Hybrid Fiber Reinforced Concrete with Pozzolanic Materials

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Abstract

This paper investigates the possibility of combining steel fibers with different weight percentages along with their functions in increasing compressive strength, indirect tensile strength and bending strength. It's been considered an important economic issue for a long time the ability to service and increase the load-bearing capacity of structural materials. Concrete as a widely used structural material is widely used today. Despite its remarkable properties including high ductility, high durability, longevity, availability and low cost, concrete is a brittle material and performs extremely poor under flexural and tensile loads. In general, the breakdown and destruction of concrete is strongly dependent on the formation of cracks and micro-cracks. As the loading increases, the micro-cracks interconnect and form cracks. In order to address this problem and to create homogeneous conditions, a series of thin filaments has been used throughout the concrete in recent decades; They are called fibers. Steel fiber is one of the most commonly used fibers in concrete. In this study, the compressive strength of concrete was investigated which in some specimens reinforced with steel and containing pozzolanic materials, the compressive strength of control samples increased with the use of fiber etc. In the present study, the flexural and tensile strength of steel fiber reinforced specimens were investigated. According to the results, flexural strength increases with increase in steel fibers. The designs contain 1%, 1.5% and 2% of the Dramix hooked steel fibers used in the research. By reinforcing the specimens with steel fibers, the behavior of tensile concrete is much more flexible than that of non-steel specimens.

1. Introduction

The concrete has advantages and disadvantages due to its structure, related to lower tensile and bending strength than compressive strength. This produces the fragile (softening) behavior of concrete, sudden failure and disintegration of the concrete structures. From the mid-18th century, steel bars have been used to improve the fragile behavior of concrete under tension. The accurate position of tensile strength has not been obvious in some cases and all steel bars cannot be spread in all given points. For this reason, the different kinds of fibers used as one of solutions are investigated to improve the fragile behavior of concrete and to decrease its permeability [1]. Steel fibers added to the concrete enhance the mechanical properties such as strength, ductility, durability, and performance under dynamic load and strike [2-3].

Due to the ability of the relevant ductility and high tensile strength, Steel fibers having high elastic modulus and fracture strain are considered as the most appropriate and cost-effective fibers in the different-looking forms (direct, tooth, hooked end) to improve the behavior of concrete [4]. There is not the accurate evidence when steel fibers have been utilized, but several individuals have used some distinct methods such as pieces of cords or metal cuts into concrete, entitled the methods to their own name [5]. In 1960s, the steel fiber-reinforced concrete was first performed by Baston and Ramualdi in U.S. Then, the industrial uses of the steel fiber-reinforced concrete have been investigated [6]. Qureshi et al. (2008) explored the properties of high strength concrete with adding steel fibers. The results showed that tensile strength is linearly increased with adding

steel fibers and the process will be rapider in the first seven days [7]. Kim et al. (2010) described correlation and dependence between tensile and bending behavior of cementitious composites. Two types of high-strength steel fibers (hooked and Torex) have been used in cementitious matrix with 8 MPa compressive strength. Bending and tensile specimens reinforced with 1 fiber volume percent have been utilized to estimate the material behavior. Bending specimens have been prepared in three sizes: 50*25*300 mm, 100*100*300 mm, and 150*150*450 mm. the results conclude that specimens made through both hooked and Torex fibers demonstrate the hardening behavior of displacement. However, Torex fiber-reinforced specimens have higher bending strength [8]. Vandewalle (2008) examined Hybrid fiber-reinforced concrete. He used three steel fibers (very short fibers 6 m in length, short fiber 13mm in length, and long hooked-end fiber 35 mm in length). In these tests, pillars were used 550mm to 13mm in length and 150 mm in height. The used fiber volume has been 0 to 90 kg per m³, added to the concrete mixture in a distinct way and in mixed way including two or three fibers. The results of measuring the crack mouth opening displacement indicates that 3 and 13 mm fibers are very effective in places of micro crack opening. While 35 mm fibers provide a good ductility in the wide and big, micro cracks grow and join together and finally they connect to big cracks. Long hooked end fibers are very active to be connected to the crack [9]. Pul (2010) examined tensile strength, bending strength, and compressive strength to divide high strength- and performance - concrete and measured the relation between properties and compressive strength. The used specimens have different strength from 48 to 81 MPa [10]. XU and Shi (2009) investigated the relation between mechanical properties of the typical concrete and fiber concrete. These fibers have

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consisted of Polypropylene, glass fibers, and steel fibers. And compressive strength, tensile strength to divide and bending strength have been considered as parameters expressing the mechanical properties [1]. Rodrigues et al. (2010) have studied the behavior of fiber-reinforced concrete pillars. There are four pillars in the study 0.25 * 0.25 m in dimensions and 3 m in height, having been reinforced through the distinct linear strap. The first pillar to third pillar include 38.8, 27.24, 16.56 kg steel fibres and 1.5 kg/m Polypropylene fiber, respectively. The fourth pillar is lack of fiber. The results showed that Polypropylene and steel fibers used in the concrete improve the behavior of pillars in fire. Polypropylene fiber can control concrete delamination. Also, the pillar always need some steel bars for strength against fire. It is not a good way to replace steel bars with steel fibers in concrete against fire [11-12]. Nili and Afroughsabet (2010) researched the effect of pulverized silica and steel fibers on impact strength and mechanical properties of the concrete. the results showed that the added steel fibers improve tensile strength and bending strength. Also, steel fibers added to the specimens including pulverized silica enhance impact strength and ductility of the concrete considerably [13].

2. Steel fiber- reinforced concrete

Fiber concrete (steel fiber) consists of a concrete skeleton mixed into cement, stony materials, water and a percentage of short steel fiber randomly spread through mixture in the different direction, and steel fiber enhances the properties of concrete to a specific condition. Steel fiber-reinforced concrete is casted and compressed as a simple concrete. The mixture of steel fiber reinforced concrete is designated the same as simple concrete. It is important to consider how fibres are invariably spread, are avoided to be detached and to be balled, and an efficient mixture is produced to cast, compact, and finish concrete [15-18].

2.1. Objective of the study

The present study is aimed at investigating the effect of fiber volume on strength parameters of steel fiber concrete and testing the amount of the different weight fiber concrete. Also, each of factors including strength and behavior have been studied here.

2.2. Compressive strength

in the study, compressive strength has been estimated in accordance with ASTM C 39 standard. According to the standard, loading speed must be constant. for this reason, cube specimens have been by size 150*150*150 mm. to determine compressive strength, compression machines having ultimate capacity of 300 tons have been used.

2.3. Indirect tensile test known as the Brazilian test

To test tensile strength, the cylindrical samples of steel fiber – reinforced concrete have been evaluated through using splitting test of specimens (Brazilian test) and the results have been compared together and to specimen without fiber. 28-day tensile strength test has been measured on the basis of ASTM C96 standard. Cylindrical tests (Fig.2) used in the test have been 100*200 mm in dimensions. The number of three specimens located at each of the given levels has been made out of four volumes without fibers; 1%, 1.2 %, and 2 %. Rupture stress has been calculated in accordance with the following equation:

$$F_{sp} = F_{cr} = T = \frac{2 \times P \times 1000}{\pi \times L \times D} \quad (1)$$

T: rupture stress at MPa

P: the maximum load of the machine at KN

L: specimen length at mm

D: specimen diameter at mm

Fig.2- cylindrical specimen is testing tension through the gap method of specimen (Brazilian)

With ASTM C78 [14] standard, bending test is performed through four-point bending machine (fig.3). As the figure has shown, four-point test machine has been used to test bending. Bending strength of rectangular-cube specimens of steel fiber-reinforced concrete are compared together and to specimens without fiber. Rectangular- cube specimens are 100*100*500 mm in dimensions. The number of three specimens located at each of the given levels has been made out of four volumes without steel fibers; 1.5%, 2 %, and 2.5 %.

2.4. CRACKING PATTERN

To examine cracking pattern of the matrix tensile specimens reinforced with the different percentages of fibers, parameters such as the number of cracks, width of cracks, and their distance from each other are investigated. In cracking of the matrix specimens reinforced with fibers, it is true that the energy of material and their ductility are higher when the number of cracks and their distance from each other is more.

3. The used material

Quartz grains have maximally been used 5.0 mm in dimensions. The dimension of the grains used in the study are shown in table 1:

Table.1. Some properties of the quartz grains

Bulk dry specific gravity		2.62
Absorption, %		0.41
Dry-rodded unit weight,	kg/m ³	1700
	lb/ft ³	106.2
Sieve		Percent passing
25.0 mm	(1 in)	100
19.0 mm	(3/4 in)	75
12.5 mm	(1/2 in)	50
9.5 mm	(3/8 in)	25
4.75 mm	(No. 4)	0
Fine aggregate, natural sand, Lot 7284		
Bulk dry specific gravity		2.59
Absorption, %		1.16
Fineness modulus		3.12
Sieve		Percent passing
4.75 mm	(No. 4)	100
2.36 mm	(No. 8)	82
1.18 mm	(No. 16)	62
600 μm	(No. 30)	32
300 μm	(No. 50)	9
150 μm	(No. 100)	3
75 μm	(No. 200)	1.5

The quality and requirements used in the steel fiber-reinforced concrete is similar to water used in the typical concrete. Water used in the study was provided with drinking water in Arak which is qualitatively acceptable. Concrete used to make all specimens are type 2 concrete from Delijan concrete factory. Micro silica (silica fume) grout and PCE super plasticizer used in the study have been from products of Vand chemical company. Hooked steel fibers and wavy steel fiber used in the study have been presented in table 2. Fig. 2 shows the test machine used in this research. In one of the plates on the upper part, there are two holes in the middle of the passage of the

vacuum hose from the first hole. The load cell is inserted into the second hole, and four sets of studs on the four sides of the plate lift the plate using a welding crane. On the sides of the plates, three holes of the bolt are intended to be six in total, until the configuration shown in Fig. 2 is achieved. The reason for these six bolts is the installation of a top plate assembly, which, when tested with the crane, prevents these bolts from entering the axial load into the cylinder. Also, the fibers employed in the research consist of three types of hooked steel fiber. the characteristics of which are shown in Fig. 3.

Fig.3. The fibers

Table. 2. Properties of the steel fibers

Elastic Modulus (GPa)	Tensile Strength (MPa)	Special weight (kg/m ³)	Length (mm)	Diameter (mm)	Mechanical Control	Name of the fiber
2100	1225	7850	60	0.75	hooked	DRAMIX 3 D
2100	1500	7850	60	0.9	hooked	DRAMIX 4 D
2100	2300	7850	60	0.9	Hooked	DRAMIX 5 D

3.1. The plan of mixture

The experimental work is aimed at obtaining the high-strength and efficient cementitious matrix and measuring the mechanical properties. The study has investigated how the different percentages of steel fibers have effect on specimens including micro silica (silica fume). To examine compressive strength, cylindrical specimens (fig.4) have been made 100 *200 mm in dimensions. To examine bending strength, prismatic specimens have been 100*100*350 mm in dimensions. To examine tensile strength, cylindrical specimens have been made 100*200 in dimensions. Water-cement ratio (w/c ratio) in steel fiber-reinforced concrete is lower than in rich concrete. According to way of composing the concrete, water-cement ratio is about 0.30-0.55. The study aims to compare the effect of steel fibres on the mechanical properties of steel fibre-reinforced concrete. in all plans of mixture, water-cement ratio and quartz grain-cement have been fixed, so they have been considered 0.30 and 1.58, respectively. to provide the control plan, nine plans without fibre to fracture have been made in 3,7,28 days. To provide specimens reinforced with 1%, 1.5%, 2% fibres (based on weight of cement), three specimens to fracture was made in 28 days old with 10% in cement-micro silica weight. To produce fibre specimens, the amount of super plasticizer is equal to /6% by weight of total cement –silica fume ratio for all given plans. The procedure of mixture and the final plan of mixture from cement matrix have been presented in Table 3 and Table 4.

Table.3. The mix

Grain	2 min
Cement	2min
Micro silica (silica fume)	1min
Super plasticizer+70% water	4min
30 % rest water	4min

Table. 4- The final plan of mixture from cement matrix

Cement matrix	Cement	Micro silica	Grain	Water	Super plasticizer
Weight ratio	1.00	0.10	1.58	0.35	0.006

Fig.4. The samples

4. Results

To examine the effect of using steel fiber on compressive strength of steel fiber –reinforced concrete, graphs of compressive-strength changes in specimens reinforced with 1%, 1.5%, 2% fibers have been drawn in Fig. 5-7 for 28 days, respectively.

Fig.5. The effect of steel fiber volume on 28-day compressive strength of concrete reinforced with 1 % steel fiber

The compressive strength of the specimens decreased with increasing amount of hooked steel fibers used in concrete. One possible reason is that increasing the amount of steel fibers, in addition to reducing the efficiency of the concrete, creates a gap between the concrete particles and decreases the integrity of the cement mortar. Also, the best amount of hooked steel fibers is 2% which controls the decreasing trend of compressive strength of concrete.

As the above graphs have showed, 28- day compressive strengths of the fracture specimens are close each other. In the condition, steel

fibers cause to decrease long -time compressive strength of the concrete in some specimens. According to Fig. 10, not only the plan including 1.5 percentage of 4-D hooked steel fiber but also 28-day compressive strength have been enhanced in all specimens. According to the results, the highest 28-day compressive strength is related to specimens reinforced with 1 percentage of 5-D steel fiber (hooked steel fiber L/D= 65), increased by 57.13 %. Also, the lowest compressive strength is related to 4-D hooked steel fiber (L/D=65), decreased by 4.33%.

Fig.6. The effect of steel fiber volume on 28-day compressive strength of concrete reinforced with 1.5 % steel fiber

Fig 7. The effect of steel fiber volume on 28-day compressive strength of concrete reinforced with 2 % steel fiber

Fig.5- Four-point Flexural machine

To examine bending strength, specimens have been tested (fig.5) after 28 days. A support is placed at a distance of 15 cm from two heads of specimens. Thus, duration of the experiment is 450 mm. tensile strength is calculated through the following formula:

$$F_r = \frac{P \times L \times 1000}{bh^2} \quad (2)$$

Fr: modulus of rupture at MPa

P: the maximum load of the machine at KN

L: distance between two supports of the specimen at mm

B: width of the specimen at mm

h: height of the specimen at mm

Fig. 8. The effect of steel fiber volume on 28- day bending strength of concrete reinforced with 1% fiber

Fig. 9. the effect of steel fiber volume on 28- day bending strength of concrete reinforced with 1.5% fiber

According to Fig. 9, 28-day bending strength of plans of the mixture has somewhat been changed. In the condition, the used steel fiber increases the long-time bending strength of concrete in all specimens considerably. The highest 28-day bending strength is related to specimens reinforced with 2% steel fiber (3-D hooked steel fiber L/D=

80 and 5-D steel fiber L/D=65) with 31.7 MPa and bending strength with 56.64% growth.

Fig. 9. shows that the lowest bending strength is related to specimens reinforced with 1 % steel fiber (3-D hooked steel fiber L/D= 80) with 27.3 MPa and bending strength with 47.14 % growth.

Fig. 10. the effect of steel fiber volume on 28-day bending strength of concrete reinforced with 2% fiber

As shown in Fig. 10, application of steel fibers has increased short-term tensile strength of concrete in all cases. According to Fig. 6, tensile strength of all samples has increased. Based on these results, the highest tensile strength exists in samples reinforced with 5D steel

fibers (hooked steel fibers) with 56.39% tensile strength increase according to Fig 11. The tensile toughness of concrete has significantly increased and concrete behavior become softer.

Fig. 11. The percentage graph of 28-day bending strength in steel fiber specimens to specimens without fiber

To examine tensile strength, the produced specimens have been tested after 28 days. 28-day tensile strength of control specimens related to the plan of mixture has been shown. Fig. 11-14 have indicated the final strength of the plans for specimens with different percentage of 28-day cylindrical hooked steel fiber volume (1%, 1.5%, and 2%).

Generally, the results related to the effect of steel fiber on tensile strength can indicate as follows: Specimens reinforced with steel fiber show that the behavior of concrete under tensile is more ductility than specimens without fiber. According to the results, the fracture of specimens without steel fiber has been fragile. While steel fiber-reinforced specimens have gradually been cracked.

Fig. 12. the effect of steel fiber volume on 28-day tensile strength of concrete reinforced with 1% fiber

Fig. 13. the effect of steel fiber volume on 28-day tensile strength of concrete reinforced with 1.5% fiber

Fig. 14. the effect of steel fiber volume on 28-day tensile strength of concrete reinforced with 2% fiber

No-ruptured specimens and the available fiber have joined grains each other. The increased number of steel fiber enhances tensile strength of concrete considerably. The more the number of fiber is, the higher tensile strength of concrete becomes.

The lowest tensile strength is related to plans including Four-D hooked steel fiber ($L/D = 65$). As shown in Fig. 10, 28-day tensile strength in the plans of mixture have mainly been changed.

According to Fig. 12, 28-day tensile strength have increased in all specimens. the results have demonstrated that the highest 28-day tensile strength is related to specimens reinforced with 2% Five-D steel fiber (hooked steel fiber $L/D = 65$) with 135 MPa and 162.03% growth of tensile strength.

Fig.15. The cracking patterns

To survey cracking pattern of fig.6 tensile-matrix specimens reinforced with the different percentages of fiber, parameters such as the number of cracks, width of cracks and their distance from each other have been investigated. Cracking of the reinforced matrix specimen has presented that energy absorption of materials and their ductility are further when the number of cracks is more and they have the short distance from each other. The best cracking pattern in reinforced with cementitious composites is when cracking has been innumerable in very short distance. And demonstrates strain-hardening behavior. When energy to make new crack is more than energy to open crack, matrix tends to innumerable cracking. The added different percentages of fibers change cracking pattern of material. If the percentage of fibers is enough and properties of matrix are suitable, the behavior of materials moves strain-softening into strain-hardening. Fig 15 has indicated cracking in specimens reinforced with 1%, 1.5% and 2 % fibers. The cracking pattern is similar in specimens reinforced with 1 and 1.5 fibers and there are a min crack and some micro cracks around the pattern. Fracture of specimen follows the crack opening. as presented in the figure 15, cracking pattern of specimens reinforced with 2% fiber has been in form of several close cracks (less than 1cm in distance) and other micro cracks in far distance and finally ruptured specimens have been created through connection of small cracks. the added percentages of fiber improve the behavior of strength and energy absorption in the given movement after cracking of materials and causes ductility of materials. Also, emerging innumerable cracking and decreasing width of cracks, compared with growth of a crack and its more opening, help control width of cracks and improve strength of materials.

CONCLUSION

Tests of compressive, tensile, and bending strengths have concluded the following results in the study:

- Steel fiber, even in high percentage, doesn't have a considerable effect on compressive strength but toughness strength is mainly increased in specimens and the behavior of concrete will be softer.
- The added steel fiber enhances tensile strength of concrete remarkably. The more the volume of fiber is, the more tensile strength of concrete is. The added steel fiber causes to enhance tensile toughness and softening behavior of concrete. The results of 28-day tensile strength indicate that the addition of steel fiber increases tensile strength linearly.
- Fiber enhances bending strength of concrete considerably which is actually related to the volume of used fiber.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest.

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