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ORIGINAL RESEARCH

Experimental investigation the effect of Carbon, Glass and Steel fibers on the failure strength and slump of standard concrete samples

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Abstract

Fiber reinforced concretes have been evaluated in many researches due to their acceptable performance on the structural members such as beams and columns. Since many materials are used as substitutes for common materials or as improvers in concrete, investigating their effect on the concrete strength is very challenging. In this experimental research, the effect of three type of fiber such as Glass, Carbon and double hook steel on the tensile strength, compressive strength and slump of standard concrete samples have been investigated. Four different percentages of these fibers have been used in the concrete samples (0.5, 1.0, 1.5 and 2% of cement weight). The tests were done at the ages of 7 and 28 days of concrete age. Results showed that in the all dosage of Glass and Steel fiber, compressive strength is increased but in the samples are containing 1.5 and 2% carbon the compressive strength is decreased. The tensile strength has increased in all the percentages of the fibers. Adding fibers in the concrete led to decrease in the slump values in comparison with the concrete sample without fiber.

Keywords: Carbon and Glass fiber, Double hook steel fiber, Compressive strength, Tensile strength, Slump

1. Introduction

Concrete is a cement base material that has a vital role in the construction. An important property of concrete is difference between compressive and tensile strength. So, high strength material could be used in the concrete mixture to increase the strength. In this research, carbon, glass and double hook steel fiber are used in the concrete combination. Standard samples are constructed in cylindrical and cubic shape. Cylindrical samples were used to determine the tensile strength and cubic samples were used to determine the compressive strength. Tensile and compressive strength were achieved in the 7 and 28 days of concrete age. The samples were constructed with 0.5, 1.0, 1.5 and 2 percent of cement weight and a simple concrete sample is existing to comparison with fiber concrete samples. Currently a lot of study was done by researchers in this field and mainly focused on the compressive strength. The influence of steel fibers on compressive and tensile strength of ultra high-performance concrete was reviewed and show that the influence of fibers on compressive strength is

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questionable (Larsen & Thorstensen, 2020). A new design approach of steel fiber reinforced ultra-high performance concrete composites is presented and a novel method for determining equivalent spherical diameter is proposed (Fan et al., 2020). Elaboration of eco-efficient vegetable fibers reinforced cement-based composites using glass powder residue and sand results also showed that the production of 1 ton of cement partially replaced by glass powder residue requires lower energy than the cement partially replaced by limestone (Rodier et al., 2020). Experimental and multi-scale numerical investigation of ultra-high performance fiber reinforced concrete (UHPFRC) with different coarse aggregate content and fiber volume fraction was done and it is found that with the increase of fiber volume fraction, the compressive strength, tensile strength and four-point bending strength of UHPFRC increase first and then decrease (Yu et al., 2020). Influences of the volume fraction and shape of steel fibers on fiber-reinforced concrete subjected to dynamic loading was studied and structural responses of several types of fiber-reinforced concrete with steel fibers are introduced and compared (Soufeiani et al., 2016). Workability, fiber distribution, and mechanical properties of UHPC with hooked end steel macro-fibers was reviewed and results indicated that although a higher silica sand content led to an improved workability for UHPC, it reduced the homogeneity of fiber distribution (Hung et al., 2020). Influence of steel fibers corroded through multiple microcracks on the tensile behavior of ultra-high-performance concrete was investigated and shows that better tensile performance is achieved if steel fibers are moderately corroded (Shin & Yoo, 2020). In regard to the influence of steel fibers in UHPC (Yu et al., 2014) showed that the addition of micro-steel fibers resulted in a lower slump flow value and a higher air content in UHPC. It was also reported by (Soliman & Nehdi, 2012) that the addition of polypropylene fibers and wollastonite micro-fibers adversely affected the workability of UHPC. (Laskar & Talukdar, 2008) demonstrated that the yield stress and plastic viscosity increased with a higher fiber content. (Kang et al., 2010) showed that the tensile strength of UHPC increased linearly with a higher content of steel micro-fibers up to 5%. (Dupont & Vandewalle, 2004) indicated that the increasing interaction of fibers due to a higher fiber content might cause a balling effect during mixing, and this led to a reduction in the mechanical performance of UHPC. (Park et al., 2011) and (Kim et al.,2011) showed that UHPC with deformed steel macro fibers had enhanced tensile and flexural performance compared to the one with non-deformed steel macro- or micro-fibers. Past studies have indicated that the use of deformed steel fibers enhanced the bond properties by more than three times (Wu et al., 2018 and Yoo & Kim, 2019) and the bending strength by 17%–50% (Wu et al., 2018) when compared to those with straight fibers. Studies (Park et al., 2011, Kim et al., 2011 and Yoo & Yoon, 2018 and 2016) also have demonstrated that the UHPC with deformed steel macro-fibers enhanced mechanical performance in terms `of the post-peak response and ductility, as compared to that with straight steel micro-fibers, which is beneficial for earthquake-resistant applications. Despite the advantageous mechanical performance of deformed steel macro-fibers, there is a critical concern regarding the workability as well as the balling and segregation of macro-fibers during mixing and casting processes. (Razzaghi et al., 2022) evaluated the steel fiber reinforced recycled aggregate concrete by means of correlation between ultrasonic and point load tests. (Khaksefidi & Ghalehnovi, 2020) assessment the effect of Reinforcement Type on the Tension

Stiffening Model of Ultra High-Performance Concrete (UHPC). (Sadrmomtazi & Qodousian, 2019) Studied the Effect of Paste Volume, Water to Cementitious Materials and Fiber Dosages on Rheological Properties and In-Situ Strength of Self-Compacting Concrete. (Ahmadi et al., 2021) evaluated the simultaneous Effect of Aggregate and Cement Matrix on the Performance of High Strength Concrete. (Bengar & Yavari, 2016) studied the Reactive Powder Concrete (RPC) Behavior Reinforcing with Resistant Fiber Subjected to Blast Load. (Jagan et al., 2021) studied mechanical and durability properties of the concrete with copper slag. In this research, the effect of three type of fiber such as Glass, Carbon and double hook steel on the tensile strength, compressive strength and slump of standard concrete samples have been investigated. Four different percentages of these fibers have been used in the concrete samples (0.5, 1.0, 1.5 and 2% of cement weight). The tests were done at the ages of 7 and 28 days of concrete age. Results showed that in the all dosage of Glass and Steel fiber, compressive strength is increased but in the samples are containing 1.5 and 2% carbon the compressive strength is decreased. The tensile strength has increased in all the percentages of the fibers. Adding fibers in the concrete led to decrease in the slump values in comparison with the concrete sample without fiber.

. Experimental procedure

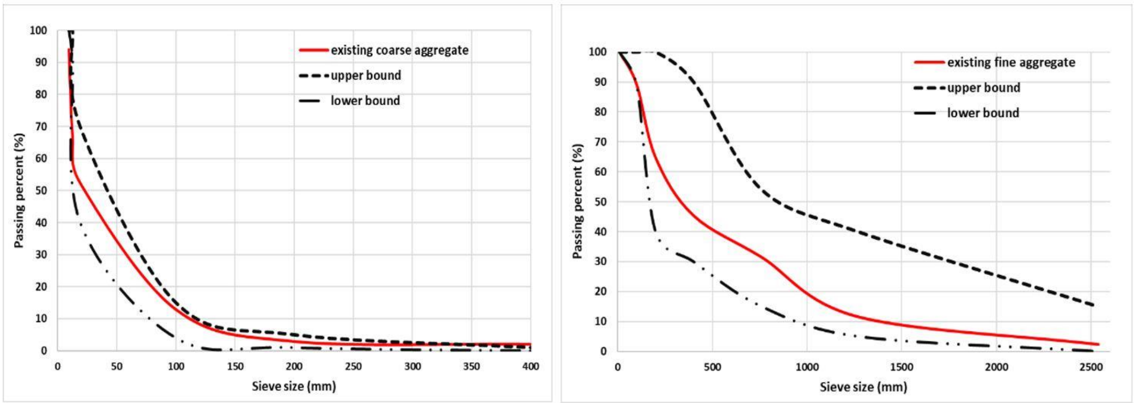
In this research experimental tests were conducted on two cylindrical and cubic samples. Compression tests were performed on the cubic 150x150x150 mm and tensile tests were done on the cylindrical 150x300 mm samples. Tensile tests were done based on the ASTM C496. Grading materials was done based on the ACI standard. Table 1 shows the material grading.

Table 1 Material grading

Sieve size (mm)	Retained weight (garam)	Percent retained (%)	Cumulative retained (%)	Percent passing (%)
19	238.5	3.975	3.975	96.025
12.5	1082.1	18.035	22.01	77.99
9.5	582.9	9.715	31.725	68.275
6.3	1054.3	17.57	49.295	50.705
4.75	745.1	12.42	61.715	38.285
2.36	887.3	14.79	76.505	23.495
1.18	422.7	7.045	83.55	16.45
0.6	278.2	4.64	88.19	11.81
0.3	398	6.63	94.82	5.18
0.15	185	3.08	97.9	2.1
Under last sieves	125.9	2.09	100	0
summation	6000	-	-	-

Based on the ACI upper bound and lower bound distribution for fine and coarse aggregates were specified and Fig. 1 shows these bounds. Concrete mixing was done based on the (ACI-211, 1997). In this research a constant mixing design was selected for without fiber samples and defined as (A1). For all other fibers such as glass, carbon and steel, four mixture design were considered based on the percentage of cement weight. In Table 2, G1: concrete mixing design for glass fiber sample with

0.5% glass fiber, G2: concrete mixing design for glass fiber sample with 1.0% glass fiber, G3: concrete mixing design for glass fiber sample with 1.5% glass fiber, G4: concrete mixing design for glass fiber sample with 2.0% glass fiber. C1: concrete mixing design for carbon fiber sample with 0.5% carbon fiber, C2: concrete mixing design for carbon fiber sample with 1.0% carbon fiber, C3: concrete mixing design for carbon fiber sample with 1.5% carbon fiber, C4: concrete mixing design for carbon fiber sample with 2.0% carbon fiber. S1: concrete mixing design for steel fiber sample with 0.5% steel fiber, S2: concrete mixing design for steel fiber sample with 1.0% steel fiber, S3: concrete mixing design for steel fiber sample with 1.5% steel fiber, S4: concrete mixing design for steel fiber sample with 2.0% steel fiber.



(a) (b)

Fig.1 Granulation curve; a) coarse aggregate, b) fine aggregate

Table 2 shows the concrete mixing design for various fiber samples with constant water to cement ratio. Fig.2 and Table 3 indicate the fiber materials and properties, respectively. Drinking water is used to make all samples. Type 5 Portland cement was used. This cement is used in the areas with sulfated and chlorinated environmental conditions.

Fig.2 Glass, carbon and steel fibers (left to right)

Table 2 concrete mixing design of samples

Mixing design notation	**Fiber (Kg/m^3)**	**Cement (Kg/m^3)**	**Water (Kg/m^3)**	**Coarse aggregate (Kg/m^3)**	**Fine aggregate (Kg/m^3)**	**Water to cement ratio**
A1	-	472	243	926	893	0.47
G1	2.36					
G2	4.72					
G3	7.08					
G4	9.44					
C1	2.36					
C2	4.72					
C3	7.08					
C4	9.44					
S1	2.36					
S2	4.72					
S3	7.08					
S4	9.44					

Table 3 properties of fiber materials

Fiber type	**Diameter (mm)**	**Length (mm)**	**Specified weight (Kg/m^3)**	**Tensile strength (MPa)**
Glass	0.01	15	2560	3310
Steel	0.7	50	7850	1200
Carbon	0.01	3	1950	3700

2-1 Setup

In this research, a force-control loading setup with a capacity of 3000kN has been used. The rate of loading is constant and equal to 4.4kN / s. Fig.3 shows the loading setup, lab equipment, curing condition, under loading sample and failure view of sample, tensile test and slump analysis.

Fig.3 a) loading setup, b) lab equipment, c) curing condition, d) under loading sample, e) failure view of sample, f) tensile test and g) slump analysis.

2-2 Compression test

In this part compressive tests are conducted on the cubic samples. Each test was repeated twice and average of them was reported as final compressive strength. In Table 4, compressive strength of samples in the age of 7 and 28 days are presented.

Table 4 compressive strength of samples

Mixing design notation	**Compressive strength (MPa)**	
	7 days	**28 days**
A1	23.12	35.3
G1	24.6	35.4
G2	25.03	37.3
G3	28.65	39.04
G4	30.02	41.9
C1	31.44	39.9
C2	30.67	37.8
C3	30.22	33.4
C4	29.43	30.9
S1	23.54	35.9
S2	23.6	36.4
S3	28.33	37.5
S4	29.35	39.12

2-3 Tensile test

In this part the tensile strength of cylindrical samples is examined. Splitting Tensile Strength Test (Brazilian test) is used to determinate the tensile strength. Table 5 shows the tensile strength of various samples

Table 5 Tensile strength of samples

Mixing design notation	Tensile strength (MPa)	
	7 days	28 days
A1	2.035	2.9
G1	2.5	3.3
G2	2.51	3.4
G3	2.85	3.42
G4	3.02	3.8
C1	2.4	3.1
C2	2.85	3.3
C3	2.64	3.44
C4	3.04	3.72
S1	2.08	3
S2	2.41	3.2
S3	2.56	3.31
S4	3.04	3.42

2-4 Slump test

Slump values were calculated for various mixing and reported in Table 6. Fig.3 (g) shows the slump test.

Table 6 Slump value

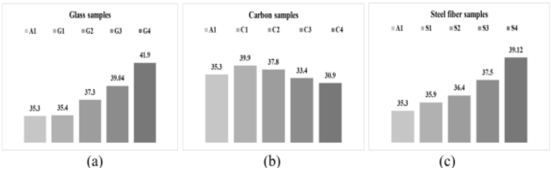
Mixing design notation	Slump (mm)
A1	100
G1	85
G2	65
G3	50
G4	35
C1	95
C2	85
C3	80
C4	75
S1	100
S2	95
S3	90
S4	85

3- Results and discussio

3-1 Effect of mixing design and fiber type on the compressive and tensile strength

3-1-1 Compressive strength

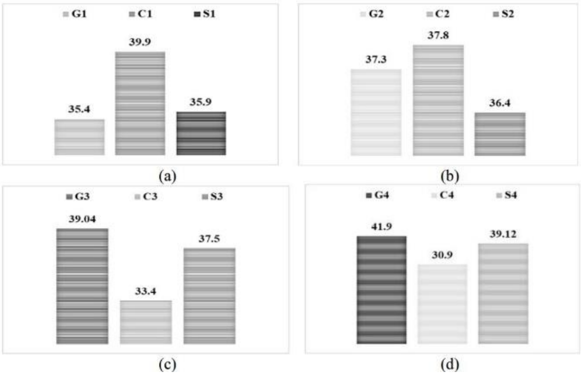
As shown in Fig.4-a glass fiber led to increase in the compressive strength and also with increase in the dosage of glass fiber the compressive strength is increased in comparison with lower dosage. Fig.4-b shows that samples with lower dosage of carbon fiber have more compressive strength and when carbon dosage more than 1% has inverse effect on the compressive strength and led to decrease in comparison with simple sample (C3 and C4 sample have lower compressive strength in comparison with A1 sample). Fig.4-c shows that double hook steel fiber led to increase in compressive strength and increase in dosage led to increase in compressive strength in comparison with lower dosage of steel fiber.



(a) (b) (c)

Fig.4 Effect of fiber dosage on the compressive strength (MPa) of Glass (a), Carbon (b) and steel fiber samples

Fig.5 indicates the effect of fiber type in identical dosage on the compressive strength. Figs.5-a,b show that in the 0.5 and 1% dosage the carbon fiber has more effect on the compressive strength in comparison with glass and steel fiber and Figs.5-c,d indicates that in the 1.5 and 2% dosage the glass fiber has more effect on the compressive strength in comparison with carbon and steel fiber.



(a) (b)

(c) (d)

Fig.5 Effect of fiber type on the compressive strength (MPa) for various mixture design a)0.5%, b)1.0%, c)1.5% and d)2.0%

3-1-2 Tensile strength

Figs.6-a, b and c show that glass, carbon and steel fiber led to increase in tensile strength and increase in fiber dosage led to increase in tensile strength in comparison with lower dosage in all type of fibers.

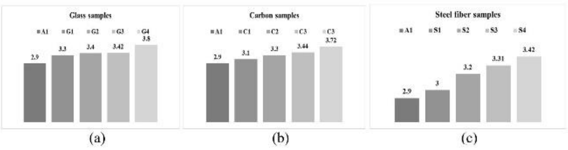


Fig.6 Effect of fiber dosage on tensile strength (MPa) of Glass (a), Carbon (b) and steel fiber samples

In the identical dosage of fibers (Figs.7-a,b,c and d), glass fiber has more effect on the tensile strength in comparison with steel and carbon fiber.

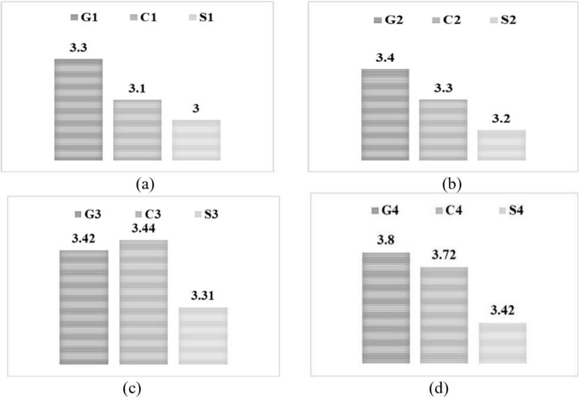


Fig.7 Effect of fiber type on tensile strength (MPa) for various mixture design a)0.5%, b)1.0%, c)1.5% and d)2.0%

3-2 Slump

Fig.8 shows that fiber decreases slump values in comparison with simple sample. In identical fiber dosage the glass fiber more decreases slump value in comparison with carbon and steel fiber.

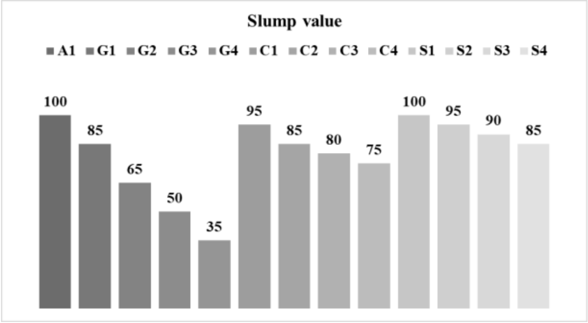


Fig.8 Effect of fibers on slump value (mm)

Finally, to better understanding the effect of fibers on the compressive strength, tensile strength and slump value, variation in their values in comparison with simple sample are shown in the Fig.9.

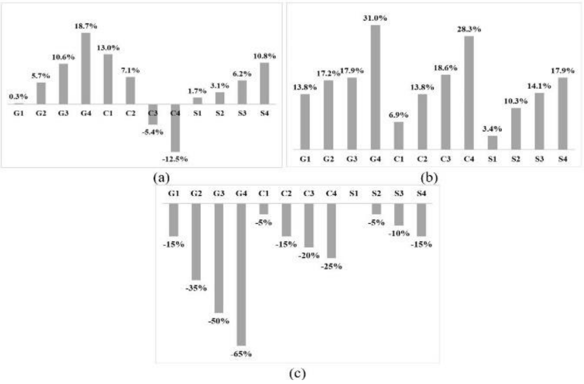


Fig.9 a) Change in compressive, b) Change in tensile strength, c) Change in slump values

the glass fiber led to increase in compressive strength in all dosage ratio and maximum increase was occurred in the 2% dosage and also with increase in the glass fiber dosage the compressive strength increased in comparison with lower dosage. samples with carbon fiber showed wonderful behavior because with increase in the carbon dosage the compressive strength was decreased in comparison with simple sample (in 0.5, 1.0, 1.5 and 2% of carbon fiber the compressive strength changed 13, 7.1, -5.4 and -12.5% in compare with simple sample, respectively). Also, double hook steel fiber led to increase in compressive strength and increase in steel dosage led to increase in compressive strength in comparison with lower dosage of steel fiber. Effect of fiber type in identical dosage on the compressive strength was evaluated and showed that in the 0.5 and 1% dosage, the carbon fiber has more effect on the compressive strength in comparison with glass and steel fiber and in the 1.5 and 2% dosage the glass fiber has more effect on the compressive strength in comparison with carbon and steel fiber. Glass, carbon and steel fiber led to increase in tensile strength and increase in fiber dosage led to increase in tensile strength in comparison with lower dosage in all type of fibers and in the identical dosage of fibers, glass fiber has more effect on the tensile strength in comparison with steel and carbon fiber. Finally, the effect of fiber on the slump values was evaluated and showed that fiber decreases slump values in comparison with simple sample and in identical fiber dosage the glass fiber more effect on the slump value in comparison with carbon and steel fiber. Maximum decrease in slump value was occurred in the 2% dosage of glass fiber and minimum variation was experienced in the steel fiber type.

4- Conclusion

In this research the effect of glass, carbon and double hook steel fiber on the three properties of concrete samples such as tensile strength, compressive strength and slump is investigated. For the compression test cubic sample and for the tension test cylindrical sample was used. Results showed as bellow:

- The addition of glass fibers led to increase in the the compressive strength. With the increase of glass fibers, the compressive strength increased and the highest strength was obtained by adding 2% of glass fibers.
- By adding carbon fibers as 0.5 and 1% to the concrete mixture, the compressive strength was increased in in comparison with control sample and with the increase in carbon percentage (1.5 and 2%) the compressive strength was decreased.
- The addition of steel fibers led to increase in the the compressive strength. With the increase of steel fibers, the compressive strength increased and the highest strength was obtained by adding 2% of steel fibers.
- The maximum increase in compressive strength was observed with the addition of 2% glass fibers.
- By adding steel, carbon and glass fibers, the tensile strength increased in comparison with the control sample.
- The maximum increase in tensile strength was observed with the addition of 2% glass fibers.
- By adding steel, carbon and glass fibers, the slump values were decreased in comparison with the control sample.
- The maximum reduction in slump was observed with the addition of glass fibers.

5- Data Availability Statement

No data, models, or code were generated or used during the study.

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