International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-11, September 2019

Durability and Physical Properties of Glass Fiber Reinforced Concrete Subjected to Elevated Temperatures

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Abstract*: Addition of glass fibers into concrete significantly modifies its tensile strength. The fibers are placed at desired locations and orientations by the matrix surrounding it, thereby making the fibers as principal load carrying members and also protecting them from environmental damage. Glass fibers provide resistance to high temperature, and the ease of incorporating them into the matrix either in continuous or discontinuous lengths. In this work, carbonation test representing the durability of Glass Fiber Reinforced Concrete (GFRC) was carried out, and then experimental program determines the properties like compressive strength, split tensile strength and flexural strength of GFRC for 7 days and 28 days of curing, with percentage of fibers in ratios 0.5%, 1%, 1.5%, 2% and performance of GFRC at elevated temperatures of 300°c, 500°c, 700°c, 1000°c are compared with conventional concrete. The results depict that, the residual compressive strength capacity of GFRC is greater than unreinforced concrete both at elevated and normal temperatures.

Keywords: Glass fiber reinforced concrete, compressive strength, flexural strength, carbonation test, elevated temperature.

I. INTRODUCTION

Generally, the quality of concrete mainly relies on the strength of the concrete. It is well known that concrete is strong in compression and weak in tension. Since concrete is brittle in nature, has less ability to take tensile loads. In order to increase the ability of concrete to take more tensile loads, fibers are incorporated into concrete. The fibers incorporated into the concrete alter its mechanical properties and thereby differentiating it from normal conventional concrete.

Ordinary Plain Cement Concrete (PCC) is prone to cracks in plastic and hardened state as well. When the water on the surface of concrete evaporates rapidly than the bleeding water plastic shrinkage is likely to occur. Surface cracks are caused due to volume changes, as the concrete is weak in tension in its plastic state. But gradually as the concrete gets hardened, the pore water present in the concrete matrix begins to evaporate, thereby causing the concrete to shrink due to volume changes. Now this shrinkage of concrete is restrained by the reinforcement steel and develops a tensile stress which again further leads to cracks. Also development and appearance of cracks on the surface is a negative impression in terms of quality and serviceability. Addition of fibers into concrete reduces such issues as they help in arresting the cracks in plastic as well as hardened state which eventually results in durable concrete. Besides enhancing the strength properties and controlling cracks, fibers also alters the thermal properties of concrete when subjected to high temperatures. Throughout its service life, structure might experience abrupt temperature changes. Many studies show that concrete has relatively low thermal conductivity and takes time for heat transfer which means that it performs well when subjected to fire to some extent. But concrete might show drastic changes at micro structure and mieso structure level when exposed to high temperatures. Thermal shocks in concrete cause cracking and spalling, and also produce the stress within the concrete matrix, due to aggregate and reinforcement expansion at high temperatures.

The behavioral properties of concrete at high temperature are influenced by many factors such as rise rate of temperature, the aggregate matrix and also fibers in case of fiber reinforced concrete. The level of enhancement of the mechanical and thermal resistant properties of fiber reinforced concrete by and large depends upon the type of fibers and quality of fibers added into the concrete.

There are various types of fibers available namely steel, synthetic, polypropylene, glass, carbon fibers, etc. Among many available fibers, glass fibers exhibit higher thermal resistance and provide greater mechanical properties to the concrete even at high temperatures. This paper pertains to the study of glass fiber reinforced concrete at elevated temperatures.

F.U.A Shaik and Taweel (2015) of Australia has made a similar study on fiber reinforced concrete and has elevated the concrete from 400 ºc to 800 ºc and compared it to unreinforced concrete, from the study he has mentioned that he used both steel and basalt fibers, where on elevating to temperatures he concluded stating that the residual compressive strength capacity of steel fiber is more when compared to basalt fibers and conventional concrete at elevated and normal temperatures. K. Srinivas Rao, et. al. (2013) focused on comparing the performance of standard concrete to fiber reinforced concrete at elevated temperatures. In his study he focused on physical changes and spalling that takes place in concrete when exposed to high temperatures.

Manuscript published on 30 September 2019.
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The paper reports that cubes were exposed from 50ºc to 250ºc for 3 hours and results have depicted that the strengths got increased until the temperatures reached 50ºc and then gradually got reduced beyond 50ºc.

Venu Malagavelli and Rao (2011) have made use of polyester fibers to improve the crack resistance property and strength of the concrete.

Venu Malagavelli et.al. (2016) in his study used rubber as a replacement of aggregates intending to impart thermal resistant property to the concrete.

II. MATERIALS AND MIX PROPORTION

In this study Ordinary Portland Cement (OPC) confirming by IS: 8112-2013 was used to cast all the concrete. Granite rock of sizes 10mm and 20mm were used as coarse aggregate. River sand was used as fine aggregate. Tests on fine aggregate were conducted by the guidelines given in IS: 2720:1991. The glass fibers with 20mm in length and 0.5mm in diameter were used. Design mix was made basing on IS: 10262:2009. All the proportions used are tabulated in Table-I.

Table- I: Mix Proportion used (kg/m^3)

Constituents	CC	GFRC1	GFRC2	GFRC3	GFRC4
cement	560	560	560	560	560
Water	233	233	233	233	233
Fine aggregate	671.1	671.1	671.1	671.1	671.1
Coarse aggregate	919.2	919.2	919.2	919.2	919.2
Glass fiber	-	0.5%	1%	1.5%	2%

III. METHODOLOGY

A. Experimental Program

Specimens of total five mixes of concrete were casted. One mix is of normal conventional concrete (cc) of grade M30 and the other mixes are glass fiber reinforced concrete with volume fraction of glass fibers and details of the mix proportions are shown in the Table- I. A pan mixer was used for controlled mixing of fiber reinforced concrete. Firstly, the coarse aggregates, fine aggregates and cement were dry mixed for approximately five minutes. Then water was slowly added into the dry mixture and continued to mix for another five minutes. Fibers were added gradually into the slurry and continuously mixed until uniformity in dispersion of fibers was achieved in the mix. Then the concrete slurry was filled into the cubes of dimensions 150 mm, cylinders of diameter 300 mm × 150 mm, and beams of dimensions 150 mm × 150 mm × 450 mm. To achieve full compaction, the moulds filled with concrete were kept on a vibrating table and compacted. The concrete moulds were then demoulded after 24hours and are left into the curing tank for curing period of 7 and 28 days. Then the specimens were tested for compressive strength, flexural strength and split tensile strength.

B. Heating Regime

A heating oven which can heat up to 1200ºc was used for heating the test specimens. Then the glass fiber reinforced concrete with fiber percentages as mentioned above were subjected to high temperatures for 2hours of time period. Before subjecting the test specimens to elevated temperatures, they were pre heated to 100ºc, so that blasting of specimens can be avoided. The rate of heating was continued until the ambient temperature in the oven reached the target temperature.

C. Activated Carbonation Test

The objective of this phase of study was to compare the rates of carbonation on the concretes casted. Concrete durability, unlike many properties of concrete cannot be determined indirectly, and so calculating the durability of the concrete is very important to know how concrete behaves at deteriorating environments and to minimize the expenditure on repairs and maintenance. A carbonation chamber as shown in the Fig.1 has been prepared using non porous acrylic sheets which are made air tight by sealing them on all sides and then a layer of salt (4 cm) is placed at the bottom, a steel mesh having 5 mm thick is placed above the salt layer so as to avoid direct contact with cubes. Then carbon-di-oxide gas is sent into the chamber in a controlled pressure and cubes are exposed to gas for 30days of duration.

Fig. 1.Preperation of Carbonation chamber

IV. RESULTS AND DISCUSSIONS

A. Depth of Carbonation

All the cubes which were placed in carbonation chamber for 30days were taken out and the cubes are cut into two half's, when phenolphthalein indicator was sprayed on the surface of the cubes, the un-carbonated area turned into pink color and carbonated area remained colorless as shown in the Fig.2. All the concretes have shown good resistance to carbonation and proved their durability, thus we carried out further investigation on this study.

Fig. 2.Phenolphthalein indicator sprayed on the carbonated cubes

B. Compressive Strength

The Table-II gives us a review on the compressive strength values measured for all five concrete types at ambient conditions. It can be seen that the early strength (7 days) of GFRC4 concrete has shown 27.6%, and later strength (28 days) has shown 27.8% increase in compressive strength than conventional concrete.

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The addition of fibers sometimes have shown similar results, when 1% and 1.5% addition of fibers to concrete has shown similar early strength and a little variation in their later strength also. The fibers placed in the matrix have played a crucial role in reducing the cracks by holding the matrix and eventually increasing the compressive strength capacity of the concrete.

F.U.A Shaikh and Taweel (2015) has done a similar study and has stated that the use of steel fibers was effective in increasing the strength.

Table- II: Compressive Strength Results.

Trial	7 Day (Mpa)	28 Day (Mpa)
CC	24.12	32.36
GFRC 1	28.88	42.22
GFRC 2	31.11	43.55
GFRC 3	31.11	44.44
GFRC 4	33.33	44.88

C. Split Tensile Strength

Table-III summarizes the tensile strength values obtained by all concretes. It can be seen that the tensile strength values have been gradually increased on addition of fibers to the matrix. GFRC4 concrete has shown an increase of 34.4% in its tensile behavior when compared to normal concrete. The fibers that are oriented in all the directions in the matrix helped the concrete to achieve better strength in all directions.

Table- III: Split Tensile Strength Results.

Trial	Tensile Strength (Mpa)
CC	3.35
GFRC 1	4.10
GFRC 2	4.67
GFRC 3	4.89
GFRC 4	5.11

D. Flexural Strength

S.P Singh and Kaushik (2001) observed that addition of fibers to the concrete would greatly affect the flexural strength than compressive and tensile strengths. The results shown in Table-IV clearly states that the flexural strength gradually got increased by adding fibers to the concrete matrix and GFRC4 has shown an increase of 25.7% in its flexural strength than conventional concrete.

Table- IV: Flexural Strength Results

Trial	Flexural Strength (Mpa)
CC	4.03
GFRC 1	4.67
GFRC 2	4.92
GFRC 3	4.98
GFRC 4	5.43

E. Behavior of Concrete at Elevated Temperature

The compressive strength values obtained when the concretes are exposed to elevated temperatures are tabulated in the Table-V. It is very clear that the residual compressive strength value of all the concretes got gradually reduced as the temperature is elevating. Even then, the concretes having glass fiber induced in them gave satisfying results and can be seen that GFRC4 having 2% glass fibers performed well than other concretes. Even at 1000°c the residual compressive strength of GFRC4 was 49.04% more than conventional concrete. From the Fig.3 it can be clearly seen that at high temperatures the glass fibers present on the interface have got damaged whereas all the deeper fibers were unaffected.

Table- V: Compressive values at Elevated Temperatures

Trial	300°c	500°c	700°c	1000°c
CC	21.36	16.43	11.31	6.37
GFRC 1	32.31	23.31	16.37	10.16
GFRC 2	34.65	26.15	18.55	10.98
GFRC 3	34.71	26.41	18.74	11.07
GFRC 4	35.88	28.67	20.57	12.5

Fig. 3. Concrete interface when exposed to high temperature

The compressive strength values of the experiment depict the strength variation of the concrete cubes when they are exposed to varied temperatures. These values show considerable variation from 300ºc to 1000 ºc, as shown in Fig. 4, and are tabulated in Table-V.

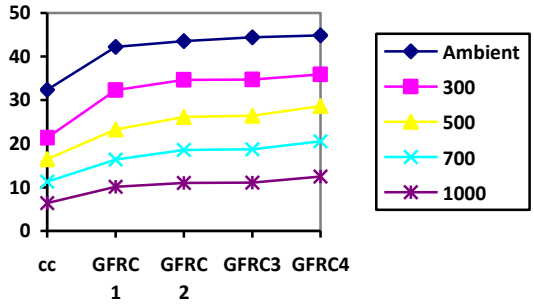

Fig. 4. Compressive Strength values at elevated temperatures

From the results obtained, we can state that the compressive strength of the conventional concrete which was 32.36 Mpa, when exposed to 300°c got reduced by 33.99% and on further heating the value got reduced by 49.2% at 500°c, 65.04% at 700°c, and 80.3% at 1000°c . Similarly, the compressive strength of the GFRC 1 which was 42.22 Mpa, when exposed to 300°c got reduced by 23.4% and on further heating the value got reduced by 44.7% at 500°c, 61.22% at 700°c, and 75.9% at 1000°c . The compressive strength of the GFRC 2 which was 43.55 Mpa, when exposed to 300°c got reduced by 20.4% and on further heating the value got reduced by 39.9% at 500°c, 57.4% at 700°c, and 74.7% at 1000°c. The compressive strength of the GFRC3 which was 44.44 Mpa, when exposed to 300°c got reduced by 21.8% and on further heating the value got reduced by 40.5% at 500°c, 57.83% at 700°c, and 75% at 1000°c. The compressive strength of the GFRC4 which was 44.88 Mpa, when exposed to 300°c got reduced by 20% and on further heating the value got reduced by 36.1% at 500°c, 54.16% at 700°c, and 72.1% at 1000°c. However the values obtained by using glass fibers were far more convincing than the conventional concrete.

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V. CONCLUSION

- From the experimental study, it is clear that the addition of fibers to the conventional concrete has enhanced the compressive, flexural, tensile properties of the concrete to great extent.
- Fibers in the concrete could induce tensile character to the concrete and would clog the spaces present in the concrete to increase the strength and also it prevents the corrosion of steel by blocking the small water pores.
- It could also be stated from the experiment that, addition of fibers to greater extent say for about greater than 2% would reduce the workability of the concrete. When these cubes of concrete having varied percentages of fiber content was exposed to high temperatures, they acted differently depending on the amount of fibers present in them.
- Hence, we can conclude saying that 28 day strength of the GFRC4 was having 49% more strength than conventional concrete, and also at 1000^{o}c the strength lost by conventional concrete was 80.3% whereas GFRC4 lost only 72.1% of its strength, thus addition of glass fibers to the concrete would enhance its mechanical properties both when in normal conditions and when they are exposed to high temperatures as glass fiber has more thermal resistant property.

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