the fibres produced worldwide is currently used in concrete. It offers increasing toughness and ductility, tighter crack control and improved load-carrying capacity. Different types of fibres are available in the market for reinforcing concrete and they are: steel, glass, acrylic, aramid, carbon, nylon, polyester, polyethylene, polypropylene, etc. Besides, natural fibres like sisal, wood cellulose, banana, jute, etc., have also been used. From the above mentioned fibres, glass fibre is more advantageous on the basis of strength and fire resistant characteristics.

It has been recognized that adding small, closely spaced and uniformly dispersed fibres to concrete serves to arrest cracks and improve its properties under static and dynamic loading. Round steel fibre is the most common variety in use for improving the tensile, flexural, impact and fatigue strength of concrete. The ductility and toughness of concrete are also improved with the addition of this fibres. Steel fibre have been used in various types of structures such as earthquake resistant structures, road overlays, airfield pavements and bridge decks. Alkali resistant glass fibre reinforcement is a relatively new addition to the family of fibres that impart high tensile strength, high stiffness, high chemical resistance and considerable durability to FRC (Fibre Reinforced Concrete). Adding polyesters fibre to concrete pavements resulted in the developments of the micro shrinkage cracks induced during hydration. These fibres improve the flexural strength and energy absorption of concrete .

Glass fibres are useful because of their high ratio of surface area to weight. However, the increased surface area makes them much more susceptible to chemical attack. By trapping air within them, blocks of glass fibre makes good thermal insulation, with a thermal conductivity of order of 0.05 w/(mk). The strength of the glass fibre is usually tested and reported for “virgin” or pristine fibres those which have just been manufactured. The freshest and thinnest fibers are more ductile. The more the surface is scratched, the less the resulting tenacity. Because glass has an amorphous structure, its properties are the same along the fiber and across the fiber. Humidity is an important factor in the tensile strength. Moisture is easily absorbed, and can worsen microscopic cracks and surface defects, and lessen tenacity. Glass fibres improve the strength of the material by increasing the force required for deformation and improve the toughness by increasing the energy required for crack propagation. FRC is a relatively new material. This is a composite material consisting of a matrix containing a random distribution or dispersion of small fibres, either natural or artificial, having a high tensile strength. Due to the presence of these uniformly dispersed fibres, the cracking strength of concrete is increased and the fibres act as crack arresters. Fibres suitable of reinforcing concrete have been produced from steel, glass and organic polymers. Many of the current applications of FRC involve the use of fibres ranging around 1-5%, by volume of concrete.

Chandramouli et al (2010) had conducted experimental investigation to study the effect of using the alkali resistance glass fibres on compressive, split tensile and flexural strength on M20, M30, M40 and M50 grades of concrete. The mechanical properties of glass fibre reinforced polyester polymer concrete were evaluated. The author observed that the modulus of rupture of polymer concrete containing 20 per cent polyester resin and about 79 per cent fine silica aggregate is about 20 MPa. The addition of about 1.5 per cent chopped glass fibres (by weight) to the material increases the modulus of rupture by about 20 per cent and the fracture toughness by about 55 per cent.

Naaman (1977) described the range of tensile properties currently achievable using HPFRCC (High Performance Fibre Reinforced Cement Concrete) focusing in particular on the trade-off between strength and strain capacity and the importance of large strains. Also, a brief summary of three representative applications involving the use of HPFRCC in repair and rehabilitation is givan namely, 'the use of fibres in the tensile zone of reinforced concrete beams to control cracking and improve durability', the use of Simcon for repair and reinforced concrete beams and columns to satisfy seismic requirements and the use of Simcon as a jacket in reinforced concrete columns, also to improve seismic resistance.

Muthuswamy and Thirugnanam (2013) described the experimental work on Hybrid Fibre Reinforced High Performance concrete using three types of fibres namely, steel, glass and polyester fibres of a reputed brand. Slica fume was added as a mineral admixture to partially replace the cement in concrete and a super plasticizer was used to get the desired workability. A comparison with steel fibre reinforced concrete and plain concrete showed significant improvement in the strengths of the hybrid fibre reinforced concrete due to the inclusion of both fibres and silica fume.

Bantia et al (1997) studied the performance of E-glass and AR-Glass fibre reinforced composites with the cementitious matrices. The results were compared with those of ordinary Portland cement composites. It was shown that by adjusting the composition of the matrix, there is a potential for developing highly durable fiber – cement composites, even with E – glass, which is probably the most sensitive to corrosion of the man – made high strength fibers

Bentur and Kovler (1997), has observed that the use of low percentages of synthetic fibers is significantly effective in floor slab applications. Low fiber content is defined as less than an equal to 0.3 percent by volume of concrete mix. The paper is the results of the experimental investigation of the effect of low percentages of nylon and polypropylene fibers on slump, inverted slump cone time, air content, compressive and flexural behaviour and impact resistance of concrete. Three percentages of fibres, viz., 0.15%, 0.22%, and 0.30% by volume of concrete mix with one fiber length (25 mm) were used. It is observed that the addition of fibers reduces workability of the concrete and there is no significant effect on the compressive strength of concrete. Marginal increase in flexural strength of the order of 10 to 22% with nylon fibers and 8 to 15.5% with polypropylene fibers is observed. Nylon and polypropylene fibers also exchanges the ductility of concrete. Both the fibers increases the impact strength considerably. The increase in impact strength is 206 kN to 373 kN with nylon fibers.

Siddique (1997) has stated that the effectiveness of fibers in controlling shrinkage and thermal cracking in cement based materials is well recognized. For any cement based composite, however, the type of fiber and its aspect ratio are the two most important factors controlling such cracking. In this investigations four types of polyolefin fibers namely, l/d = 19/15, 25/15, 25, 38 and 50/63 were used wherein l is the length of the fiber and d is the equal diameter. Type 19/15, for example is 19 mm long and 0.15 mm in equal diameter and manufactured by the 3M Corporation. A novel technique developed at UBC was employed for the purpose. In this technique fibre reinforced concrete to be tested is laid on top of a fully hardened base concrete which provided the bottom restraint, and resulted in cracking in the overlay which was then monitored as a function of time. It was noted that while the polyolefin fibers are generally effective in reducing the amount and size of the shrinkage cracking of the fibers as they have a decisive influence on the result.

Chawla and Tekwari (2012) outlines the experimental investigation conducted on the use of glass fibres with structural concrete. CEM-FILL anticrack high dispersion, alkali resstance glass fibre of diameter 14 micron, having an aspect ratio 857 was employed in percentages varying from 0.33 to 1 percent by weight in concrete and properties of this FRC, like compressive strength, flexural strength toughness, modulus of elasticity, were studied.

Sinha et al (2013) studied the effect of ternary blends on the strength characteristic of steel fibers reinforced concrete. Both binary and ternary blends were made using SCMs such as fly ash, ground slag, silica fume, granulated blast furnace, and metakaolin. Thirty percent of cement was replaced by one SCM or combination of two SCMs. The results of compressive strength and tensile strength are presented.

Experimental Programme

Conventional concrete of M25 grade was used in this investigation using glass fiber as reinforcement with varying percentages of 0 to 1.5. The basic materials were tested to evaluate their properties. The rheological properties such as slump (Fig. 1) and compaction factor were studied. Control specimens such as cubes, cylinders, prisms were cast and tested at 7 and 28 days to determine the mechanical properties. The results of strength testing at 7 and 28 days are presented in Table 1.

Fire Resistant Test

The concrete cubes were subjected to elevated temperature of 300°C for two hours duration. Afterwards they were tested under Compression Testing Machine to determine their residual strength as, generally, the compressive strength of the concrete will be reduced after it is heated. The objective of this study here is to determine whether the glass fibre concrete is highly resistant to fire as compared to conventional concrete.

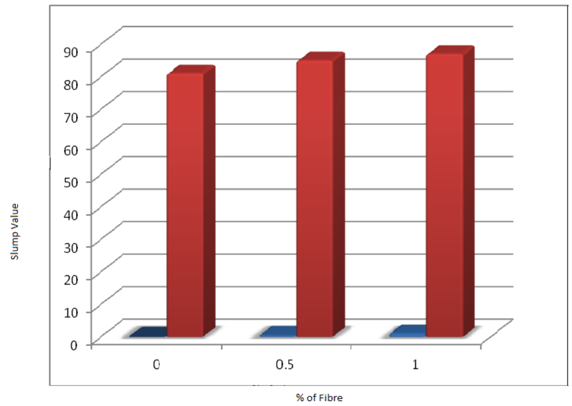

Fig.1. Slump test results

Table 1 Results of strength testing of concrete

Per centage addition of fibre	Strength (MPa)					
	7 days			28 days		
	Compressive	Split tensile	Flexural	Compressive	Split tensile	Flexural
0.0	23.10	2.91	6.66	31.53	3.34	7.24
0.5	24.01	3.61	9.66	35.66	4.04	10.29
1.0	26.07	3.83	10.66	42.87	4.66	12.67

II. Results And Discussion

From Table 1 it is obvious that the 28 day compressive strength of control concrete is 36 per cent higher than that at 7 day's strength and that of fibre reinforced concrete varies from 49 to 64. Therefore reinforcing with glass fibre contributes immensely in enhancing the compressive strength of concrete and the increase is 1.78 times that of normal concrete. Similarly, the split tensile strength of concrete without fibre is 15 per cent higher than that at 28 day strength when compared to 7 day strength. The 28 day split tensile strength of glass fibre reinforced concrete is about 40 per cent higher than that of normal concrete for all percentages of fibre addition. The 28 day flexural strength of glass fibre reinforced concrete is 9 per cent greater that that at 7 days. The increase in flexural strength of fibre reinforced concrete at 28 day ranges from 42 per cent to 75 percent. These parameters establish the supremacy of glass fibre reinforced concrete.

Figure 2 shows the damaged cylinders tested under split tensile strength. In Fig. 2(a) the fractured plain cylinder of conventional concrete is shown whereas Fig. 2(b) shows the damaged fibre reinforced concrete cylinder. As can be seen they have not been fractured into two pieces.

a) Conventional concrete Fractured into two pieces (b) Specimen reinforced with fibre

Fig. 2 Crack pattern of cylinder

Figure 3 shows the failure pattern of prisms. Figure 3(a) shows a failure pattern of normal concrete prism whereas Fig. 3(b) that of fibre reinforced concrete. The normal concrete prism was fractured near centre whereas fibre reinforced concrete prism fractured on the left one-third portion.

(a) Normal concrete (b) Fibre reinforced concrete

Fig. 3 Fractured prisms

The normal as well as fibre reinforced concrete cubes were exposed to elevated temperature of 300°C for two hours as shown in Fig. 4. Afterwards, they were tested to determine their residual strength. The results are shown in Table 2. There is a reduction of about 32 per cent in strength of normal concrete after fire. There is a reduction of 20 per cent in strength of 0.5 per cent fibre reinforced concrete over that of its original strength. Corresponding value in the case of 1.0 per cent fibre addition the reduction in strength was 10 per cent. It is quite clear that with higher percentage of fibre addition, there is a lesser degradation in strength. The fire rating of concrete with higher fibre content is better.

Fig. 4 After heating at 300˚C for 2 hours

Table 2 Reduction in the compressive strength (N/mm^2)

Percentage addition of fibre	7 days	28 days
0.0	12.91	21.36
0.5	16.58	28.62
1.0	20.14	38.47

III. Conclusions

The followings are the conclusions drawn from the study on addition of glass fibre in concrete. With 0.5 per cent addition of fibre, the increase in the compressive strength is 13 per cent, the increase in flexural strength is 42 per cent and the increase in split tensile strength is 20 percent over conventional concrete. With 1 per cent addition of fibre, the increase in the compressive strength is 35 per cent, the increase in flexural strength is 75 per cent and the increase in tensile strength is 37 per cent. Therefore reinforcing with glass fibre contributes immensely in enhancing the compressive strength of concrete and the increase is 1.78 times that of normal concrete. From the test results, it is found that the glass fibre possesses the high flexural strength.

The fire resistant test results show that there is a reduction in the compressive strength, after heating the concrete at 300C for 2 hours. Without the addition of fibre, the decrease in the compressive strength is 32 per cent over its original strength. For 0.5% addition of fibre, the decrease in the compressive strength is 25 per cent over its original strength. Similarly, with 1 per cent addition of fibre, the decrease in the compressive strength 10 per cent over its original strength. This investigation shows a higher resistance of fibre reinforced concrete to fire when compared to normal concrete. So, glass fiber concrete has a better fire resistant characterisitcs.

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