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Experimental Analysis on Strength Properties of Glass Fiber Concrete

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ABSTRACT
The current world is witnessing the construction of challenging and innovative civil engineering structures. It has been established that when fibers are added in certain percentage to the concrete improves the strength properties as well as crack resistance and ductility. Fibers impart energy absorption, toughness and impact resistance properties to fiber reinforced concrete material and these characteristics in turn improve the strength properties. In the present experimental investigation the alkali resistant glass fiber of diameter 14 micron, length 24mm, having an aspect ratio of 855 was employed in percentage varying from 0, 10%, 20%, 30%, 50%, 60% and 80% to study the effect on compressive, split tensile and flexural strength on M40 grade concrete. At early age strength, the concrete with more than 20% of glass fiber gain strength around 61% until 82% faster than normal concrete. This implies that glass fibers assist in increasing the Compressive strength of concrete. The higher the glass fiber, in the mix the compressive strength also increases.

Keywords: *Glass fiber, fatigue, fracture, concrete, toughness, impact and workability*

1. INTRODUCTION

Glass fiber also known as fiberglass is a material consist of numerous extremely fine fiber of glass. Before, glass fiber was known as “glass wool” was inverted in 1938 by Russell Games Slayter of Owen-Coming as the material to be used for insulation. Ever since manufacturing, it has been used widely as an insulating material; Glass fiber is also used as a reinforcing for many agents and polymeric products or glass-reinforced plastic (GRP) (Cuevas, 2012).

Glass fibers are widely used for reinforcement due to their mechanical properties such as high strength (tensile strength of 3.40 GPa, tolerance to high temperature, resistance to corrosive environment as well as low cost, despite of low stiffness. The stiffness for glass fiber range from approximately 70 to 90 GPa. Moreover, glass fibers are more sensitive to moisture. Johnston and Colin (2000), suggested that the strength of a glass fiber specimen decrease by 35% (769 – 499) when exposed to water at a room temperature under constant load.

Production of glass fiber requires much energy and fossil fuels. Glass processing is dusty, which make the production of glass fiber a contributor to environmental pollution mostly air pollution (Daniel and Negtegaal, 2001). Glass fibers also require high temperature to manufacture like any fiber such as carbon fiber. The amount of carbon emission and by-products produced as the result of manufacturing needs to be quantified for carbon fiber and all other basic construction materials in order to assess the sustainability of glass fiber (Johnston and Colin 2000).

Jain and Lee, (2012) highlighted that there are significant environmental benefits to choose sustainable fiber glass. First, no large smoke plumes or other forms of environmental pollution produced from GRP (Glass Reinforced Plastic) / FRP (Fiber Reinforced Plastic) products. Unlike wood and metal products, generally glass fibers are environmental friendly, economical, highly resistant to corrosion and more suitable than steel, aluminium and timber. Use of fiberglass in lieu of steel, aluminium and timber also means there will be less demand upon our natural resources and a reduction of the environmental impact resulting from the production of metals and the disposal of their waste.

Alkali Resistant Glass Fiber is a recent introduction in making fibrous concrete. Glass fiber which is originally used in conjunction with cement was found to be affected by alkaline condition of cement. Heurik et al. (2004) has outlined the classification and structural applications of composite materials. Majumdar et al. (1991) has worked on the development of fiber reinforced cements. Sivakumar et al. (2007) has studied the properties of FRC using high percentage dosages of hybrid fiber like steel, glass and polypropylene. High strength concretes were produced by using the above fibers. From the various investigations studied it is clear that non metallic fibers like glass and polypropylene can be tried in FRC to derive benefits like more ductility, impact resistance, crack resistance etc.

However, this paper presents the effect of glass fibers on the compressive, split tensile and flexural strength of the concrete.

2. Methodology

2.1 Materials used

Cement

The cement was of 53 grade, with specific gravity of 2.9 and fineness of 2800 cm^2/gm, prior preparation of specimens it was stored in a humidity controlled room to prevent it being exposed to the moisture.

Coarse aggregate

The coarse aggregate used for this research was well graded angular granite machine crushed, passed through 20mm sieve test, the specific gravity is 2.7, flakiness index of 4.35% and elongation index of 3.64%. The aggregate was washed to be free from dust, clay or any other organic matter.

Fine aggregate

Fine aggregate are normally obtained locally from rivers or lakes. British Standards defined this material as material passing 5.0 mm test sieve but retained on a 75 µm test sieve. The fine aggregate used for this research having specific gravity of 2.4 passed through 5mm sieve test. The aggregate was kept in a dry place prior mixed to ensure the moisture content is controlled during mixing process.

Water

Portable water available in locality suitable for drinking was used to prepare the concrete mix, the main purpose of water as we have seen in literature review is to set cement (to start chemical reaction within cement pastes). The same type of water was also used for curing concrete.

Glass Fiber

These are the main materials which were added to reinforce the concrete. As stated in the literature review glass fiber has high tensile strength of 2 – 4Gpa and elastic modulus of 70 – 80Gpa, brittle stress strain characteristic from 2.4 – 4.8 elongation at break and low creep at room temperature. Glass fiber also is susceptible to alkali attack.

Type of glass fiber used was alkali resistance (AR-Type) glass fiber having the following properties:-

- Aspect ratio of 857:1
- Density of 2.6t/m3
- Elastic modulus of 73GPa
- Tensile strength of 1.7GPa
- Density of 14micronon
- Length divided into 24mm
- Number of fiber 212million/kg

2.2 Mix design

The concrete mix design is based on the method published by Department of the Environment (DOE) in 1988 edition. The description provided in that article illustrate the principle for methods, number of design exercise were carried out in order to become familiar with the design procedure. The DOE method also provide information necessary to design concrete for indirect tensile strength, containing entrained air and using cement replacement but that was the focus. The method is divided into five sections where by section 1 is to deal with strength of concrete; section 2 is to deal with workability; section 3 is to deal with cement content; section 4 is to deal with density of fresh concrete; and finally section 5 is deal with proportion of sand. Results were obtained from various graphs and filled in the **Table 1** provided by DOE.

The aim was to design the concrete of characteristic strength of 40 N/mm^2 at 28 days by using Ordinary

Portland Cement (OPC); The proportional defective (percentage of failure) to be of 5 percent. The slump range from 30 – 60 and the Vebe time within 3 – 6 seconds.

The relative density of aggregate was considered to be 2.7; the aggregates were well crushed with the maximum size of 20mm. By using the DOE method of mix design (1988 Edition) the quantities of cement, water, sand and aggregate were obtained per cubic meter. The amount of each quantity was divided by the total volume for the specimens to acquire the precise amount of each ingredient to be added in the mix.

2.3 Casting and Curing of Concrete

After preparing the mix, cylindrical moulds of diameter 100mm and height 200mm, cubes of 150 x 150 x 150mm and beam moulds of 110 x 110 x 5000mm were casted. Fresh concrete mix containing different percentages by volume of glass fiber was casted into the moulds. The mix was casted carefully to avoid segregation. The concrete was compacted by using a steer bar to remove the voids. After 24 hours the cement had set and hardened enough, the moulds were removed. All the concrete cylinders, cubes and beams were set into the curing tank for curing. The curing was done at an average temperature of $27^{\circ}C$ for the period of 7days, 28days and 56days.

3. Results and Discussion

3.1 Compressive Strength

The most valuable property in concrete is the concrete compressive strength because it gives the overall definition of the quality concrete strength that relates to the hydrated cement paste. Basically, the specimens were being tests for three selected curing periods namely: 7, 28, 56 days, detail test results are shown in Table 2.

Table 2: Compressive strength of concrete specimens at 7, 28, and 56 days of curing

Glass Fiber (%)	Average 7 Days Strength (N/mm^2)	Average 28 Days Strength (N/mm^2)	Average 56 Days Strength (N/mm^2)
0	22.63	38.52	42.21
10	24.74	40.63	46.2
20	36.52	43.8	48.43
30	36.63	48.54	49.64
50	40.27	49.24	50.02
60	40.16	49.04	50.67
80	41.08	52.45	51.53

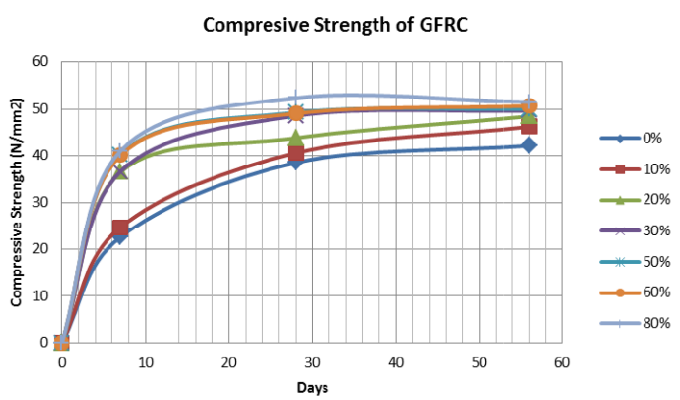

Figure 1: Graph of average compressive strength vs. days of curing

The effect of Glass fiber on strength of concrete is shown in Figure 1, which presents the substantial increment compressive strength values of concrete mixtures with different proportions of glass fiber cured at 7 days, 28 days and 56 days. It is observed that the concrete with higher percentage of glass fiber gain strength between 61% until 82% faster than normal at early age. For instance the GFRC with 80% fiber content was able to achieve the targeted strength after 7 days of curing. Once more it is observed that there is an enormous 48% increment in strength between GFRC with 10% and 20% of fiber. Concrete with 20% of fiber is adequate to improves the bond between cement and aggregates. The presence of fiber also speeds up the hydration. During hydration process water is absorbed by glass fiber results strengthening of inter-molecule bond.

Apparently, addition of glass fiber contributing much on strength of the concrete, as it is observed in the graph at 7 days of curing, specimens with high percentage of glass fiber (50% 60% and 80%) have achieved compressive strength above the targeted characteristics strength of 40 N/mm^2. Nevertheless, the graph shows that at 56days of curing all the specimens where able to achieve strength above the targeted strength.

3.2 Tensile Strength

The split tensile strength of the concrete specimens was determined at 7, 28 and 56 days following BS EN 12390 part 6: 2009.

Table 3: Split Tensile strength of concrete specimens at 7, 28, and 56 days of curing

Glass Fiber (%)	Average 7 Days Strength (N/mm^2)	Average 28 Days Strength (N/mm^2)	Average 56 Days Strength (N/mm^2)
0	3.42	4.24	4.51
10	3.52	4.5	5.05
20	3.83	5.15	5.81
30	4.12	4.92	6.25
50	4.16	5.3	6.32
60	4.29	5.59	6.55
80	4.58	6.84	7.2

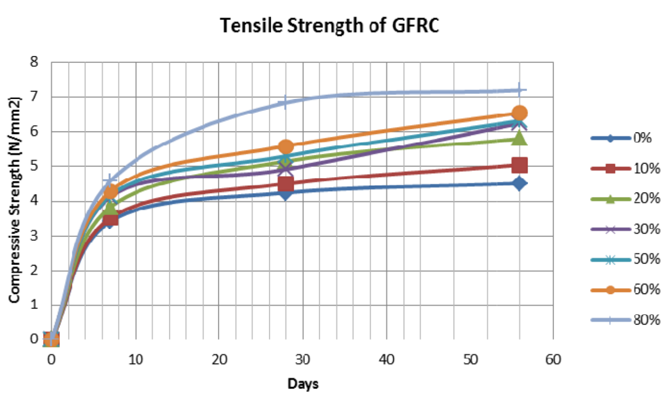

Figure 2: Graph of average tensile strength vs. days of curing

Figure 2 shows the tensile strength of GFRC against days of curing. The figure illustrates the evidence that the split tensile strength of GFRC increases with the increase of curing days together with content of fiber incorporated into the mix. The graph shows that specimen with high percentage of glass fiber (80%) have achieved extremely high split tensile strength at all days of curing. Concrete with 80% of glass fiber gain 60% and 61% of split tensile strength respectively at 28 days and 56 days of curing compared to the higher percentage strength of tensile for the normal concrete. This implies that GFRC achieves most of its split tensile strength after the age of 28 days however the strength is slightly increasing as the day of curing is increasing. Other than that, samples with glass fiber have shown remarkable increase in split tensile strength with ages of curing unlike the control samples (0%) glass fiber.

3.3 Flexural Strength

Flexural strength can be described as the capacity of a beam or even a slab of concrete to resist failure due to bending. This flexural strength is also known as *Modulus of Rupture*. The effect of concrete with various percentage of glass fiber on flexural strength is shown on table 4. The flexural strength was tested on 7, 28 and 56 days of curing.

Table 4: Flexural strength of concrete specimens at 7, 28, and 56 days of curing

Glass Fiber (%)	Average 7 Days Strength (N/mm^2)	Average 28 Days Strength (N/mm^2)	Average 56 Days Strength (N/mm^2)
0	2.76	4.11	4.31
10	3.76	4.5	4.92
20	4.09	4.81	5.32
30	4.37	5	5.72
50	4.55	5.28	6
60	4.8	5.3	6.18
80	4.82	5.65	7.3

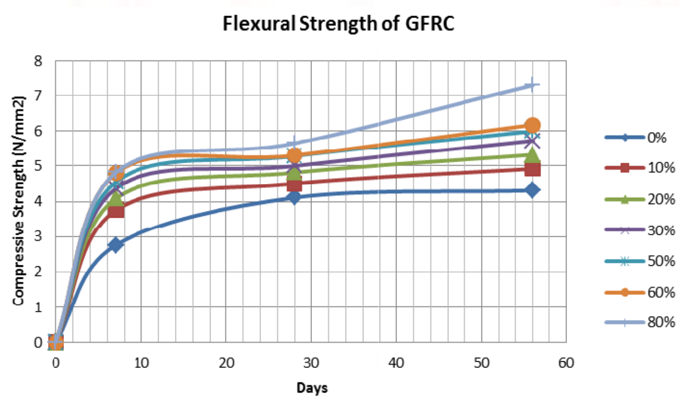

Figure 3: Graph of average flexural strength vs. days of curing

Based on the figure 3, the graph shows that concrete with higher percentage of glass fiber have higher flexural strength, also concrete of with lower percentage of glass fiber have lower flexural strength. In other words, the graph shows the evidence that flexural strength increases with the increase in fiber content.

The graph also shows that, the gain of flexural strength is higher between 7 to 28 days than 28 to 56 days. This implies that at 28 days of curing GFRC achieves sufficient strength. It is observed that the flexural strength for the specimens having 80 percent of fiber increased dramatic for 28 and 56 days while for 7 days the increase is marginal.

4. Conclusions

Extensive experimentation was carried out with various glass fiber percentages on concrete. For all mixes, compressive strength, tensile strength and flexural strength were determined at 7, 28 and 56 days. The following conclusions can be derived from the investigation:

A. With minimum of 20% glass fiber is adequate to improve the early age strength of the concrete. This implies that glass fibers assist in increasing the compressive strength of concrete. However, the strength of the concrete at 56days are relatively similar with the higher different of strength only 22% for concrete with 80% glass fiber.
B. The split tensile strength of "AR Glass fiber" for M40 concrete is maximum when 80% of glass fiber was incorporated into mix, this implies that split tensile strength of Glass Fiber Reinforced Concrete is high when the amount of fiber incorporated into the concrete is also higher.
C. The flexural strength of "AR Glass fiber" for M40 concrete in this research is found to be maximum at 80% glass fiber mix. This also implies that flexural strength of Glass Fiber Reinforced Concrete is high when the amount of fiber incorporated into the concrete is also higher.
D. Fibers impart energy absorption, toughness and impact resistance properties to fiber reinforced concrete material and these characteristics in turn improve the strength properties.

5. Acknowledgements

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TABLE 1: CONCRETE MIX DESIGN BY DOE

Job title ....

Stage	Item		Reference or calculation	Values
1	1.1	Characteristic strength *fc*	Specified	40 N/mm² at 28 days
				Proportion defective 5 %
	1.2	Standard deviation	Fig 3.7	8 N/mm² or no data .... N/mm²
	1.3	Margin	Table 3.2	(*k* = 1.64) 1.64 X 8 = 13.12 N/mm²
				= 13.12 N/mm²
	1.4	Target mean strength *fm*		40 + 13.12 = 53.42 N/mm²
	1.5	Cement strength class	Specified	42.5/52.5
	1.6	Aggregate type: coarse Aggregate type: fine		Crushed/uncrushed Crushed/uncrushed
	1.7	Free-water/cement ratio	Table 3.3, Fig 3.8	0.56
	1.8	*Maximum free-water/ cement ratio*	*Specified*	.... Use the lower value 0.56
2	2.1	Slump or Vebe time	Specified	Slump 30 - 60 mm or Vebe time 3 -6 s
	2.2	Maximum aggregate size	Specified	20 mm
	2.3	Free-water content	Table 3.4	210 — 210 kg/m³
3	3.1	Cement content		210 ÷ 0.56 = 375 kg/m³
	3.2	*Maximum cement content*	*Specified*	.... kg/m³
	3.3	*Minimum cement content*	*Specified*	.... kg/m³
				use 3.1 if ≤ 3.2 use 3.3 if > 3.1 — 375 kg/m³
	3.4	Modified free-water/cement ratio		....
4	4.1	Relative density of aggregate (SSD)		2.7 known/assumed
	4.2	Concrete density	Fig 3.9	2400 kg/m³
	4.3	Total aggregate content		2400 – 210 – 375 = 1815 kg/m³
5	5.1	Grading of fine aggregate	Percentage passing 600 µm sieve	55 %
	5.2	Proportion of fine aggregate	Fig 4.0	36 %
	5.3	Fine aggregate content	C5	0.36 X 1815 = 653.4 kg/m³
	5.4	Coarse aggregate content		1815 – 653.4 = 1161.6 kg/m³