World Journal of
Engineering and Technology Research
Journal homepage: https://zealjournals.com/wjetr/
ISSN: 2945-316X (Online)

(RESEARCH ARTICLE)

The effect of glass fiber reinforcement on properties high strength concrete mix using local materials

Habiballa Sara and Abu-Elgasim Ebtihaj *

Faculty of Engineering, School of Civil Engineering, Sudan University of Science and Technology, Khartoum, Sudan.

World Journal of Engineering and Technology Research, 2022, 02(02), 001–008

Publication history: Received on 10 October 2022; revised on 22 November 2022; accepted on 24 November 2022

Article DOI: https://doi.org/10.53346/wjetr.2022.2.2.0043

Abstract

The usage of high strength glass fiber reinforced concrete (HSGFRC) in the construction applications has been increasing worldwide. Especially in plain concrete due to it is less ductility and high brittle behavior. Use of fiber in plain concrete treating shrinkage cracking as well improve tensile behavior. On the other hand, glass fiber material has some advantage like alkali resistance and light weight compared to steel. Due to these advantages researchers prepared glass fiber reinforced concrete (GFRC) to improve concrete properties. GFRC is composed of fine sand, cement, water, admixtures and alkali-resistant glass fibers (AR-GF). The main objective of this research is to study the effect of addition of alkali resistant glass fiber reinforced polymer (AR-GFRP) in concrete properties. Six different mixes were prepared using different percentage of glass fiber 0.0, 0.75, 1.0, 1.25 and 1.5 by weight of cement the target compressive strength was calculated to be 55.2 MPa. Available materials in the local market were used. Results showed that it is possible to produce HSGFRC in Sudan using locally available materials if they are carefully selected. Based on the experimental results, the compressive strength, splitting tensile strength and density of HSC was found to be increase as fiber percentage increases for both ages of 7 and 28 days. The maximum 28 days compressive strength of HSC was found to be 63.81 MPa recorded in M50 F4 with 1.5 glass fiber reinforcement. The density of HSC is found to increase slightly as fiber percentage increases, density value ranged from 2.415 to 2.442 kg/m3. The maximum 28 day's splitting tensile strength of HSC was found to be 6.45 MPa recorded in M50 F4 with 1.5 glass fiber reinforcement. It can be concluded that the use of chopped glass fiber in concrete improve the mechanical properties and ductility.

Keywords: HSC; GFRC; AR-GF; HSGFRC; Local material; Mechanical properties

1 Introduction

High Strength Glass Fiber Reinforced Concrete (HSGFRC) is an advanced model for concrete mix. It combines the advantages of high strength concrete (HSC) and Fiber Glass (FG). By using this form of concrete mix, the problems and disadvantages that are difficult for concrete to overcome alone can be overcome by taking advantage of the properties of Fiber Glass. HSC has a brittle behavior at ultimate limit state of loading, so, fibers can be added to improve the structural properties of concrete. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its mechanical behavior. The addition of fibers results in a product which has higher flexural and tensile strengths as compared with normal concrete [1]. Many types of fibers are available, glass fiber reinforced polymer (GFRP) are preferred than other types due to high ratio of surface area to weight and high strength properties to unit cost ratio. However, glass fiber which is originally used in conjunction with cement was found to be affected by alkaline condition of cement. The alkali resistant glass fiber reinforced polymer (AR-GFRP), has overcome this defect and can be effectively used in concrete [2]. Qureshi et al, 2013[3] studied the effect of using alkali resistant glass fiber on mechanical properties of concrete. Eight mixes were prepared using different glass fiber percentage. Workability, compressive strength, flexure strength, tensile strength,

* Corresponding author: Abu-Elgasim Ebtihaj
Faculty of Engineering, School of Civil Engineering, Sudan University of Science and Technology, Khartoum, Sudan.

and ultrasonic pulse velocity have been studied. The results showed improvement in compressive flexural and tensile strength when using 1.5% of glass fiber, while decreasing in workability was recorded with fiber percentage increase. The author recommended using some water reducing admixtures to get required workability without affecting strength [3]. Jacob et al, 2016 [4] studied the changes in concrete properties using recycled concrete aggregate and glass fiber. Six concrete mixes were prepared with 20-100% replacement of aggregate and 0.01, 0.02 and 0.03 of glass fiber by volume. The results showed that the workability decreased with glass fiber increased. Compressive flexure and tensile strength were also increase as glass fiber percentage increase. The author reported that the use of glass fiber reduce crack compared to conventional concrete [4]. Dayalan, 2017 [5] conduct an experimental investigation on strength properties of M30 and M40 grades concrete mix using glass fiber and pozzolana cement. Four mixes for each grade were prepared using 0, 0.03%, 0.06% and 1% of glass fiber by volume of concrete. The results showed increasing in compressive strength, flexural strength and tensile strength with increase in glass fiber percentage. The author reported that this type of concrete is a respectable choice for marine and hydraulic structure [5]. The aim of this research is to study the effect of the addition of short chopped Glass Fiber with various percentages on the mechanical behavior of high strength concrete using locally available materials in SUDAN.

2 Material and methods

2.1 Materials

The varieties of HSC do not require exotic materials or special manufacturing processes, but require materials with more specific properties than conventional concretes.

2.1.1 Cement

In this study ordinary Portland cement CEM II 42.5R produced from local market was used for the production of HSGFRC. The cement met the requirements of ASTM C150 (2007) specifications. Table (1) shows the physical properties of cement according to manufacturer data sheet.

Table 1 Physical Properties of Cement According to Manufacturer Data Sheet

Properties		Cement	ASTM C150-07 Requirements
Fineness (cm2/gm.)		3500	MIN 2800
Setting Time, Vicat Test (hr:min)	Initial	2 hr	≥ 45 min
	Final	5 hr	≤ 375 min
Mortar Compressive Strength (MPa)	3 Days	25	> 10
	28 Days	58	> 42.5

2.1.2 Aggregate

Two types of coarse aggregate were used in this research a stepwise coarse aggregate and broken stone of nominal size of 12.5 mm. To achieve the ASTM C33 (2003) standard requirements for coarse aggregate, a mix design of these two types by 50% of type 1 and 50% of type 2 was prepared as shown in Table (2). While Table (3) illustrates the grain distribution of fine aggregate used in this research and its properties.

Table 2 Sieve Analysis of Combined Coarse Aggregate According to ASTM C33 (2003) and Physical Properties

Sieve Size (mm)	%Passing
25	100
19	100
12.5	96.9
9.5	61.71
4.75	20.08
2.36	4.53
Unit Weight (KG/m3)	1501
Dry Specific Gravity	2.61
Saturated Specific Gravity	2.65
Absorption%	2.9

Table 3 Grain Distribution of Fine Aggregate and Physical Properties

Sieve Size (mm)	Passing (%)
4.75	100
2.36	100
1.18	96
0.6	87.66
0.425	71.52
0.3	32.81
0.15	2.02
0.075	0
Fineness Modulus FM	1.81
Dry Unit Weight (Kg/m3)	1650.17
Dry Specific Gravity	2.60
Saturated Specific Gravity	2.64
Absorption(%)	0.82

2.1.3 Admixtures

A high range water reducing admixture (HRWR) was used in this research. Table (4) shows the physical properties of HRWR.

Table 4 Properties of High Range Water Reducer

Type	Property
Appearance	brown liquid
Basis	Modified synthetic dispersion
Dose	2.5 to 0.6 % by weight of cement
Toxicity	Non-Toxic under relevant health and safety codes

2.1.4 Glass fiber

In this research, alkali resistant glass fiber reinforced Polymer (AR-GFRP) was used. According to manufacturing data sheet, the properties of AR-GFRP used in this research are shown in Table (5).

Table 5 Properties of AR-GFRP

Trade Name	CEM FIL anti crack high dispersion Glass fibers
Number of fibers	212 million / kg
Aspect Ratio	857 : 1
Typical addition rate	0.6 to 1.0 kg/m3 of concrete
Tensile Strength	1700 MPa
Modulus of Elasticity	73 GPA
Corrosion resistance	Excellent
Specific gravity	2.6
Density	26 kN/m3
Diameter	14 microns
Fiber Length	12 mm

2.2 Composition of Concrete Mixtures

The reference concrete mix (without GFRP) was developed to obtain 28- day compressive strength for design of 55.2 MPa. The first trail mix was based on British Standards Institution. BS 8110, then modifications was applied to obtain the best determinable mix design proportions that achieved the target design strength which illustrated in Table (6).

Table 6 Mix Proportioning for 1 m3 of Concrete for The Reference Mix

Material Type	Units / m3
Cement (kg)	553
Fine Aggregate (kg)	552
Coarse aggregate (kg)	1025
HRWR (Lit.)	6
W/C	0.38

2.3 Test Program

Tests which include compressive strength, splitting tensile strength, flexural strength, and density were carried out to evaluate the strength properties of HSGFRC. Five mixes were prepared with five fiber percentages typically, 0.0, 0.75, 1, 1.25 and 1. 5 by weight of cement

2.4 Preparation of HSGFRC and Mixing Procedure

For the reference mix M50 F0 (without fibers), mixing procedures were applied in accordance with ASTM C192 (2002). The glass fibers were added gradually after the mixture become homogeneous and mixed for the minimum time required to achieve uniform dispersion and to avoid the damaged by excessive mixing.

2.4.1 Compressive and Tensile Strength

The compressive strength and splitting testes were determined at different ages of 7days, and 28 days. 48 cubes were casted. For each batch of HSGFRC made. 150x150x150 mm cube specimens were prepared, Figure (1). The cubes were filled with fresh concrete, then compacted by rod method in accordance with standard. Samples cured in fresh water for 7 and 28 days. Three samples were tested for each test.

Figure 1 (a) and (b) Cube Specimens

3 Results and discussion

3.1 Compressive Strength

The results of 7- and 28-days compressive strength and 28 days density are shown in Table ,(7) the 28 days cube compressive strength of plain HSC specimens (without fiber) obtained from adopted mix proportion that achieve the 55.2 MPa target design strength used on this research. However, the 28 days cube compressive strength of plain HSC specimens as shown in Table (7) equal to 59.44.

Table 7 Average Cube Compressive Strength and Density Test Results

Designation	% GFRP by Cement Wt.	Density (t/m^3)	Average Compressive Strength (MPa)		M50 F0% 7 Days / 28 Days	% Increase Over the Reference Mix 28 Days
		28 Days	7 Days	28 Days		
M50 F0	0	2.415	48.76	59.44	82.1	0
M50 F1	0.75	2.426	50.20	61.48	81.6	3.54
M50 F2	1	2.430	50.86	62.80	81.0	5.00
M50 F3	1.25	2.438	51.40	63.73	80.6	7.33
M50 F4	1.5	2.442	51.96	63.81	80.1	7.46

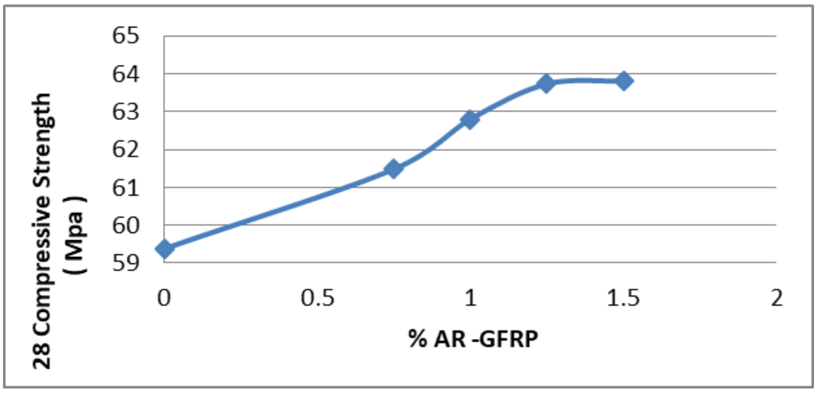

Figure 2 Effect of AR-GFRP on 28 Days Compressive Strength of HSC

From Table (7), it is observed that compressive strength increases with increase in fiber percentage. As shown in Figure (2), the 28 days' compressive strength increases sharply from 59.44 to 63.73 MPa with increase in fiber percentage from 0.0 to 1.25 respectively. Then, a very slight increase was observed in the compressive strength from 63.73 to 63.81 MPa when fiber percentage increases from 1.25 to 1.5 respectively. In general, as shown in Figure (3), the percentage of increase over the reference mix at fiber percentage of 1.25 and 1.5 is 7.33 and 7.46 percent respectively. Hence it is established that fiber percentage of 1.25 can be considered the optimum value of fiber addition for compressive strength enhancement since the difference between those values of fiber percentage is insignificant.

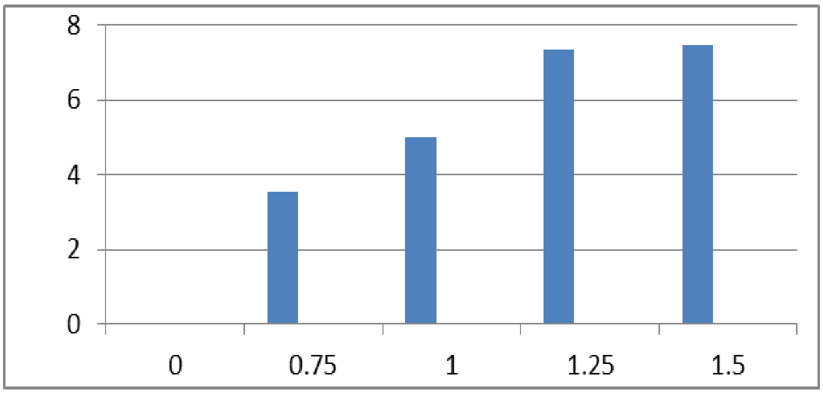

Figure 3 The Percentage of Increase in Compressive Strength over the Reference Mix Due to Addition of AR-GFRP on HSC

3.2 Tensile Strength

The results of 7days and 28 days splitting tensile strength are shown in Table (8). As mentioned before, the 28 days compressive strength of plain HSC (without fiber) was equals to 59.44 MPa. From which the predicted splitting tensile strength equals to 4.55 MPa which seems very close to the average experimental value of plain HSC specimens (M50 F0) equal to 4.23 MPa shown in Table (8).

Table 8 Average Splitting Tensile Strength Test Results

Designation	**% GFRP by Cement Wt.**	**Average Split Tensile Strength (MPa)**	**Average Split Tensile Strength (MPa)**	**% Increase over the Reference Mix (28 Day)**
		7 Day	**28 Day**	
M50F0	0	3.24	4.23	0
M50F1	0.75	3.74	4.81	13.71
M50F2	1	3.93	5.26	24.35
M50F3	1.25	4.32	5.62	32.86
M50F4	1.5	5.16	6.45	52.45

From Table (8), it is observed that with increase in fiber percentage, the splitting tensile strength also increases. As shown in Figure (5), the splitting tensile strength increases continuously from 3.24 to 5.16 MPa with increase in fiber percentage from 0.0 to 1.5 respectively for 7 days, and from 4.23 to 6.45 MPa when fiber percentage increase from 0.0 to 1.5 respectively for 28 days. From the test results shown in Table (8), it is observed that the percentage of increase in the splitting tensile strength over the reference mix due to addition of fibers is much higher than for the compressive strength as shown in Figure (5).

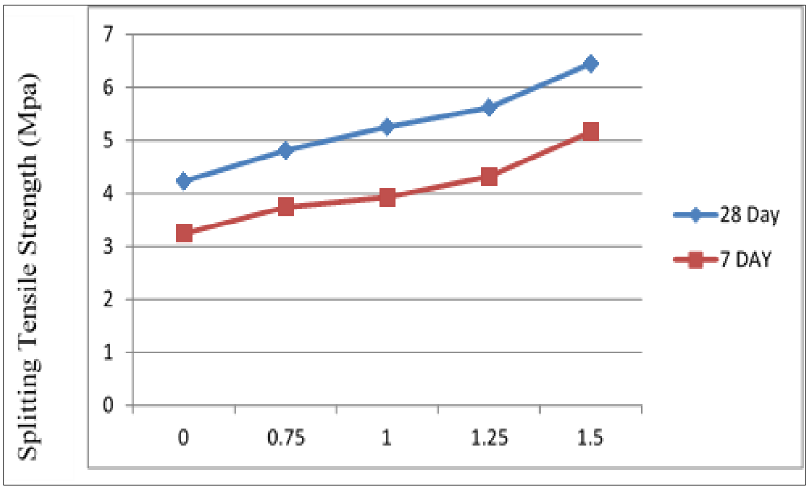

Figure 4 Effect of AR-GFRP on Splitting Tensile Strength of HSC

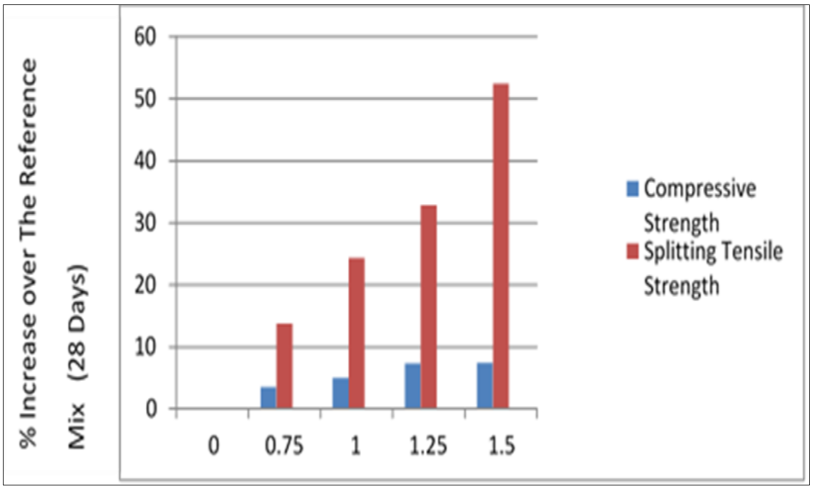

Figure 5 Comparison between percentage increase in Compressive Strength and Splitting Tensile Strength

4 Conclusion

Based on the results of this research, the followings could be concluded

- The addition of alkali-resistant glass fiber reinforced polymer (AR-GFRP) into HSC increases the mechanical property of the concrete.
- The compressive strength of HSC increases by 7.46 at 1.5 percentage of fiber compared to the reference mix. However, it is considered that the optimum percentage of fiber was 1.25 with 7.33 percentage of increasing over the reference mix since the difference between those values of fiber percentage is insignificant.
- The ratio of 7 days to 28 days' compressive strength was found to be decrease as fiber percentage increase from 82.1% to 80.1%.
- The density of HSC increases very slightly as added fiber percentage increases from 0.0 to 1.5, typically from 2.415 to 2.442 kg/m^3
- The splitting tensile strength of increases continuously until the highest value of 1.5 fiber percentage with 52.45 percentage of increasing over the reference mix at 28 days.

Compliance with ethical standards

Acknowledgments

The authors would like to thank the concrete Laboratory of University of Geira, for their support on this work.

Disclosure of conflict of interest

The authors declare no conflicts of interest regarding the publication of this paper.

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