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The Effect of Type of Fiber in Density and Splitting Tensile Strength of SIFCON

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ABSTRACT

SIFCON is characterized as a construction material of high ductility and very high strength. It is suitable for concrete structures used for special applications. However, the density of SIFCON is much higher than that of Fiber Reinforced Concrete (FRC) due to the need for a large amount of high-density steel fibers. This work examines the split tensile behavior of modified weight slurry infiltrated fiber concrete utilizing a mixture of two types of fibers, steel fiber, and polyolefin fiber. For the investigation, 30 cylinders and 15 cubes were poured. The used volume fraction (V.F) is (6 %) and the use of five series once as each type separately and once a hybrid in proportions of 2/3 polyolefin with 1/3 steel fiber and vice versa. The splitting tensile strength and the unit weight of SIFCON resulting from tests were studied. The results indicate that SIFCON produced from a mixture of 1/3 hook-end steel fibers with 2/3 polyolefin fibers achieved good results in reducing density while maintaining a high split tensile strength. It significantly decreased density by 140 kg per cubic meter and improved splitting tensile strength by 494%.

Keywords: Steel fiber, Polyolefin fiber, Slurry infiltrated fiber concrete, Modified unit weight.

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تأثير نوع الالياف على كثافة ومقاومة شد الانشطار في السيفكون

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الخلاصة

يتميز الـ SIFCON بأنه مادة بناء ذات ليونة عالية إلى جانب مقاومة عالية جدًا. إنها مناسبة للهياكل الخرسانية المستخدمة في التطبيقات الخاصة. ومع ذلك، فإن كثافة ال SIFCON أعلى بكثير من الخرسانة المسلحة بالألياف بسبب الوزن الثقيل للألياف الفولاذية ومحتوى الالياف الكبير. يهدف هذا البحث إلى التحقق من سلوك شد الانشطار لخرسانة الألياف المتسربة ذات الوزن المعدل باستخدام خليط من نوعين من الألياف ، الألياف الفولاذية ، وألياف البولي أوليفين. للتحقق، تم صب 30 اسطوانة و 15 مكعبًا. النسبة الحجمية المستخدمة (6٪) وتم استخدام خمس خلطات , مرة كل نوع على حدة ومرة هجين بنسب 3/1 الياف فولاذية مع 3/2 بولي أوليفين والعكس بالعكس. تمت دراسة مقاومة شد الانشطار وكذلك الكثافة لـ SIFCON الناتج عن الاختبارات. تشير النتائج إلى أن SIFCON المنتج من خليط من 3/1 ألياف فولاذية ذات نهاية خطافيه مع 3/2 ألياف بولي أوليفين حقق نتائج جيدة في تقليل وزن الوحدة مع الحفاظ على قوة شد انشطار عالية. حيث حققت انخفاضا ملموسا في الكثافة بمقدار 140 كيلوغرام لكل متر مكعب واحد , وكذلك تحسنا في مقاومة شد الانشطار بنسبة 494%.

الكلمات الرئيسة : الياف فولاية, الياف البولي اوليفين, ملاط خرسانة الالياف المتخللة, وزن الوحدة المعدل

1. INTRODUCTION

SIFCON is high-strength material containing a large volume of fiber fraction compared with steel fiber-reinforced concrete. Lankard proved that one could obtain a material with extremely high strength if the proportion of steel fibers in the cement slurry can be significantly increased, which he termed SIFCON **(Najeeb and Fawzi, 2019)**. SIFCON has good applicability in structures with blast and impact resistance and high ductility, especially in earthquake-resistant conditions, besides in impact-exposed structures. **(Jerry and Fawzi, 2022b).** Some investigators have examined the effect of including various volume fractions of steel fibers. They studied the characteristics of concrete utilizing volume fractions (0.5, 0.75, and 1) with substantial volume fractions and an aspect ratio of 100. Specimens (prisms and cubes) of hard concrete and fiber-reinforced concrete were checked **(Fawzi and AL-Ameer, 2013).**
Fiber Reinforcing Concrete is not insufficient for utilizing steel fibers particularly. Some researchers have noticed that alternative fibers enhance the resistance of concrete to impact loads, such as polypropylene **(Fawzi, 2005).** The presence of fibers in SIFCON has a positive effect on the performance of SIFCON. Due to this, the tensile strength of the fiber is higher than the slurry. In addition, their rough surface conforms well to the slurry **(Jerry and Fawzi, 2022a).** The high content of fiber in SIFCON improves the splitting tensile strength.

This improvement can be ascribed to micro-cracks being managed by arresting and bridging the fiber mechanism.
Furthermore, using steel fiber results in a stronger connection between the fiber and the matrix, increasing the mechanical characteristics of SIFCON, also mentioned in **(Al-Abdalay et al., 2020)**. The splitting tensile strength improves by a larger degree than the compressive strength improvement when adding fibers to the SIFCON. The beginning of cracking does not mean the failure of the materials but the beginning of another stage in the material's behavior, especially in SIFCON. The load will continue to increase after cracking. **(Naji et al., 2021)**. The considerable growth for SIFCON(with different contents of steel fiber) in tensile strength resulted from binding fiber, which is naturally available in SIFCON, where the mechanism of bridging of fiber led to control of the micro-cracks.
On the other hand, using a hooked-end type of steel fiber increases the bond between mortar and fiber, enhancing SIFCON mechanical properties **(Saeed and Flayyih, 2019)**. Due to the heavy weight of the high steel fiber content, the unit weight of the SIFCON is higher than that of fiber-reinforced concrete. A mixture of various types of fibers is used to produce a SIFCON of modified weight slurry infiltrated fiber concrete (MWSIFCON). These fibers differ from each other in the unit weight and affect the unit weight of SIFCON while trying to maintain the superiority of mechanical properties. For example, Polypropylene fibers give a good density of SIFCON, which is much lower than that of SIFCON reinforced with steel fibers and achieves good values in mechanical properties **(Naser and Abeer, 2020).**
This work aims to produce a SIFCON with a lower density and cost than the traditional SIFCON while maintaining the distinguished mechanical properties of the SIFCON by using available alternative fibers.

2. EXPERIMENTAL WORK

The sand used in this study is desert sand from southwestern Iraq (Al-Ukhaydir quarry). Sand within zone 4 is sieved on a No.16 sieve to obtain the fine sand in the agreement **(IQS No.45, 1984)**. Used silica fume agrees with **(ASTM C1240, 2020)** requirements. The steel fibers used were"350 mm" in length and 0.55 mm in diameter. The ratio of length to diameter is 64, as shown in **Fig. 1a**, and the synthetic polyolefin fibers used were 60 mm long and 0.9 mm in diameter, as shown in Fig. 1b. The characteristics of the fibers are listed in **Table 1**. A superplasticizer Concrete admixture type (Sika Viscocrete 5930) confirms to **(ASTM C494 2019)** tab water is used conforms to **(IQS 1730, 2018)**.

Table 1. Properties of fibers

Type	Length (cm)	Diameter (mm)	L/D ratio	Density (kg/m^3)	Tensile strength (MPa)
Steel	3.5	0.55	63.6	7850	1650
Polyolefin	6	0.9	66.67	910	590

3. MIX DESIGN AND PROCEDURE

SIFCON requires height cement content. After conducting several trial mixes, the mix proportion was chosen, listed in **Table 2.** An electric blender was used for slurry formation.

Cement, fine sand, and silica fume were added to the dry state and mixed for two minutes, then 2/3 of the blend/Bing water was added to the dry mixture, and the mixing was maintained during the addition to 3 minutes. Then take off for three minutes to rest. The superplasticizer was dissolved in the remaining quantity (1/3 of the mixing water) separately, then added to the mixer, and mixed for 2 minutes.

(a) Steel fiber (b) Polyolefin fiber

Figure 1. Steel fiber and polyolefin fiber.

If cement bulges are observed, the mixing time should be sufficiently extended until a homogeneous slurry is attained. It is also possible to re-mix the slurry during the pouring period for 1/2 minute each time to avoid sand settling to the underside of the mixer.

Table 2. Mix design of SIFCON

Cement (kg/m^3)	Silica fume (kg/m^3)	Sand (kg/m^3)	W/B Ratio	SP/cement Ratio	The volume fraction of fiber (V.F)
796.5	88.5	885	31	1.6	6

4. HARDENED CONCRETE TESTS

4.1 Splitting Tensile Strength

In agreement with **(ASTM C496, 2011)**, this test was given using cylinders (100×200) mm crushed with a standard test device. Each result for each series is the average of three cylinders per group with ages (7, 28) days, respectively. The split tensile strength of the sample was calculated according to the standard according to the equation below.

$$t = \frac{2p}{\pi l d} \quad (1)$$

where

t is splitting tensile strength (MPa),

p is the maximum applied load indicated by the testing machine (N),

l is the length of the cylinder (mm),

d is diameter of cylinder, (mm).

4.2 Density

This test was conducted according to **(Iraqi Guidelines No. 274, 1992)**. Cubes of 10 cm are used for this test at ages (28 days). After taking, the saturated surface dry (SSD) weight of the specimens, the density was calculated by dividing the weight by the volume, as shown in the equation.

$$D = \frac{m}{v} \quad (2)$$

where : D is density kg/m^3, m is mass kg, v is volume m^3.

5. RESULTS AND DISCUSSION

The considered symbols for the mixed samples are given in **Table 3**.

Table 3. The symbol of mixes.

Mix Symbol	Steel fiber V.F (%)	Polyolefin fiber V.F (%)	Total V.F of fiber (%)
SCO	0	0	0
SCS	0.06	0	0.06
SCP	0	0.06	0.06
SCS2P1	0.04	0.02	0.06
SCS1P2	0.02	0.04	0.06

5.1 Density

Density and the absorption and void ratio are desirable properties that increase the efficiency and durability of the structural element. The reason for this is that polyolefin fibers have a very low density compared to the density of steel fiber, as their density is 910 kg/m^3 while the density of steel fiber is 7850 kg/m^3 **(Naser and Abeer, 2020).** The reduction in both absorption and the percentage of voids is because the polyolefin fibers allow a good permeation of the slurry to fill the voids. It has a rough, serrated surface that allows for very good bonding with the mortar and allows the slurry to be compacted. The total density, bulk density, absorption ratio, and void ratio were determined for the five mixtures. We can compare the SNS series, which contains 6% steel fibers, with the other series that contain polyolefin mono or hybrid, **Table 4 and Fig. 2**.

Table 4. The result of the density test.

Mix	Density (kg/m^3)
SCO	2160
SCS	2490
SCP	2115
SCS2P1	2350
SCS1P2	2210

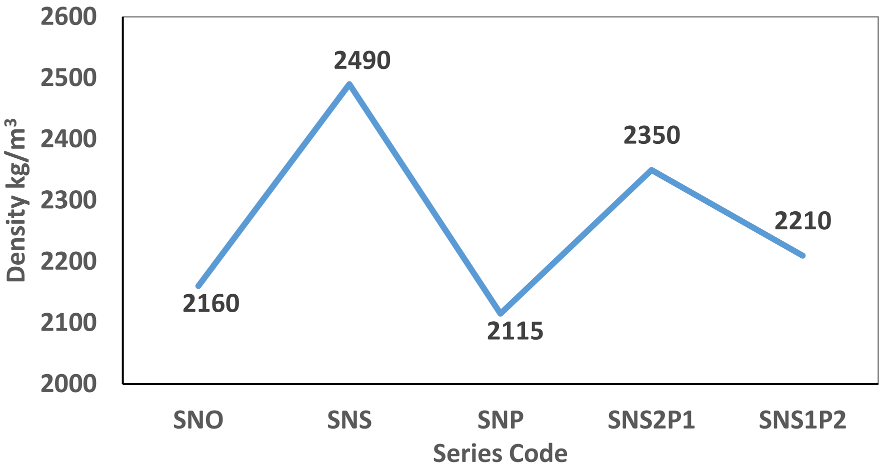

Figure 2. The density of SIFCON mixes in 28 days.

5.2 Splitting Tensile Strength

Table 5. and **Fig. 3** show the outcomes of splitting tensile strength. The results show that the splitting strength increases with age and differs according to the type of fiber. The increment percentage was (27%) when using 6% steel fiber at 28 days compared to 6% steel fiber at 7 days. The splitting tensile increased by 548% when using steel fiber compared with SNO and 253% when using polyolefin fiber. When using hybrid fibers increases by 469 % and 424%. This improvement can be ascribed to micro-cracks managed by arresting and bridging the fiber mechanism.
Furthermore, using fibers results in a stronger connection between the fiber and the matrix, resulting in a rise in the mechanical characteristics of SIFCON, as mentioned in **(Al-Abdalay et al., 2020).** Furthermore, partially replacing cement with silica fume enhances the splitting strength. It seemed that the filler effect, pozzolanic effect, and large surface area increase the connection between the fibers and the matrix interface while limiting the formation of micro-cracks, which explains the better mechanical characteristics. This could be compared with **(Salih et al., 2018; Khamees et al., 2020). Fig. 3** shows the Splitting tensile sample after testing**.**

Table 5. The results of splitting tensile test.

Mix symbol	Splitting Tensile Strength [MPa] 7 days	Splitting Tensile Strength [MPa] 28 days	Percentage Increasing [%] 28 days
SCO	2.4	2.9	0
SCS	14.8	18.8	548
SCP	7.9	10.23	252.8
SCS2P1	12	16.5	469
SCS1P2	11	15.2	424

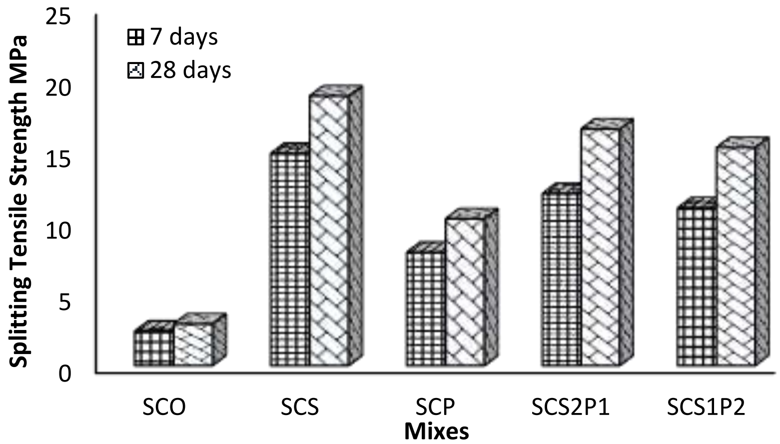

Figure 3. The results of splitting tensile strength 7 and 28 days

When taking into account the aim of the research is to decrease the density (the self-weight of the structural component) while maintaining the high mechanical properties. We note that the SCS1P2 series achieved a splitting tensile strength of 15.2 MPa, less than the maximum by only 3.6 MPa, and accomplished a significant reduction in density (280 kg/m^{3}). Therefore it is the ideal series in achieving the goal, as shown in **Fig. 4.**

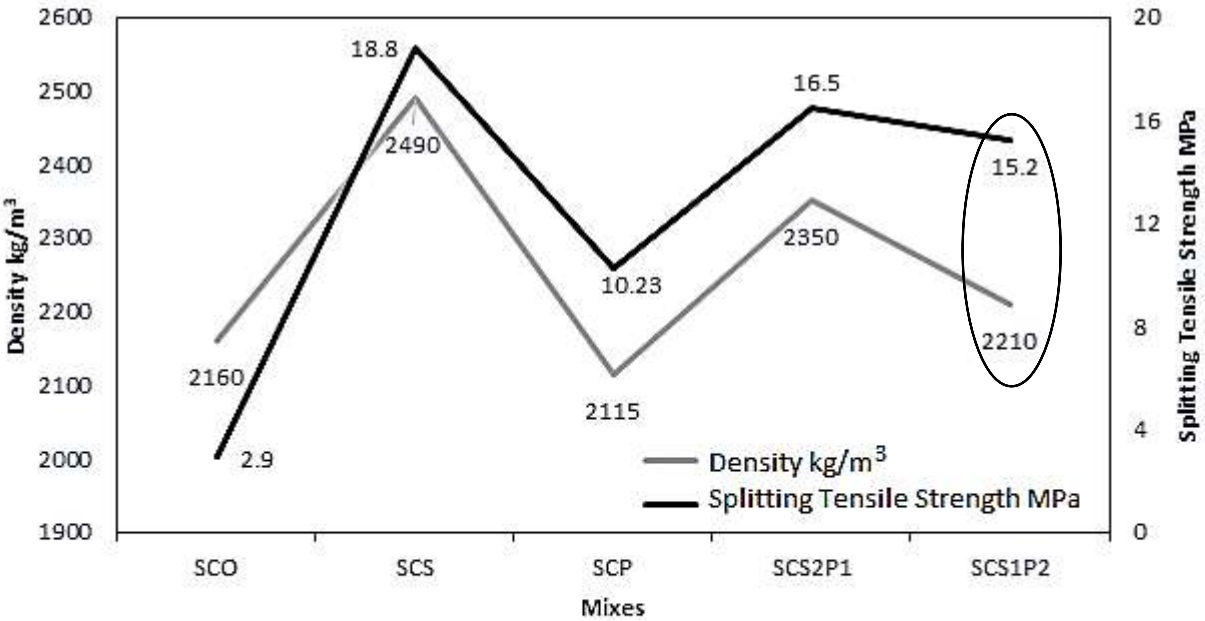

Figure 4. Density and splitting tensile strength.

6. CONCLUSIONS

Per the discussed results, it is noted that the achievement of the expected goals of the study and the improvement of the target properties, the following conclusions can be withdrawn:

1- Compared with the reference mixture (SCO), the results showed that the presence of fibers, in general, proved the fibers are a significant part of SIFCON, which is why they are high strength.
2- The highest values of splitting tensile strength were achieved by SCS mix (6% steel fiber)
3- On the other hand, the used steel fiber 6% as a mono (SCS mix) raised to a maximum density value.
4- Using polyolefin fibers as mono or hybrid reduced the density by a significant percentage compared to the SCS mixture and maintained the high splitting tensile strength of SIFCON.
5- The values achieved by SCS1P2 (2% steel fiber and 4% polyolefin fiber) series are optimum, as it decreased the splitting tensile strength for the maximum of the SCS series. In contrast, it achieved a significant decrease in the density. It achieved a decrease in density by 140 kg per cubic meter, as well as an improvement in splitting tensile strength by 494%.

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