Enhancing the flexural strength of green high performance concrete beams by carbon fiber reinforcement

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ABSTRACT

An experimental work was carried out to investigate the flexural strength of Green High Performance Concrete (GHPC) beams reinforced with carbon fibers with volume fractions 0.3%,0.6%,and 1%. For this, GHPC mixtures were produced using silica fume (SF) at 20 percent as a partial substitute by cement weight, in addition to using the super plasticizer (SP) to obtain the appropriate workability with low w/b ratio. A constant w/b ratio of 0.35 was used for the produced mixtures, and in order to control the workability of the mixtures, the super plasticizer ratios were modified. Standard curing was used in this study, then the beam specimens were tested for flexural strength. The addition of fibers to non-fibrous GHPC beams changed the non-fibrous matrix's brittle behavior to ductile behavior. The results show that carbon fibers improves beams flexural strength considerably.The beams reinforced with carbon fiber with fractions of volume of 0.6 % , demonstrated the highest flexural strength.

Keywords: Flexural Strength, Green High Performance Concrete, Silica fume, Carbon Fiber .

1- Introduction

High performance concrete (HPC) is a mixture of concrete that, compared to traditional concrete, has high toughness and high strength . HPC is the one of the best cementitious composites . It is intended to offer optimal performance qualities for the resources in the provided collection, exposure and conditions of use, according to the cost, durability and service life. Engineers and designers around the world are discovering that using High-performance concrete enables them to create more durable constructions at same costs. HPC is used to resist harsh environmental conditions, pavements and highway bridges, coastal structures, precast units, tunnels, etc.The use of mineral and chemical admixtures is basically the main difference between traditional concrete and HPC. Chemical admixtures, such as super plasticizers are used to decreases the content of water and thereby lowers the porosity of the hydrated cement paste and gives high flow ability which allow to fill in congested reinforcement zones. Mineral admixtures ensure that the mortar matrix's porosity is further decreased and improved the Aggregate Interface [1] . Cementitious materials, often known as mineral admixtures, function as both pozzolanic and fine filler materials, hence the hardened cement microstructure getting stronger and denser [2] . The use of mineral admixtures reduces the reaction velocity so the significance of treatment has decreased.[3] . There are several types of Mineral admixtures , such as : Waste glass powder , Pulverized Fly ash , Silica fume , Steel slag, Waste ceramic powder, Quartz powder, Ground Granulated

Blast furnace Slag ,etc. The term (Green High performance concrete) characterized as a concrete that utilizes waste materials as at least one of its constituents, The use of Supplementary Cementitious Materials (SCMs) as a partially substituted Portland cement (PC) to get the best concrete strength for usage in construction projects. It has been used to reduce the weight of cement in concrete mixes which leads to a significant reduction in CO2 emissions per ton of Cementitious materials . It is also a way of utilizing the by-products of industrial development Processes .The using of SCM, is very important to assure the concrete's long-term sustainability, given the growing usage of SCM, which expect large CO_2 emissions to be reduced, Mitigating the environmental effects of concrete processing [4-6] . GHPC is a brittle, high-strength concrete. The inverse connection between the two behaviors is a roadblock to high-performance concrete utilization. Discontinuous fibers can be used to produce a mix of strength and ductility. The inclusion of fibers in the concrete mixes can substantially enhance the concrete's mechanical characteristics, particularly tensile strength. There are various types of fibers that are widely used in construction ,such as: glass fibers, steel fibers, asbestos fibers, carbon fibers, polypropylene fibers, and organic fibers[7] . Several studies attempted to enhance HPC's mechanical characteristics. and use the mineral admixtures as SCMs as partial substituted of cement, Mazloom et al. [8] looked at the influence of silica fume (0%, 6%, 10%, and 15%) on the compressive strength of HPC over a 400-day period. They discovered that concrete made with silica fumes was 21% better than normal concrete. after 28 days, and after 90 days, compressive strength growth of concrete blends containing SF was negligible. However, after one year, the control concrete's strength improved by 26% and 14%, respectively, relative to its 28 and 90-day strength. The compressive strength of silica fume-containing concrete was studied by Wong and Razak [9]. They used w/cm ratios of 0.27, 0.30, and 0.33 to make concrete mixes. They noticed that SF did not instantly enhance strength; instead, after 7 days, the blended compositions were stronger than the control. Early strength loss was proportionate to the amount of cement replaced due to the diluting impact of the pozzolan and the sluggish nature of the reaction of pozzolanic; and after ninety days of curing, the increase in average strength with 10% silica fume reached a 17 percent increase. The expected enhancement in strength was not achieved when the w/c ratio was reduced from 0.30 to 0.27. The impact of silica fume on HPC flexural strength was studied by Bhanja and Sengupta [10].Five series of concrete mixes were rendered using SF as partial substitution of cement at 5, 10, 15, 20 and 25 percent at w/cm ratios of 0.26, 0.30, 0.34,0.38, and 0.42. Silica fume seems to have a considerable influence on flexural strength in addition to splitting tensile strength. Extremely high concentrations of silica fume also enhanced flexural strength substantially. Furthermore, increasing the proportion of silica fume replacement resulted in a continuous increase in flexural strength. Through previous studies on the impact of mineral additives on the characteristics of high-performance concrete , silica fume has a higher reactivity than other mineral admixtures in the design and development of HPC due to its tiny particle size, it can more effectively fill in voids between cement grains without loosening the cement grains' packing, resulting in a denser concrete mixture with finer pore structure. Therefore, in this study, GHPC was produced by using silica fume in mixtures as supplementary cementitious material. According to the literature, different fiber parameters like as type, length, aspect ratio, and content, influence the characteristics of FRC. As a result, it's critical to think about each factor's influence on concrete mixture. Many previous investigations have indicated about the effect of fibers Especially steel fibers in the concrete . Koksal et al. [11] examined the impact of steel fiber on the compressive strength of FRC containing silica fume. The impact was studied using three various amounts of silica fume, containing 5%, 10%, and 15%. Steel fiber was also utilized, with 65 and 80 aspect ratios, respectively, and fiber concentrations of 0.5 and 1%. Compressive strength values of concretes with an aspect ratio of 80 were found to be superior to that of concretes with an aspect ratio of 65 for the identical silica fume and steel fiber material. As 1% steel fiber content was added to steel FRCs with 15% SF and aspect ratios of 80 and 65, compressive strengths rose by up to 117.6 and 113.8 percent, respectively, when compared with control samples. According to Yazici et al. [12], the SFRCs compressive strength rose from 4% to 19% after steel fiber was introduced. SFRCs with fiber concentrations of 1.5, 1.0, and 0.5 percent were also found to have the maximum compressive strength at 45, 65, and 80 aspect ratios. According to Yazici, the steel fiber aspect ratio had a substantial influence on the enhancement of concrete flexural strength. The flexural strength of the control concrete was determined to be 5.94 MPa. Flexural strength values for aspect ratios of 45, 65, and 80 were 6.13, 6.22, and 6.40 MPa and 7.74, 9.31, and 10.73 MPa, respectively, for 0.5, 1.0, and 1.5 percent fiber content.

Some researchers studied the mechanical characteristics of normal and high performance- carbon fiber- concrete. For example, Chen and Chung [13] found that using chopped CF with nominal lengths ranging between 3.0mm and 12.7mm and a volume fraction of 0.189 percent in normal strength concrete, along with a silica fume, chemical agents, and dispersant, obtained the following results: 22 percent improve in compressive strength, 205 percent improve in flexural toughness, 85 percent improve in flexural strength, 90 percent reduction in drying shrinkage. The slump has shrunk from 152mm to 102mm. They got to the conclusion that the carbon fiber content in concrete must be at least 0.1 by volume to be effective in enhancing flexural strength. Chen and Chung [14] investigated the impact of chopped silica fume and carbon fibers on concrete of a normal strength with low drying shrinkage (with fine and coarse aggregates). The carbon fibers were divided into different volume fractions, and the silica fume dosages were varied. They discovered that combining 0.19 vol. percent chopped CF (10μm diameter, nominally 5mm length) with 15 % silica fume in concrete improves flexural toughness, flexural strength. Wasan & Khalil [15] investigated the mechanical characteristics of high performance carbon fiber concrete, Producing HPC with super plasticizer and concentrated silica fume combined with various volume percentages of carbon fiber (0 percent , 0.2 percent , 0.3 percent , 0.4 percent , and 0.5 percent) is part of the research. The impact of chopped CF on the mechanical characteristics of HPC such as compressive strength, splitting tensile, modulus of elasticity, and flexural strengths was also investigated. The findings show that adding carbon fibers to high-performance concrete enhances its mechanical properties, the flexural strengths and splitting tensile rise considerably. For high performance concrete with a 0.5 % fiber volume fraction, the percentage increase in flexural strengths and splitting tensile after 28 days is about 45 % and 46 %, respectively. Deng[16] used three-point bending experiments to analyze carbon fiber reinforced concrete. The test findings revealed that when pre-cyclic loading stress levels above a specific threshold, the fracture characteristics of concrete with carbon fiber reinforcement and normal concrete are dropped, with the threshold value for concrete with carbon fiber reinforcement being greater than that of normal concrete. Regardless of fatigue life or pre-cyclic loading history, concrete with carbon fiber reinforcement has a significantly longer critical effective fracture length than conventional concrete. A concrete beam with carbon fiber reinforcement with a central notch has a significantly longer flexural fatigue life than the matrices, i.e., concrete with carbon fiber reinforcement with a maximum fraction volume of 0.3 % has a fatigue life of approximately 2.8 times that of normal concrete with such a fatigue stress value of 0.9. It is noted that most of the previous studies focus on the impact of fibers, especially steel fibers, on the flexural strength of ordinary concrete beams and some other types of concrete beams, and there are few studies on the impact of carbon fibers on the flexural strengths of green high-performance concrete beams. Therefore, this study, investigated the influence of carbon fibers and in different contents on the flexural strengths of green high-performance concrete beams.

2-Material and methods

2.1 Materials

2.1.1 Cement

Ordinary Portland Cement(OPC) was used in the current work meeting the Iraqi Specification (IQS:No5, 1984) requirements .

2.1.2 Silica Fume (SF)

U.A.E. produces silica fume (SF), in accordance with ASTM C1240-05 specifications[17] was used as supplementary cementitious material .

2.1.3 Mixing Water(W)

Tap water (W), which is considered safe to drink, was used for concrete mixes.

2.1.4 Super plasticizer(SP)

A new third generation super plasticizer (SP) that made of apoly carboxylic Ether based high range water reducing, was used in various quantities to keep the mixtures' workability at the desired level .

2.1.5 Coarse Aggregate (CA)

The aggregate used was normal river aggregate with a maximum size of 12.5mm. It was graded according to ASTM C 33-C 33M-13[18].

2.1.6 Fine Aggregate (FA)

River sand with 3.94 fineness modulus was utilized according to the ASTM C 33-C 33M-13[18].

2.1.7 Carbon Fibers (CF)

Chopped carbon fiber filaments with a length of 5-6 mm were used as fiber reinforcement. The properties of carbon fibers are mentioned in Table 2.1, according to the manufacturer. Figure 2.1 depicts a photograph of the CF.

Table 2.1 Properties of CF

Carbon content , %	98
Filament length , mm	5-6
Filament diameter , µm	7
Specific Density , gm /cm^3	1.7
Tensile strength , MPa	3440
Modulus of elasticity, GPa	235
Elongation , %	1.5

Figure 2.1 Photographic image of the CF

2.2 Methods

The experimental program included two stages. The first stage includes the production of GHPC mixture as a reference mixture using silica fume at 20% as a partial substitution by cement weight, in addition to using the super plasticizer to obtain the appropriate workability with low w/b ratio. The second stage included adding carbon fiber to the components of the reference mixture with volume fractions 0.3%,0.6%,and1% . Then, the flexural strengths of beams made from the above-produced mixtures were investigated. A constant w/b ratio was used for the produced mixtures, and in order to control the stable workability for the blends, the super plasticizer ratios were modified to investigate the effect of fibers content on the flexural strengths of GHPC beams .

2.2.1 Mixture Proportioning

The symbols for the reference mixtures were coded (OR),the symbols for Carbon fiber reinforcement mixtures were coded (CFR).The volume ratios of the fibers are indicated next to the symbol, for example ,CFR 0.3 indicates the mixture of 0.3% volume of carbon fiber. In addition to the reference mixture, 3 mixes were developed for CF fiber reinforcement based on its volume ratio, resulting in a total of 4 mixtures, as shown in Table 2.2.

Table 2.2 Mix proportions (kg/m^3)

Mixture symbol	PC	SF	FA	CA	W	SP	w/b	CF
OR	400	80	726	1088	168	4.32	0.35	0
CFR0.3	400	80	726	1088	168	6.72	0.35	5.1
CFR0.6	400	80	726	1088	168	7.92	0.35	10.2
CFR1	400	80	726	1088	168	9.36	0.35	17

2.2.2 Flexural Strength Test

Flexural strength is the tensile strength of concrete beams in bending. The aim of a flexural strength test is to determine the maximum load at which concrete beam can crack due to tension . In this study beam samples were tested under simply supported conditions at 7 and 28 days, according to ASTM C78/C78M – 15 specifications[19]. A third point load test is carried out on a digital testing machine with rating load of 50±10 N/s. The bending moment at failure is divided by the section modulus of the beam under consideration to determine flexural strength. According to the above specification, there are three cases for calculating flexural strength according to the fracture initiates of the examined beams, as mentioned below.

Case one: The flexural strength is calculated as an indicated in the Equation 1, if the fracture starts in the tension surface within the middle third of the span's length.

$$R = MC/I = PL/bd^2 \quad (1)$$

Where:
R: flexural strength, MPa
M: maximum bending moment, N.mm
C: cross-sectional centroid = d/2, mm
I: moment of inertia = $bd^3/12$, mm^4
P: maximum applied load, N
L: length of span, mm
b: the specimen's average width, mm (at the fractured section)
d: the specimen's average depth, mm (at the fractured section)

Case two: The flexural strength is calculated as an indicated in the Equation 2, if the fracture occurs in the tension surface outside the middle third of the span length, by < 5 % of the span's length.

$$R = 3Pa / bd^2 \quad (2)$$

Where:

a: the average distance between a fracture line and the nearest support on the tension surface of the beam, mm.

Case three: flexural strength test results should be discarded, If the fracture occurs outside of the middle third of the span length, by >5% of the span's length.

Since all of the fracture cases in this study were similar to the first case as shown in Figure (2.2), so the flexural strength was calculated using Equation 2. The results of three specimens were averaged and recorded.

Figure 2.2 Fracture initiates of the examined beams

3 - Results and discussions

The average flexural strengths of three GHPC beam specimens with differing carbon fiber content at seven and twenty-eight days are shown in Figure 3.1,3.2 respectivly. Flexural strengths increased significantly as the fiber volume fraction increased up to 0.6 percent, and then steadily decreased. When the fiber volume fraction was 0.3 percent, 0.6 percent, and 1%, the growth in flexural strengths at 28 days was 43.2 percent, 81.7 percent, and 77.6 percent, respectively, when compared to plain GHPC. This behavior may be explained by the dismantling properties of fibers during the mixing phase, which resulted in the formation of massive tiny particles. However, these small particles can improve interfacial transition zone with a logic scale, after which they will not contribute to improving it, particularly when particle sizes are much larger than the other concrete constituents, especially at fiber contents of 1%. As a result, a volume fraction of 0.6 percent provides maximum flexural strengths of 10 MPa.

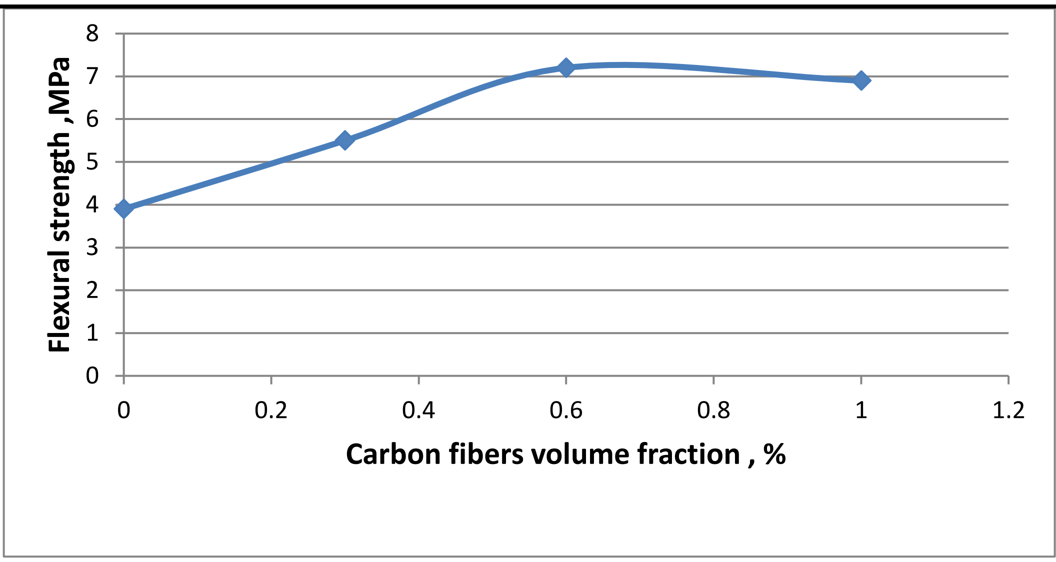

Figure 3.1 Flexural strength of GHPC beams at 7 days

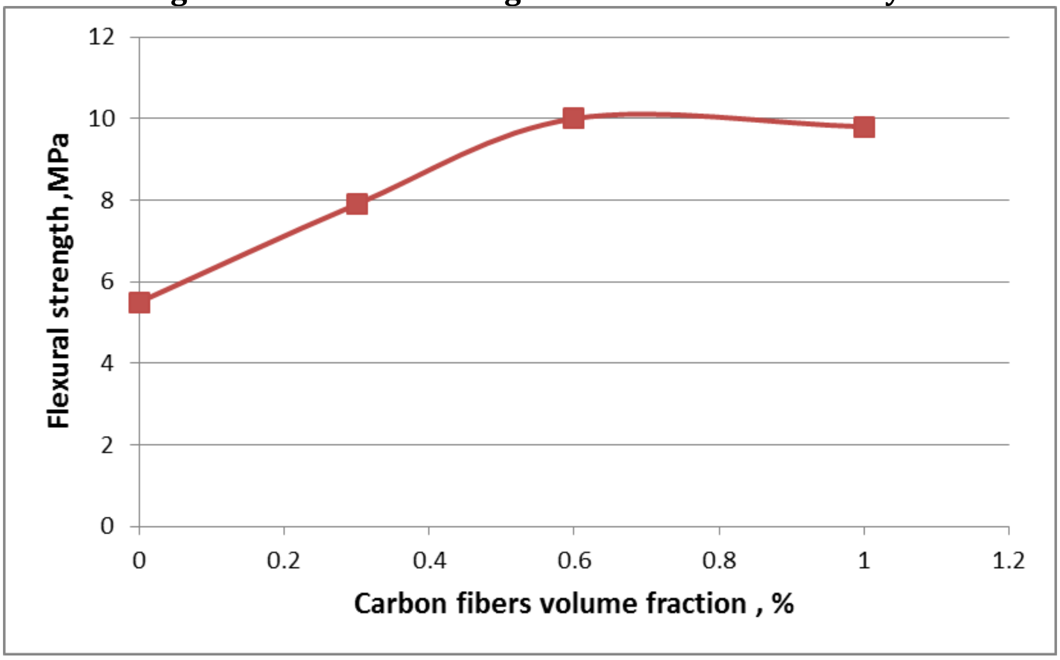

Figure 3.2 Flexural strength of GHPC beams at 28 days

In general, it is evident that adding fibers to GHPC increases its flexural strength significantly. This is due to the fact that fibers can block and delay the spread of tensile cracks, as well as pass stress through the cracks and prevent crack development. Furthermore the experimental test revealed that plain GHPC beams (without fiber) collapsed suddenly in a brittle manner and split into two pieces as shown in Figure 3.3 , while fiber reinforced specimens had cracks in the tension face prior to failure as shown in Figure 3.4. This is due to the fibers' action in the matrix, which prevents the initiation and propagation of arbitrarily directed micro - cracks, resulting in enhanced strength and ductility.

Figure 3.3 Failure mode of plain GHPC beams

Figure 3.4 Failure mode of carbon fiber reinforced GHPC beams

4 - Conclusions

The effects of various CF contents on the flexural strength of GHPC beams were investigated using an experimental program. The following conclusions were drawn based on the results of this study :

1. All GHPC specimens had early strengths, which increased with curing age. This may be due to the importance of silica fumes in improving both short- and long-term strengths.
2. The addition of fibers to non-fibrous GHPC beams changed the non-fibrous

matrix's brittle behavior to ductile behavior.

3. The addition of carbon fibers improves flexural strength considerably. This may be due to its main properties, such as high tensile strength and aspect ratio, which made it possible to use a lot of energy to fracture the beams.
4. It was noticed that raising the carbon fiber content up to 0.6 percent resulted in a systemic increase in strength, after which the findings showed that the carbon fiber content had little effect on beams flexural strength, therefore the optimal carbon fiber content ratio was o.6%, which resulted in a maximum flexural strength of 10 MPa.

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References

[1] Hover KC, Concrete mixture proportioning with water reducing admixtures to enhance durability, quantitative model. Cement & Concrete Composites, 20, 113-119, 1998.

[2] KE Hassan, JG Cabrera, RS Maliehe, The effect of mineral admixtures on the properties of high-performance concrete. Cement & Concrete Composites, 22,267-271, 2000.

[3] Khan M, Ayers ME., Minimum length of curing of slica fume concrete. Journal of materials in civil engineering, 7(2),134-139,1995.

[4] SUHENDRO , B ., Toward green concrete for better sustainable environment. Procedia Engineering, 95, 305–320, 2014.

[5] LOTHENBACH, B., SCRIVENER, K. and HOOTON, R. D. ,Supplementary cementitious materials, Cement and Concrete Research, 41, 1244–1256, 2011.

[6] SAMAD, S. and SHAH, A. , Role of binary cement including Supplem Cementitious Material(SCM), in production of environmentally sust- entary ainable concrete : A critical review. International Journal of Sustainable Built Environment, 6, 663–74, 2017.

[7] PRIYA, C. and SUDALAIMANI, S. ,Properties of Fiber Reinforced High Performance Concrete-A Case Study. International Journal of Engineering Research & Technology (IJERT), 8, 123-131, 2019.

[8] Mazloom M, Ramezanianpour AA, Brooks JJ. , Effect of silica fume on Mechanical properties of high - strength concrete. Cement & Concrete Composites,26(4),347-357, 2004.

[9] Wong HS, Razak HA. , Efficiency of calcined kaolin and silica fume as cement replacement material for strength performance. Cement and Concrete Research, 35(4), 696-702, 2005.

[10] Bhanja S, Sengupta B., Influence of silica fume on the tensile strength of concrete. Cement and Concrete Research , 35(4),743–747,2005.

[11] Köksal F, Altun F, Yiğit İ,Ş ahin Y. , Combined effect of silica fume and steel fiber on the mechanical properties of high strength concretes. Construction and Building Materials, 22(8), 1874–1880, 2008.

[12] Yazıcı Ş, İnan G, Tabak V. , Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. Construction and Building Materials, 21(6), 1250–1253, 2007.

[13] Chen, P. W. , Chung, D. D. L, Cement Reinforced with Up to 0.2 vol. % of Short Carbon Fibers. Cement and Concrete Composites, 24, No. 1,33-52. 1995.

[14] Chen, P. W. , Chung, D. D. L. , Low – Drying - Shrinkage Concrete Containing Carbon Fiber, Cement and Concrete Composite , Part B 27B, 269-274.1996.

[15] I.Khalil, W. , Abdulrazaq, A. , Mechanical Properties of High Performance Carbon Fiber Concrete, Eng.& Technology Journal, 29,No.5, 906–924.2011.

[16] Deng, Z., The fracture and fatigue performance in flexure of carbon fiber reinforced concrete, Cement and Concrete Composites, 27, 131–140.2005 .

[17] ASTM C 1240-05, Standard Specification for Silica Fume Used in Cementitious Mixtures. Annual Book of ASTM Standard, 2007.
[18] ASTM C 33-C 33M-13, Standard Specification for Concrete Aggregates . Annual Book of ASTM Standard, 2013.
[19] ASTM C78/C78M – 15, Standard Test Method for Flexural Strength of Concrete(Using Simple Beam with Third - Point Loading), Annual Book of ASTM Standard, 2015.