Challenge Journal of Concrete Research Letters

Research Article

Effects of fibers geometry and strength on the mechanical behavior and permeability properties of slurry infiltrated fiber concrete

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ABSTRACT

The use of slurry-infiltrated fiber concrete (SIFCON) has been increasing in recent years. SIFCON is a very good alternative, especially in structural reinforcement processes. In this study, the effects of 2 different steel fibers of normal strength (3D) and high strength (5D) with different geometry and strength properties and polyolefin origin synthetic fiber are examined on the mechanical behavior and capillary water permeability properties of SIFCON. Steel fibers were used in 2 different ratios by volume 4% and 8%, while polyolefin synthetic fiber was used at 4% by volume. The bending strength and splitting tensile strength of SIFCON containing 5D steel fiber are 46.47 MPa and 18.47 MPa, respectively, 4.9 and 2.1 times higher than plain concrete. In addition, the fracture energy of SIFCON containing 5D steel fiber is 20400 N/m, and it is 358 times higher than plain concrete, 1.6 and 3.1 times higher than concrete containing the same amount of 3D fiber and polyolefin synthetic fiber, respectively. The capillary water absorption of SIFCON, which contains 4% synthetic fiber and 8% 3D steel fiber by volume, is 0.121 mm and 0.112 mm, respectively, which is higher than all other mixtures in the study. As a result of the study, higher splitting tensile strength, bending strength and fracture energy values were obtained in concretes containing 5D steel fiber, which have high tensile strength and have better adhesion to concrete due to its geometry. The use of synthetic fibers or high amounts of steel fibers increased the permeability.

ARTICLE INFO

Article history:
Received 7 September 2022
Revised 11 October 2022
Accepted 31 October 2022

Keywords:
SIFCON
Steel fiber
Synthetic fiber
Mechanical behavior
Fracture energy
Permeability

1. Introduction

Slurry Impregnated Fiber Concrete (SIFCON) is a fiber-reinforced cementitious composite in which steel or synthetic fibers can be used separately or as a hybrid, with very high tensile and flexural strengths, and can reach extraordinary toughness values (Farnam et al. 2010; Ali and Riyadh 2018; Khamees et al. 2020; Mohan et al. 2020). Its use in many areas such as precast products, elements exposed to impact and dynamic loads, pavements, applications requiring heat resistance, repair and reinforcement works, places that need protection against explosion and fire, and prestressed reinforced concrete beams has recently become widespread. Depending on this situation, studies to determine the mechanical behavior, fire resistance, behavior against dynamic loads, impact resistance for explosion and ballistic effects, and durability to environmental effects of this special type of concrete are increasing day by day (Lankard 1984; Schneider 1992; Tuyan and Yazıcı 2012; Rattan and Singh 2019; Soylu and Bingol 2019).

Steel fibers are widely used to improve the mechanical properties of concrete. Apart from steel fibers, different fibers such as polyolefin, polypropylene, polyethylene, nylon, glass, carbon and basalt fibers can be used to improve the mechanical properties of concrete (Topcu and Canbaz 2007; Sun et al. 2018; Yildizel 2018; Akcay and Ozsar 2019).

Ipek et al. (2019) in their study to examine the mechanical properties of SIFCON, they filled 1/3, 2/3 and 3/3 of the beam molds with fibers. The highest flexural

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ISSN: 2548-0928 / DOI: https://doi.org/10.20528/cjcrl.2022.04.003

strength values were reached in the samples using 60mm and 35mm long steel fibers together and in combination of 60mm steel fiber and 50mm polypropylene fiber. Flexural strength values are 44.02MPa and 41.23MPa, respectively. It has been determined that steel and polypropylene fibers are effective in improving the mechanical properties of SIFCON, however, since polypropylene fiber is lighter and its cost is lower than compared to steel fiber, it can provide significant advantages in terms of unit weight and cost.

In their study, Canbaz and Ünüvar (2016) investigated the properties of SIFCON produced with different fibers and binders. Polypropylene fibers and two different lengths of steel fiber were used to investigate the effect of the fiber. Portland cement, fly ash, pozzolanic cement, and calcium aluminate cement were used as binders. The effects of fiber type and binder on the test results were determined by performing unit weight, ultrasonic pulse velocity, bending strength, compressive strength, and water absorption tests on the produced samples. It has been observed that the binder type affects the SIFCON properties. It has been evaluated that the use of steel fiber is more suitable than polypropylene fiber as it improves mechanical properties. It has been determined that macro-sized steel fibers are more effective in improving mechanical properties.

In his study, Al-Mashhadani (2021) produced SIFCON samples with five different fiber types. It was determined that the steel fiber samples gave better flexural strength results compared to the samples reinforced with other fiber types. In addition, when high temperature is applied to the samples, less strength losses occurred in steel fiber reinforced samples compared to other fibrous samples.

Yazıcı et al. (2010) investigated the effects of mineral additives such as Class C fly ash and ground granulated blast furnace slag on the mechanical properties of SIFCON concrete. In addition, they also examined the effects of steel fiber alignment on SIFCON. The test results showed that the use of mineral additives positively affects the mechanical properties of SIFCON and that the alignment of the steel fibers is an important factor in obtaining superior performance.

Yalçınkaya et al. (2014) in their study on SIFCON, stated that many parameters such as fiber type and geometry, curing conditions, properties of the fiber-matrix interface, and matrix strength affect fiber-matrix bond properties. They stated that this bond can be strengthened with mineral additives such as metakaolin. In their study, they determined that the use of metakaolin improved compressive strength and fiber-matrix bond properties. They also determined that hooked fiber performs better than straight fiber.

In his study, Sengul (2018) used hybrid steel fibers recovered from scrap tires to produce SIFCON. The compressive strength, bending strength, and splitting tensile strength of the samples were determined. In addition, the load-displacement curves of the samples were also obtained. The test results showed that the flexural strength and toughness increased as the fiber content increased and the waste steel fibers could be used successfully in SIFCON.

Numerous studies have been carried out in the literature on the use of 3D, 4D and 5D steel fibers in concrete (Gao et al. 2021; Ding et al. 2022). Abdallah et al. (2016) investigated the fracture behavior of concretes with different water/cement ratios containing 3D, 4D and 5D fibers. The results showed that the pull-out load and total pull-out work of mixtures containing 5D fiber were greatly higher than mixtures containing 3D and 4D fibers. In addition, at lower water/cement ratios, the performance of the fibers is much better. Chen et al. (2022) investigated the flexural strength properties of concretes in different strength classes containing varying amounts of 3D, 4D, and 5D steel fibers. The results showed that increased fiber dosage and the number of hooked ends were effective in improving the flexural tensile behavior of concrete beams in general, especially high-strength concrete beams. Venkateshwaran et al. (2018) obtained stress versus crack-mouth-opening and displacement curves of 69 different specimens with multiple hook tip geometry by 3-point bending test. Based on the test results, empirical models were established to determine residual flexural stresses through multiple regression analysis. The results show that residual flexural strengths were found to be proportional to the square root of the concrete compressive strength and the square of the number of hooks at the fiber ends.

Guler and Akbulut (2022) used single-hooked 3D fiber and multi-hooked 4D and 5D steel fibers to evaluate the performance of the fibers at room conditions and after high-temperature effects. As a result of the study highest residual compressive, bending, and residual toughness capacity after high- temperature effect were obtained in the samples using 5D steel fiber.

Studies comparing the performance of steel fibers with polyolefin fibers are also available in the literature (Tagnit-Hamou et al. 2005; Alberti et al. 2014; Enfedaque et al. 2021). In the studies, the mechanical properties and fracture energies of concretes containing steel fiber were higher than concretes containing polyolefin fiber. However, due to the fact that polyolefin fibers are lighter and have less corrosion risk, it is recommended in some studies to use them in concrete as a hybrid with steel fibers (Alberti et al. 2015).

The main aim of this study is to determine the effect of fibers with different geometry and tensile strength on the mechanical behavior and permeability properties of SIFCON. In this context, compressive strength, splitting tensile strength, bending strength, and capillary water absorption tests were performed on the samples. In addition, load-displacement curves of all samples were obtained to determine the fracture energies.

2. Experimental Study

In the study, various SIFCON concrete mixtures were prepared in the laboratory by using different types of steel fibers and macro synthetic fibers. Compressive strength, splitting tensile strength, and bending strength tests were carried out to determine some mechanical properties of SIFCON concrete on cube and beam samples of the prepared concrete mixtures. In addition, the fracture energy values of all concrete mixtures were determined. For the permeability properties of concrete samples, capillary water absorption tests were carried out. Thus, the effect of fiber type on the mechanical behavior and permeability properties of SIFCON concrete was evaluated by making performance-based comparisons.

2.1. Materials and mix proportions

2.1.1. Cement and aggregates

CEM I 42.5 R type portland cement was used in the study. The aggregate used is a silica-based aggregate with a maximum size of 1 mm. In high-performance concrete, aggregates with silica and quartz properties are frequently preferred because they are stiffness, clean, and highly durable. In this study, the siliceous aggregate was also preferred for its high strength and stiffness. Some physical and chemical properties of cement and silica aggregate used in the study are given in Table 1. The particle size distribution of siliceous aggregate is presented in Table 2.

2.1.2. Steel and synthetic fibers

In the mixtures, 2 different steel fibers with normal and high strength and 1 polyolefin origin synthetic fiber were used. Some properties of these fibers are given in Table 3.

The water/cement ratio was kept constant as 0.27 in all SIFCON mixtures. One of the steel fibers used in the mixtures is of normal strength and has a tensile strength of 1100 MPa and the other is high strength and has a tensile strength of 2250 MPa. The polyolefin fiber has a tensile strength of 590 MPa. All fibers were used in the same proportion (4%) by volume in concrete mixtures, and 314 kg/m^3 for steel fibers and 36.4 kg/m^3 for polyolefin synthetic fiber. Siliceous aggregate was used in all mixtures and the maximum particle size is 1 mm. The superplasticizer additive is a high-range water reducer and was used at a rate of 3% by weight to the total binder in all mixtures. It was used the slurry in a flowing consistency with a diameter of 750 mm in all mixtures. The amounts of materials for the concrete mixes were given in Table 4.

Table 1. Properties of cement and siliceous aggregate.

	Cement	Siliceous aggregate (0-1 mm)
SiO_2 (%)	20.1	98.1
CaO (%)	63.5	0.3
SO_3 (%)	2.7	0.2
Al_2O_3 (%)	4.2	0.7
Fe_2O_3 (%)	3.2	0.3
MgO (%)	1.3	0.02
Na_2O (%)	0.9	0.01
K_2O (%)	0.2	0.04
Specific gravity (gr/cm^3)	3.16	2.62
Specific surface area (cm^2/gr)	3892	-
Chloride (Cl^-)	0.003	0.010
Activity index, 7 days (%)	-	-
Loss on ignition (%)	3.4	0.2
Particle ratio (<0,045 mm) %	-	-
Insoluble residue (%)	0.4	-

Table 2. Particle size distribution (%) of siliceous aggregate.

Sieve size (μm)	Siliceous aggregate (0-1 mm)
+1600	-
1000-1600	0.5
710-1000	4.2
500-710	12.6
355-500	25.2
250-355	32.5
180-250	20.8
125-180	3.1
90-125	0.7
63-90	0.3
0-63	0.1

Table 3. Properties of steel and polyolefin fibers.

	Normal strength steel fiber	High strength steel fiber	Polyolefin fiber
Length (mm)	60	60	50
Diameter (mm)	0.75	0.75	0.50
Aspect ratio	80	80	100
Density (kg/m^3)	7850	7850	910
Modulus of elasticity (MPa)	210000	210000	11000
Tensile strength (MPa)	1100	2250	590

In the coding of the mixtures, it was named as plain concrete mixture (REF), mixture containing normal strength steel fiber (3DSF-4), mixture for high strength steel fiber (5DSF-4) and mixture containing polyolefin (PE-4). In addition, a mixture (3DSF-8) containing 628 kg/m^3 (8% by volume) normal strength steel fiber was also prepared to determine the effects of the increase in fiber content on the SIFCON properties. All specimens were taken from the mold after 24 hours and kept in a water-filled curing tank until the test day.

Table 4. Materials used in concrete mixtures.

	REF	3DSF-4	5DSF-4	PE-4	3DSF-8
Cement (kg/m^3)	1000	1000	1000	1000	1000
Silica fume (kg/m^3)	250	250	250	250	250
Siliceous powder (0-1 mm) (kg/m^3)	820	820	820	820	820
Water (kg/m^3)	270	270	270	270	270
Superplasticizer (kg/m^3)	30	30	30	30	30
Normal strength steel fiber	-	314	-	-	628
High strength steel fiber	-	-	314	-	-
Synthetic fiber	-	-	-	36.4	-
Water/Cement	0.27	0.27	0.27	0.27	0.27
Water/Binder	0.22	0.22	0.22	0.22	0.22
Unit Weight (kg/m^3)	2370	2684	2684	2406	2998

Steel fibers used in the study were produced in accordance with EN 14899-1 standard. The hooked ends in all steel fibers ensure the desired fiber is pulled out. This is the mechanism that actually produces the known concrete ductility and post-crack strength. In the high-strength fiber apart from the normal strength fiber, the hook ends are shaped to form the perfect anchorage with the concrete, where the pull-out mechanism from the concrete is replaced by the elongation of the fiber. The tensile strength of a steel fiber has to increase in parallel with the strength of its anchorage. Otherwise, if the strength of the anchor is increased and the tensile strength of the steel fibers is not sufficient, the steel fibers will fracture. The geometry and strength of normal and high-strength steel fibers used in the study are given in Fig. 1 (Bekaert 2021).

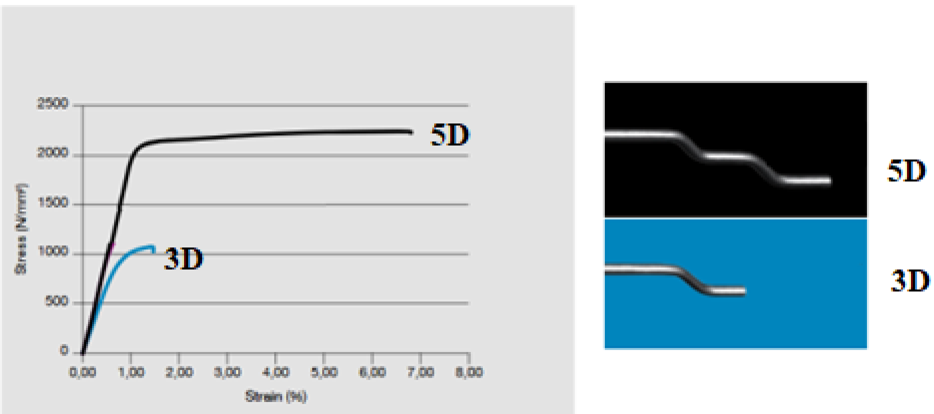

Fig. 1. Geometry and strength of normal and high-strength steel fibers (Bekaert 2021).

2.2. Specimen preparation

In the preparation of the mixtures, first of all, dry cement, silica fume and silica powder aggregate were mixed for 30 seconds. 3/4 of the mixing water was added to the dry materials and mixed for 1 minute. Afterwards, the remaining water and the superplasticizer chemical additive, which has a very high water reducing feature, were mixed in a container and added to the mixture. Thus, a more homogeneous distribution of the chemical additive was ensured and the dry materials are prevented from absorbing the water of the superplasticizer additive and reducing its effectiveness. The active ingredient ratio of the superplasticizer used in the study was 30%, and 70% water amount was used in calculating the water/cement and water/binder ratios. Therefore, the water/cement ratio in the mixtures was 0.27 and the water/binder ratio was 0.22. Schematic flow diagram of SIFCON is given Fig. 2. Finally, the fibers used in the study were placed in the molds in determined amounts and the prepared slurry was poured into the steel molds (Fig. 3). Within the scope of the study, compressive strength, splitting tensile strength, and capillary water absorption tests were performed on the samples. In addition, the 3-point bending test was applied to the samples, and the bending strength and fracture energy test results of the samples were also determined.

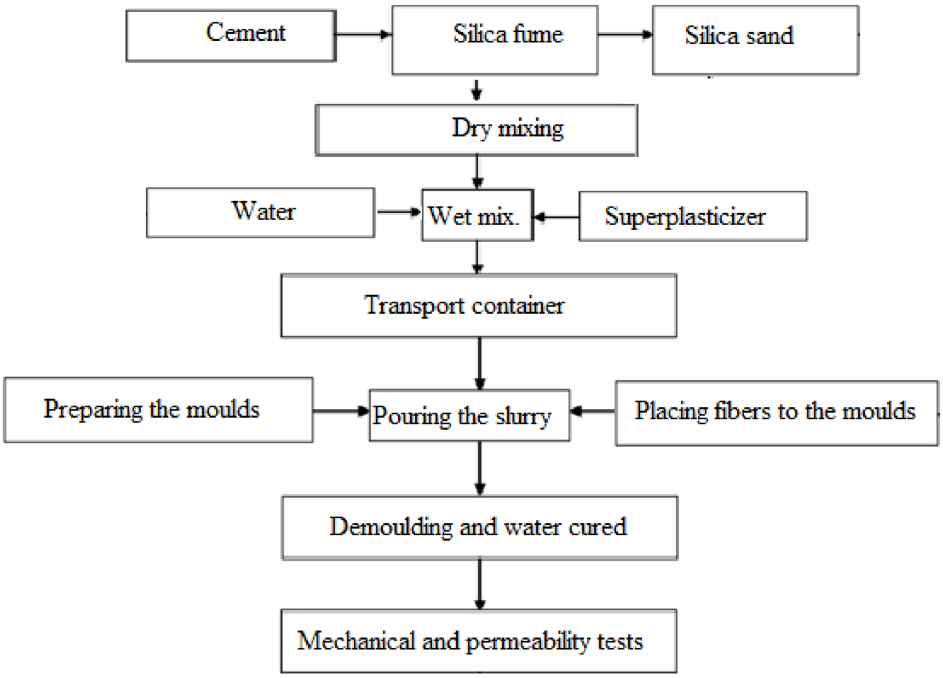

Fig. 2. Schematic flow diagram of water cured SIFCON.

Fig. 3. Preparation of test samples.

In the study, 6 pieces of 100*100*500 mm prism specimens were prepared for bending tests in each SIFCON mixture, and after bending tests compressive strength and splitting tensile strength tests were performed on the remaining specimens at 100*100 mm^2 cross section. In addition, capillary water absorption tests were also carried out on some beam samples.

2.3. Fracture test procedure

3-point bending tests were performed on plain concrete samples and fiber-containing SIFCON samples. The beam samples used in the tests are 100x100x500 mm in size and the test setup is given in Figure 3. In order for the loading to be controlled, the displacement velocity is lower in plain concrete and 0.01 mm/min is used. The displacement velocity of the samples containing steel fiber and synthetic fiber was chosen as 0.0175 mm/min up to 0.5 mm deflection and then 0.1 mm/min higher until 10 mm deflection. In order to ensure that the fracture occurs in the desired cross-section in all beam specimens, notches were created in the middle of the specimens by using a diamond saw, corresponding to 40% of the beam depth. Thus, beam samples with an effective cross-sectional area of 100x60 mm were obtained.

Deviations in the middle of the beam were determined using two Linear Variable Displacement Transducers (LVDT) and the average of both measurements was taken. The load-deflection curves of both plain and fiber-containing SIFCON concrete beam samples were determined by 3-point loading tests. Crack opening displacement (CMOD) was used as a feedback variable for stable crack formation in the samples. All samples were tested in a 200 kN capacity displacement-controlled test device. In this study, the equation given below, proposed by RILEM TC-50-FMC, was used to determine the fracture energy. The fracture energies of all samples were determined by calculating the areas under the load-displacement curve. Test setup and test images are given in Figs. 4 and 5, respectively.

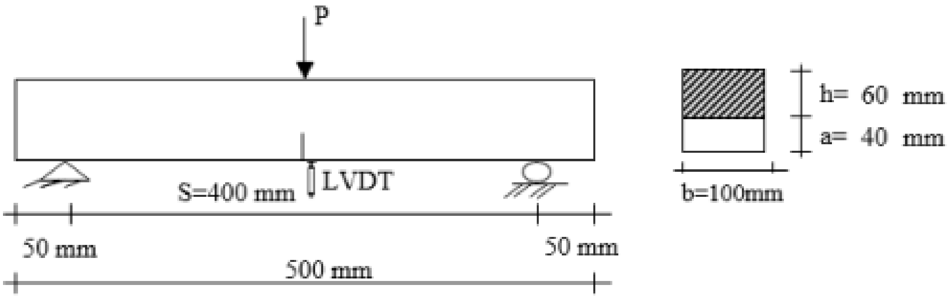

Fig. 4. Setup of the three point bending test.

Fig. 5. Displacement controlled loading test device and bending test images.

$$\frac{Wo+mg\frac{S}{L}\delta s}{B(D-a)} \quad (1)$$

where, m, L, S, a and D are the mass, length, span, notch depth, width of the beam, respectively. W_0 is the area under the load-mid span deflection curve, g is the gravitational acceleration and δ_S specified deflection of the beam (i.e. 10 mm).

The characteristic length (l_{ch}) was used for the ductility of the samples. This value was calculated using the formula proposed by Hiilerborg et al. (1976). However, in this study, splitting tensile strength values were used instead of direct tensile strength. In the equation, the modulus of elasticity was denoted by E, the fracture energy by GF, and the splitting tensile strength ft.

$$l_{ch} = \frac{E.GF}{(ft)2} \quad (2)$$

3. Tests Results and Discussion

3.1. Compressive strength

Compressive strength tests were carried out on cube samples with a side of 100 mm obtained from the samples remaining after the bending test from 100*100*500 mm beam specimens. All compressive strength tests were carried out according to EN 12390-3 standard. The results of the compressive strength tests applied to the samples as well as other mechanical behavior and permeability test results are given in Table 5.

When the compressive strength test results were examined, a small increase was observed in the compressive strength of the containing steel fiber SIFCON samples compared to the plain SIFCON samples without fiber. The most critical result is that the compressive strength of the samples using polyolefin based synthetic fiber is significantly lower than all other samples. When polyolefin fibers are used in concrete at higher than certain ratios, they cause significant homogeneity problems. Even the very fluid mortar in the form of slurry could not flow sufficiently and homogeneously between the fibers. For this reason, the compressive strength of SIFCON samples containing polyolefin fiber is significantly lower than other all samples. While the compressive strength of the plain concrete samples is 86.2 MPa, the compressive strength of the samples containing polyolefin fiber is 66.6 MPa, and a 23% loss in compressive strength is observed with the use of synthetic fiber compared to plain samples. Similarly, in a study, the compressive strength of concrete decreases with the use of polyolefin fibers (Alberti et al. 2014). Since polyolefin fibers were used much more in SIFCON than in conventional fiber reinforced concrete, the decrease in compressive strength occurred more radically. It was observed that the compressive strength of the samples containing steel fiber increased between 1.07 and 1.14 times compared to the plain concrete samples. When polyolefin fibers are used in high amounts, the strength decreases as it becomes difficult for the slurry to flow homogeneously between the fibers.

Table 5. Mechanical and permeability properties of plain and fiber reinforced SIFCON concretes.

	Compressive strength (MPa)	Splitting tensile strength (MPa)	Flexural strength (MPa)	Fracture energy (N/m)	Chr. length (mm)	Capillary water absorption (mm)
REF	86.2	8.92	9.51	57	32	0.059
3DSF-4	98.2	17.20	36.41	12448	1945	0.083
5DSF-4	96.4	18.47	46.47	20438	2750	0.091
3DSF-8	92.1	15.29	39.46	17523	3389	0.112
PE-4	66.6	10.19	13.87	6558	2559	0.121

The modulus of elasticity is determined according to the ACI 318-14 (2014).

Coefficient of variation (C.O.V.) ranges from 1.6 % to 5.1%

3.2. Flexural and splitting tensile strength

Flexural strength tests were performed on 100*100*500 mm beam samples according to RILEM-TC-50-FCM. Then, the splitting tensile strength tests were carried out on the specimens remaining from the bending tests at an effective cross-sectional area of 100*100 mm^2 according to EN 12390-6 standard.

When the flexural strength and split tensile strength test results were examined, it was determined that there were significant increases in flexural and splitting strength in all of the fiber-containing SIFCON concrete samples compared to the plain samples. The highest bending and splitting strength values were obtained in SIFCON samples containing 5D type steel fiber, which has better adhesion to concrete and high strength. 3D steel fibers with normal strength and weaker adhesion to concrete due to their geometry have lower bending and splitting strength than samples containing 5D fibers, even when used two times by volume. As a result, it is understood that fiber strength and geometry significantly affect the bending and splitting tensile strength of SIFCON concrete.

Among the fibrous SIFCON samples, the lowest bending strength and splitting tensile strength were obtained in SIFCON samples containing polyolefin fiber. Polyolefin fibers prevent the flowable slurry from pouring completely into the molds and homogeneously dispersed. For this reason, although it increases the bending and splitting tensile strength compared to plain SIFCON samples, their bending and splitting tensile strength is much lower than SIFCON samples containing the same amount of steel fiber by volume. The use of polyolefin fibers in SIFCON concrete, even at 4% by volume, causes significant homogeneity problems. The images of some SIFCON samples containing steel fiber and synthetic fiber after bending test are given in Fig. 6. It was observed that the splitting tensile strength of the samples containing steel fiber increased between 1.71 and 2.07 times compared to the plain concrete samples. The increase in the samples containing polyolefin fiber was 1.14 times. In addition, It was determined that the flexural strength of the samples containing steel fiber increased between 3.83 and 4.89 times compared to the plain concrete samples. The increase in the samples containing polyolefin fiber was 1.46 times.

3.3. Fracture energy

The load-displacement curves of all fibrous and plain SIFCON samples produced in the study are given in Fig. 7. The highest fracture energy values were obtained in SIFCON samples containing 5D type steel fiber with high tensile strength, similar to the bending and splitting tensile strength test results. 3D steel fibers with normal strength and poorer adhesion to concrete compared to 5D fibers due to their geometry have lower fracture energy than samples containing 5D fibers, even if doubled in volume. As a result, it has been understood that fiber strength and geometry significantly affect the fracture energy of SIFCON concrete.

All fibers significantly increased the fracture energy of SIFCON concrete compared to plain concrete. It was observed that the fracture energy of the samples containing 4% steel fiber increased between 218 and 358 times compared to the plain concrete samples. However, when the fiber-containing SIFCON concretes are evaluated within themselves, the lowest increases were observed in the SIFCON samples containing polyolefin fiber. This result is due to the inability of the liquid slurry to penetrate the network between the polyolefin fibers. However, samples containing polyolefin fibers have much higher fracture energy than plain concrete. By using 4% polyolefin fiber by volume, 115 times higher fracture energy values were obtained compared to plain SIFCON samples.

Fig. 6. Images of some SIFCON samples containing steel fiber and synthetic fiber after bending test.

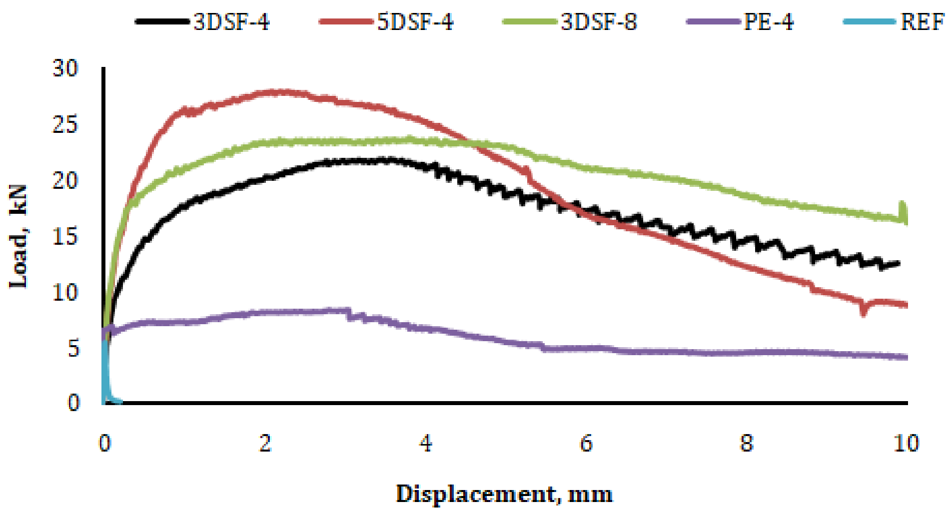

Fig. 7. Load versus displacement curves of SIFCON concrete series.

There are many studies in the literature on the use of 3D, 4D, and 5D steel fibers in concrete. The common result of all these studies is that the splitting strength, bending strength, and fracture energy values of concretes containing 5D-type high-strength steel fibers are much higher compared to concretes containing 3D and 4D-type steel fibers. This situation was associated with the hook-end geometries and high tensile strength of the 5D fibers, which provide better adhesion to concrete (Abdullah et al. 2018; Lee et al. 2019; Kizilirmak et al. 2019). The results of this study, similar to all other studies in the literature, also show that when 5D steel fibers are used in SIFCON, there is a significant improvement in all mechanical properties, especially in fracture energies, compared to the use of 3D steel fibers.

3.4. Capillary water absorption

Capillary water absorption tests were performed on the samples remaining from the bending tests. Capillary water absorption tests were carried out according to ASTM C1585 -20 (2020) standard and the amount of water absorbed by the capillary way was determined after 6 hours.

When the fibers are used in low volume ratios in concrete, there is no significant effect on the capillary water absorption of the concrete (Frazão et al. 2015). However, the fibers used above certain ratios may prevent the homogeneous distribution of the concrete. For this reason, capillary water absorption values may increase (Atiş and Karahan 2009). In this study, capillary water absorption values of all fiber reinforced SIFCON samples are higher than plain samples. It was determined that the capillary water absorption of the samples containing steel fiber increased between 1.41 and 1.90 times compared to the plain concrete samples. In the use of fiber, the diameter and amount of the gaps increase due to the problem that the concrete cannot flow sufficiently between the fiber networks. As a result, this situation increases the capillary water absorption value of the fiber-containing SIFCON samples. When the fiber-containing samples are evaluated among themselves, the capillary water absorption of the samples containing 8% by volume of 3D type steel fiber and the samples containing polyolefin is significantly higher than others. High steel fiber content or using polyolefin fiber notably increases capillary water absorption.

4. Conclusions

The results of the study can be summarized as follows:

- The compressive strength of the SIFCON samples increased slightly with the addition of steel fiber compared to the plain mixtures. However, the compressive strength of SIFCON samples containing synthetic fiber is significantly lower than plain SIFCON samples. This result is explained by the inability of the cement slurry to flow sufficiently and homogeneously into the polyolefin synthetic fiber network.
- When the splitting tensile and bending strengths of SIFCON samples are examined, the strength of all SIFCON samples increases with the use of steel fiber and synthetic fiber compared to plain samples. The highest splitting tensile strength and bending strength values were obtained in the samples using 5D type steel fibers with high strength and better adherence to concrete with their geometry.
- Fracture energies of SIFCON samples using steel fiber and synthetic fiber are significantly higher compared to plain SIFCON samples. Similar to the bending and splitting strength test results, the highest values in fracture energy values were obtained in the samples using 5D type high-strength steel fiber. Even when 5D type steel fibers are used in half the weight of normal strength 3D type fibers, higher results were obtained in all mechanical strengths and fracture energy values. Thus, it is understood that fiber strength and geometry significantly affect the mechanical behavior. The characteristic length, which is an indicator of ductility, also increases significantly with the use of fiber.
- Capillary water absorption values of SIFCON samples containing fiber are higher than plain samples. This result is explained by the fact that the fibers prevent the homogeneous distribution of the slurry. Capillary water absorption values increase significantly in mixtures containing 8% fiber, where the amount of normal strength steel fibers is very high. This shows that the use of steel fibers more than certain ratios can increase permeability. It is possible to obtain SIFCON concrete with the desired mechanical properties and low permeability by using less amount high-strength steel fibers instead of using a high amount of normal-strength steel fibers. Again, it is understood that polyolefin synthetic fibers cause problems in the flow of the slurry between the fiber network and significantly increase the capillary water absorption values.

High-strength 5D steel fibers significantly improve SIFCON mechanical properties compared to normal-strength 3D steel fibers. However, 5D steel fibers are more expensive. As a future recommendation, optimum cost-benefit analysis should be done by increasing the number of mixtures. By using the fibers in industrial products other than the laboratory environment, the properties expected from these products according to the relevant standard may also be evaluated. For example, its effects on ultimate load in infrastructure pipes, punching strength in manholes or bending strength in paving flags. In addition, the use of basalt and carbon fibers with higher tensile strength other than polyolefin in SIFCON should be considered. In this study, only macro-size steel and synthetic fibers were used. Research can be carried out in which micro and macro fibers are used together as a hybrid. Other properties of fibrous SIFCON samples such as fire performance can be examined.

Acknowledgements

The concrete specimens in the study were produced by the author while he was working at ISTON. The author also would like to thank ISTON R&D employees for their contribution.

Funding

The author received no financial support for the research, authorship, and/or publication of this manuscript.

Conflict of Interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this manuscript.

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