Research Article

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The effect of using polyolefin fiber on some properties of slurry-infiltrated fibrous concrete

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Abstract: Slurry-infiltrated fibrous concrete (SIFCON) is a special type of concrete that has great strength, as well as high ductility. However, the unit weight is high, which exceeds the unit weight of fiber-reinforced concrete, because of the high fiber content. This research aims to verify the compressive and flexural strength, as well as the density of SIFCON when using two different fibers (steel and polyolefin). Sometimes mono type of fiber steel or polyolefin, sometimes by hybridizing two types of fiber steel + polyplefin. Volume fraction (6% for all species) was used. Hook-end steel fiber and polyolefin fiber are used. With hybridization, a total volume fraction of 6% was used, which is 2/3 steel fibers with 1/3 polyolefin and vice versa. In addition, silica fume replaced 10% of the weight of cement. After checking all the results, the highest compressive strength was achieved in the SNS (symbol of mix SIFCON with 6% steel fiber) series by 81 MPa, as well as the highest flexural strength by 23 MPa, but it was the highest density of 2,490 kg/m^3. The series contained 2/3 polyolefin and 1/3 steel fibers, which are ideal as they significantly reduced the density of the steel fiber series 2,490–2,210 kg/m^3, as well as there was no significant reduction in strength as it achieved 67 MPa in the compressive strength and 19 MPa in the flexural strength, which are values suitable for high SIFCON applications.

Keywords: aspect ratio, density, flexural strength, slurry, steel fiber

1 Introduction

Slurry-infiltrated fibrous concrete (SIFCON) is one of the special fiber-reinforced concretes (FRCs) that has high strength, ductile, and very strong [1]. During the last few decades, fiber-reinforced cement composites have attracted much interest because of their high strength-enhanced ductility and toughness [2]. The percentage of fibers by volume can be within the range of 4–20% at SIFCON. However, this percentage does not exceed 2% in the conventional FRC because of the most important reasons, the workability and the method of mixing and pouring, where the fibers are mixed with other components of concrete (SFRC): gravel, sand, and cement. SIFCON has high fiber content and, therefore, achieves special mechanical properties, which are superior in ductility, strength, and impact resistance [3]. For adding to steel fibers, several researchers have introduced additional materials to study their effect on improving some mechanical properties of SIFCON, e.g., the introduction of plastic strips and plastic sheets in the SIFCON's slurry. It proved the result of the flexural strength test that the plastic sheet they used inside SIFCON increased the result by about 66.6% [4]. SIFCON Developed in 1979 by Lankard when he was doing research on the inclusion of a large amount of fiber in FRC. SIFCON exhibits good strength and ductility associated with conventional FRC with a great volume fraction of steel fibers. There is a difference between FRC and SIFCON in terms of performance and terms of preparation as the increase in the volume fraction of the fibers made it difficult or impossible to add fibers during the mixing process of concrete materials, a method was invented for placing the fibers in the molds and then pouring the slurry to make high-performance FRC [5]. Some previous researchers used fibers other than the steel fibers traditionally used in SIFCON Such as plastic fibers, and they noticed that decrease workability of concrete when it presence in SIFCON because it obstruct the flow. Plastic fiber improved flexural performance. The results confirmed that the workability was a little decreased by using plastic fiber where flexural strength was enhanced by the addition of plastic fibers in concrete [6]. Particular characteristics of plain concrete are its little tensile strength and its little tensile strain abilities. It is a brittle material. Therefore, improving the ductility of concrete is very significant, especially because

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concrete structures may practice great loadings during their lifetime. Fibers are short, discontinuous, and randomly dispersed throughout the concrete to produce a more ductile and crack control matrix [7]. Generally, SIFCON is prepared using a technique known as premolding in which the first fibers are placed in the mold and then mortar slurry is poured over the condensed fiber layers. The fibers are manually placed in the mould. The amount of fiber may depend on the geometry of the fiber, the aspect ratio of the fiber, and the assignment methods of fibers, if the aspect ratio decreases; it is possible to increase the volume fraction of the fibers. By using mild vibration, the volume fraction can also be increased. The fiber volume varies from 4% to 20% in SIFCON. In the manufacture of SIFCON, the orientation of the fibers is an important factor; the fiber orientation improved the flexural performance of SIFCON. The orientation of the fibers affects the fracture energy, and this effect is much higher than the flexural strength. In addition, it can accomplish ultrahigh performance by optimizing the matrix stage, replacing silica fumes, and having a lower water/binder ratio [8]. Some researchers studied high performance concrete at different curing temperatures (30, 40 and 50) °C and studied the direct effect on the compressive strength and its development [9]. Some researchers studied the influence of the amount of polyolefin fibers on workability and the strength properties (compression, tensile, flexural, strength in uniaxial tension) of pavement concrete, they studied two methods to introduce the fiber in the first method and fibers were put up into the ready fresh concrete. In the second method, fibers were introduced into the dry mixture and blended for 2.5 min. Water was added and they blended fresh concrete for another 5 min. A forced action mixer was used. The second method of fiber introduction was performed to be better suitable, and it did not contribute to a slump [10]. Other researchers investigated the effect of polyolefin fiber orientation on the fracture behavior of FRC. They came up with an opinion that polyolefin fiber-reinforced concrete has become an interesting alternative to steel for the reinforcement of concrete members, due to its chemical stability and the residual strengths that can be reached with lower weights. Using polyolefin fibers can meet the concerns of specifications, although the main constitutive relations are based on experience with steel fibers. Therefore, the structural improvements of the fibers should be estimated by inverse analysis [11]. Some researchers checked the compressive and flexural strength in the state of hardening with the addition of polyolefin fibers, as well as the self-compatibility behavior of concrete in the fresh state. They used four different quantities of polyolefin fiber. They blend it into a concrete mixture to note differences in strength and workability properties between concrete specimens. Their results proved that increasing the quantity of fibers reduces workability. The fibers also improved the compressive strength, but continuing to increase the fibers reduced the compressive strength. On the other hand, the flexural resistance increased with increasing fiber content [12].

1.1 The aim of study

The main aim of this study is to experiment with the use of a new type of fiber other than the traditional steel fiber. In addition, checking the achievement of the most important goals, which are reducing the self-weight and maintaining the superiority of some mechanical properties at the same time. Note that polyolefin fibers are used for the first time in SIFCON, so it is a unique study.

2 Experimental work

2.1 Materials

In the field of this study, the ordinary Portland cement (OPC) type 42.5. The OPC used conforms to the provision of (Iraqi specifications limits No. (5)-2019) [13]. The sand is brought from Al-Ukhaidir quarry, southern-west of Baghdad, Iraq. The sand is categorized under gradient zone 4 and it has been sieved in the laboratory on a 1.18 mm sieve to get passing on finer sand. The sand conforms to (Iraqi specification limits No. (45)-1984) [14]. Silica fume used conforming with (ASTM C1240, 2020) [15] requirements are made in UAE product name (CONMIX). Steel fibers were used with the lengths of 35 and 0.55 mm in diameter, aspect ratio 64 product by BUNDREX company/South Korea. As shown in Figure 1a, synthetic polyolefin has also been used with a length of 60 mm, a diameter of 0.9 mm, and a density of 910 kg/m^3. As shown in Figure 1b. The properties of the two types of fiber are listed in Table 1. Moreover, a high-performance Superplasticizer Concrete admixture type (Sika Viscocrete 5930) used conforms to ASTM C494/C494M-15 [16].

2.2 Mix design and mixing procedure

SIFCON is a special type of concrete that requires a high content of cement. After conducting several trail mixes, 885 kg/m^3 of binder was used and 10% of the cement was replaced with silica fume so that the weight of the cement

(a) (b)

Figure 1: (a) Steel fiber. (b) Polyolefin fiber.

Figure 2: Flow test.

was 796.5 kg/m^3 and the weight of silica was 88.5 kg/m^3. The total amount of the binder was 885 kg/m^3: the proportion of sand used for the binder is 1:1 by weight the cement content and the ratio of water/cement was 0.31. The superplasticizer is used in slurry mixes of 1.6% by the weight of cement to have sufficient performance in the slurry. In this investigational work, 6% of the fiber volume fraction was utilized to achieve the required performance and suitable volume of the molds was used in this investigational work. The procedure of mixing: Blends the dry material for 2 min, after that, add 2/3 of water and mix for 3 min and leave to rest for 3 min, after that Add the remaining amount of water (1/3) that was mixed with SP and continue mixing for 2 min. Micro-flow V-funnel testing of the slurry was carried out according to the EFNARC [15] to guarantee the bonding among all fibers to get a homogeneous slurry. The slurry's workability was achieved with an extent diameter in this test of 27 cm as shown in Figure 2. Before the casting process, the mold completely (10 cm) cubes and (5 cm × 5 cm × 30 cm) prisms were cleaned and lubricated. The fiber amount was placed at once before pouring the slurry to penetrate the fibers. To achieve penetration, the mold was lightly knocked with a hand rod. Related to demolding all samples sank in the basin with water at 25°C in agreement with ASTM C192/C192M-07 [17]. Table 2 shows the symbols of the mixtures that were used in the tests and that appear in the results Tables and Figures.

2.3 Test samples

2.3.1 Compressive strength

The investigation of compressive strength was done on the (45 specimen) (10 cm) cubes in accordance with BS EN 12390-4:2019 [18]. A compressive strength test machine carried out this test, with 1,814-kN capacity and constant rate of load. The results are the average of three cubes for all sets at the ages of 7 and 28 days.

2.3.2 Flexural-strength test

The test of the strength of flexural was conceded in coincidence with ASTM C293/C293M-36 [19]. For this test, prismatic models with a number (32) and dimensions

Table 2: The symbols for mixtures

Groups symbol	Steel fiber V.F%	Polyolefin fiber V.F%	Total V.F% of fiber
SNO	0	0	0
SNS	6	0	6
SNP	0	6	6
SNS2P1	4	2	6
SNS1P2	2	4	6

SNO (symbol of mix without fiber).

Table 1: Properties of fibers

Fiber type	Length (mm)	Diameter (mm)	Aspect ratio	Density (kg/m^3)	Tensile strength (MPa)
Steel	35	0.55	64	7,850	1,650
Polyolefin	60	0.9	66.7	910	590

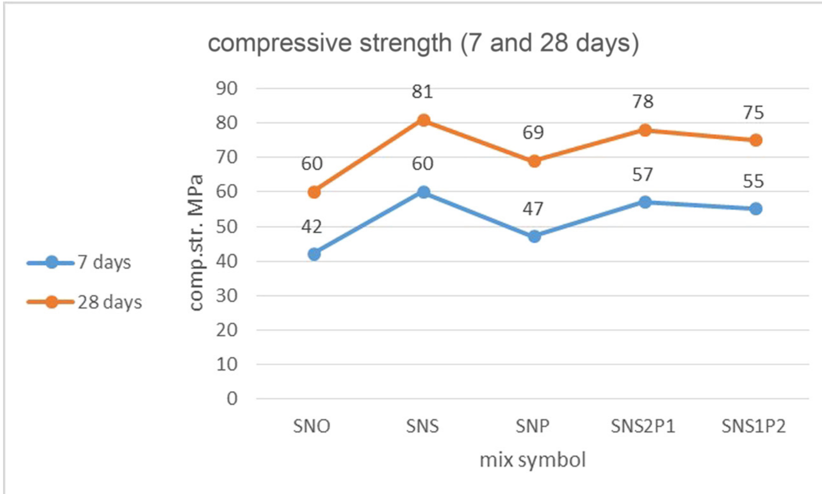

Figure 3: Compressive strength results.

(5 cm × 5 cm × 30 cm) were prepared and examined according to the abovementioned specification. This test was completed by using the test machine of flexural strength, which has the ability to 300 kN (Figure 4). The average means of each prisms group at 7 and 28 days as a result.

2.3.3 Density

The density test was performed as per the specification of ASTM C642-82 [20].

3 Results and discussion

3.1 Compressive strength

The strength of compressive at the ages of 7 and 28 days for all series and the cubes prepared for this purpose were tested. As a result, the SIFCON reinforced by steel fiber achieved the highest strength, and when polyolefin fibers were used, the compressive strength decreased, but the hybridization between the fibers achieved good results close to the reinforcement with steel fibers. The increase in compressive strength can explain the ability of the fibers to restrict and prevent the expansion of the cracks as well as reduce the growth rate of cracks and change their direction, depending on the characteristics of each type of fiber. This was in agreement with ref. [21]. The presence of high-volume fraction and dense fiber of both types randomly distributed throughout the SIFCON matrix ensures a better distribution of internal and external stresses as a result of developing a three-dimensional reinforcing net, which was in agreement with ref. [22]. The reason for enhancing the strength is the possibility of expanding the macro steel fiber and polyolefin with greater volume fraction value, which causes a decrease in the crack amounts and the width of the crack by action as a bridge for the crack in the sides, which is due to the growing strength. Figure 3 and Table 3 show the compressive strength results.

3.2 Flexural strength results

Flexural strength is confirmed by the results of the prism test (50 mm × 50 mm × 300 mm) under a center-point load. Table 4 and Figure 4 show the flexural strength obtained from different types of SIFCON at 28 days. All SIFCON groups result in the value of flexural strength varieties from 3.1 to 23 MPa and are governed by the fiber's properties, method of distribution, volume

Table 3: Compressive strength results

Mix symbol	Compressive strength 7 days (MPa)	Compressive strength 28 days (MPa)	Increased (28 days) (%)
SNO	42	60	0
SNS	60	81	135
SNP	47	69	115
SNS2P1	57	78	130
SNS1P2	55	75	125

Table 4: Flexural strength results

Mix symbol	Flexural strength (MPa)	% increased
SNO	3.1	0
SNS	23	742
SNP	15	483
SNS2P1	22	710
SNS1P2	19	613

fraction, and the proportion of hybridization. After that, the results of the SIFCON samples were compared to the unreinforced SIFCON mortar sample, we note. The presence of fibers in SIFCON blends improves flexural strength. The flexural strength of SIFCON is increased when the hooked end macro steel fibers are used, and the flexural strength increased the amount of ordinary mortar 13 times. The results also show that SIFCON with polyolefin fiber has an important increasing effect on the bending strength, which is about 7.5 times. This is a positive effect in flexural behavior SIFCON is because these fibers have higher tensile strength than mortar and their rough surface achieves good bonding with mortar, agreeing with ref. [21]. The combination of polyolefin fiber and steel fiber with a hooked end greatly increased the bending strength of SIFCON about the flexural of the reference slurry. There is a clear increase in the value of flexural strength (12.5 times) of SIFCON when the hybridization of these fibers produces a strong bonding force as well as filling all voids in the slurry. Polyolefin fibers of 6 cm in length are about twice as long as steel fiber. It extends inside the mortar for a longer distance. Thus, these long fibers bridge the fine cracks by the bridging effect and their ability to transfer emerging loads and thus increase the flexural strength [21].

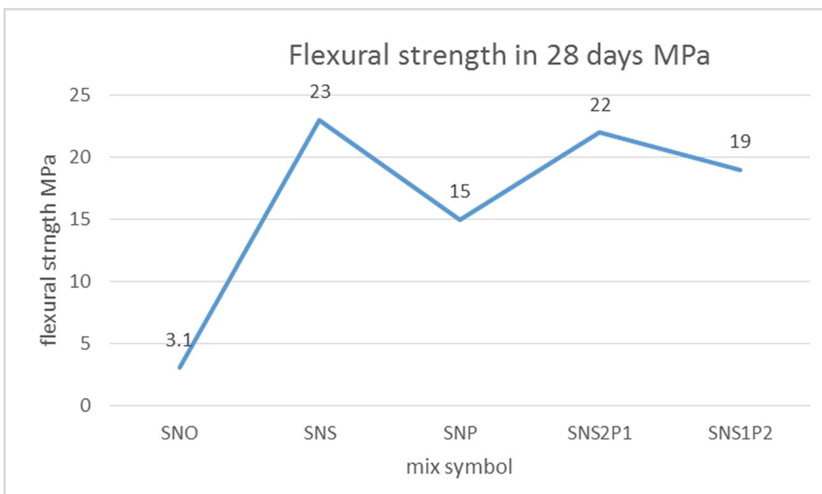

Figure 4: Flexural strength results of SIFCON.

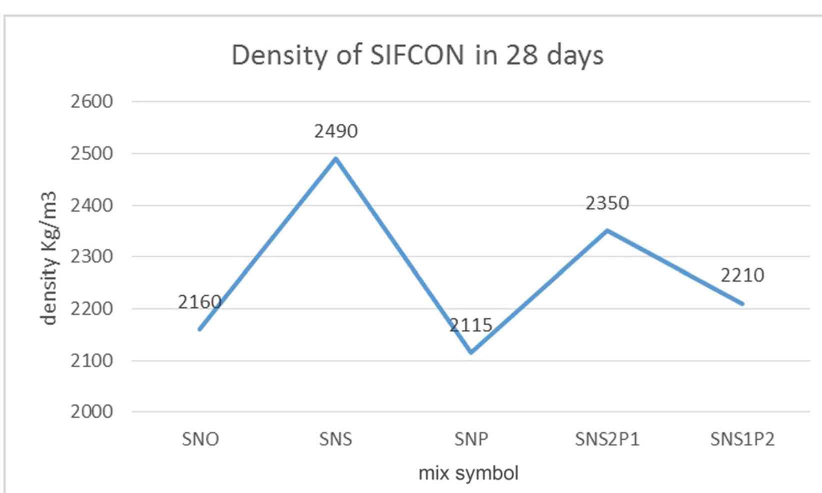

Figure 5: Oven dry density of SIFCON.

3.3 Density

The results of the oven-dry density of SIFCON in 28 days are shown in Figure 5, for mixtures of SIFCON for different fibers. It indicates that the use of polyolefin fibers in SIFCON incomes a higher reduction density ratio for SIFCON when used as a single fiber or in combination with steel fibers. The density of the oven dry has been reduced compared to that of SNS, where SIFCON is usually reinforced with steel fiber. The use of macro steel fiber resulted in a high oven-dry density. While the decrease in oven drying density was about 15% SNP, 5.6% SNS2P1, and 11.2% SNS1P2 for the same sequence. The density of fibers used as stated in Table 1 can explain these increases and decreases in density. The decrease in density (self-weight) of SIFCON when replacing some or all of the steel fibers with polyolefin fibers was the result of the lower unit weight of polyolefin compared to steel fibers. As a result, it leads to the production of structural elements with less self-weight and lower cost [23].

4 Conclusion

1. In compressive strength, compared to the reference series SNO. The mixture SNS achieved the highest compressive strength with an increase of 135%, while it decreased to 115% when using pure polyolefin fiber SNP. The percentage of increase in the compressive strength when using hybridization between the two types of fibers improved to 125 and 130% in the series SNS1P2 and SNS2P1, respectively.
2. In the flexural strength, the percentages of increase were very large, where the highest percentage of increase in the series that contained pure steel fibers was 742% and decreased when using pure polyolefin fibers to 483%. However, when hybridizing was used, it was close to the optimum increase, which is 710% for the SNS2P1 series and 613% for the SNS1P2 series.
3. In density, it is a major goal in the study to achieve a low density to reduce the self-weight of the structural element that contains the SIFCON. The highest density was in the SNS series, which reached 2,490 kg/m^3. Compared with this series, the best reduction was in the SNP series, where the density was 2,115 kg/m^3. The two-hybrid series achieved a good reduction of SNS2P1 2,350 kg/m^3, while 2,210 kg/m^3.
4. When taking into account the abovementioned properties, we find that the SNS1P2 series achieved high results in strength, which are very close to the optimum increase in SNS. Also achieved a significant decrease in density and was close to the optimal decrease in the series SNP, and accordingly it achieved all the desired properties in the production of this type of SIFCON.

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