The effect of fiber and mortar type on the freezing and thawing resistance of Slurry Infiltrated Fiber Concrete (SIFCON)

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Abstract. Slurry infiltrated fibrous concrete (SIFCON) is a relatively new material and could be considered as a type of high volume fiber reinforced concrete in which fibers are preplaced in the mold and infiltrated with cement based slurry or flowing mortar. SIFCON possess high strength, large ductility and far excellent potential for structural applications when abnormal or explosive load is encountered during services life. Other successful applications include pavement overlays, repair of prestressed beams and structural reinforced concrete element. The main aim of this investigation is to determine the effect of fiber type (hooked end steel fiber, micro steel fiber and hybrid fiber) with different volume fraction and aspect ratio (l/d), also studying the effect of SIFCON mortar type containing mineral admixtures (silica fume (SF) and/or fly ash (FA)) as a partial replacement by weight of cement, on the freezing-thawing resistance of SIFCON specimens. The lengths of hooked fiber and micro fiber were 35 and 15mm, respectively, and three steel fiber contents (6, 8.5, and 11) % were used in this investigation. Prismatic SIFCON specimens of 100 x 100 x 400 mm were exposed to 100 freezing and thawing cycles in a water bath. After that, the specimens were weighted and tested for flexural strength and the results were compared with that of unexposed companion specimens to determine the loss in unit weight and loss in flexural strength after exposure to freeze-thaw cycles. The test results show that the freezing and thawing resistance of SIFCON specimens increases with the increase in volume fraction of steel fiber and when using mineral admixture (SF and FA) as a partial replacement by weight of cement. Also the specimens reinforced with micro steel fiber or hybrid fiber have lower loss in unit weight and loss in flexural strength compared with that reinforced with hooked fiber.

Keywords: SIFCON, Hooked end steel fibers, micro steel fiber, hybrid fiber, silica fume, fly ash.

1. Introduction
Slurry infiltrated fiber concrete (SIFCON) is a high performance fiber reinforced concrete. It possesses excellent mechanical properties with greater energy-absorption characteristics [1]. SIFCON also exhibit new behavioral phenomenon, that of Fiber lock which believed to be responsible for its outstanding stress-strain properties. SIFCON can be considered as a special type of fiber reinforced concrete (FRC), but different from normal FRC in two aspects, fiber content and the method of production. Generally, FRC contains fibers with volume fraction between (1–3) %, whereas SIFCON contains (4–
20)\% of fibers. In spite of that, the practical fiber content range between (4 to 10) \% when using hooked steel fiber with length more than 30 mm. SIFCON matrix is either flowing mortar or cement slurry which different from the aggregate concrete used in FRC. So the fabrication of SIFCON different from FRC which is produced by the addition of fibers to the wet concrete, while SIFCON is fabricated by infiltrating a bed of pre-placed fibers with cement slurry and packed tightly in the molds\([2,3]\).

SIFCON possesses excellent mechanical properties with great energy-absorption characteristics. In spite of being as a new construction material, SIFCON has found application in area where high ductility and energy absorption are needed especially in seismic-resistant reinforced concrete frames, in defense structures and structures subjected to impact and dynamic loading. Other successful applications include airfield pavement overlays, repair of prestressed beams and repair of structural reinforced concrete element\([1]\). There are four design factors that affected the behavior of SIFCON specimens and should be considered in SIFCON production. These are mortar strength, fiber volume fraction, fiber type and alignment. The fiber volume fraction depends on the type of fiber and the vibration effort required for proper compaction. Shorter fibers may pack denser than longer fibers and higher fiber volumes can be achieved with sufficient vibration\([4,5]\).

Flowable mortar with rich cement is used as a binder in SIFCON production, and the using of high cement content of the slurry not only causes high production cost but also excessive heat of hydration and may cause shrinkage problems. Replacing the cement with supplementary cementitious materials seems to be a suitable solution to overcome these problems. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and improve the durability of SIFCON.

Gilani\([6]\), investigated the effects of (SIFCON matrix types, fiber contents and fiber types) on different properties related to SIFCON durability. These characteristics were water absorption, chloride penetration, drying shrinkage and freezing-thawing resistance. Two types of steel fibers (hooked and crimped) were used for each SIFCON mix, and with three volume fractions of steel fiber \((7, 9.5, \text{and } 12)\%\). While the dimensions of steel fibers used were the same \((50\text{mm length and } 1.05\text{mm diameter})\). From the test results the researcher founded that both mortar and slurry SIFCONs showed good resistance to the deterioration caused by repetitive freezing and thawing. SIFCON mortar showed better behavior than SIFCON slurry regarding freezing and thawing resistance. Some surface scaling is occurring, especially in SIFCON specimens reinforced with the high volume fraction of steel fiber.

Armagan and Canbaz\([7]\), examined the effect of fiber type (polypropylene and steel fibers) on freezing and thaw durability of SIFCON. Freeze-thaw cycles have subjected to SIFCON specimens \((4 \times 4 \times 16 \text{cm dimensions})\) for 2 hours at \(+20^\circ\text{C}\) degree and 2 hours at \(-20^\circ\text{C}\) degree with 50, 75, and 100 cycles. Freeze-thaw deterioration was determined by the changes in unit weight, ultrasonic pulse velocity, flexural and compression strengths. Two lengths of steel and polypropylene fibers were used in experiments. The lengths of steel fiber were \((35 \text{ and } 60) \text{ mm}\), while the lengths of polypropylene fibers were \((20 \text{ and } 50) \text{ mm}\). The researchers concluded that, the unit weight loss by freeze-thaw cycles significantly decreased with usage of the shorter fiber \((35\text{mm steel fiber and } 20\text{mm polypropylene fiber})\). And up to 75 cycles of freezing and thawing, there was no significant change seen in ultrasonic pulse velocity regardless of the length and type of fibers. However it was observed after 75 cycles the ultrasonic pulse velocity decreased rapidly. Also the researchers founded that in higher numbers freeze-thaw cycles the flexural strength of specimens was decreased. The using of steel fiber decreased the loss in flexural strength. The longer steel fiber influenced positively on flexural strength. While the compressive strength losses were increased after 50 freeze-thaw cycles. The loss in steel fibers SIFCON was less than that of polypropylene fiber.

Canbaz and Armagan\([8]\), studied the effect of binder type on freeze-thaw durability of SIFCON. In this experimental study different type of cements were used in SIFCON production with steel fibers.
Prismatic specimens were exposed to 50, 75 and 100 cycles of freezing-thawing. The effect of fiber length and binder type on SIFCON performance under freezing-thawing cycles was determined with examining the changes in unit weight, flexural and compressive strength. The test results showed that, the use of mineral additives with binder decreases the unit weight of SIFCON specimens. The unit weights are decreased when freeze-thaw cycles increased, and after 75th cycle unit weight was rapidly fallen down due to increase in crack quantity and length. Also SIFCON specimens with high mineral additive show a reduction in their compressive strengths after 50th cycle. The effects of fly ash additive in SIFCON specimens become significant at 60th day and after. So at early ages, SIFCON specimens, which couldn’t get enough strength, could easily lose their compressive strengths under freeze-thaw effects.

There is no detailed information about freezing and thawing resistance of SIFCON containing both silica fume (SF) and fly ash (FA) as a replacement of cement. Also there is no information about the effect of using micro steel fiber or hooked fiber on the behavior of SIFCON specimens exposed to freeze –thaw cycles. Therefore the main aim of this research is to determine the behavior of various SIFCON mixes exposed to freezing and thawing cycles and evaluate the effect of mortar type, fiber type and the effect of volume faction of steel fiber ranging from (6 to 11%) on the properties of SIFCON specimens.

2. Experimental work
2.1. Materials

2.1.1. Cement
In this study, ordinary Portland cement (type I) which is known as (Krasta) produced in Sulaymaniyah, was used throughout of the work. Its chemical and physical properties conformed to the criteria of Iraq specification No. 5-1984[9].

2.1.2. Fine Aggregate
Natural sand, brought from AL - Ukhaider region in Iraq, was used as a fine aggregate throughout the experimental work. The sand used was passing through sieve (1.18 mm) in order to obtain complete infiltration of the slurry through the dense steel fiber. It is conformed to the requirements of the Iraqi Standard No.45-1984[10] Zone 2. Its sulphate content, specific gravity, and absorption are 0.34%, 2.6, and 2%, respectively.

2.1.3. Mixing Water
Portable water (tap water) was used for all specimens mixing and curing

2.1.4. Silica fume (SF)
In this work densified silica fume from BASF Company, which is commercially known as MEYCO/MS610, with fineness of (21000 m²/kg) was used as a partial replacement of cement. It conforms to the requirement of ASTM C1240-05[11].

2.1.5. Fly ash (FA)
Class F fly ash is used in this work which was a result of coal combustion during production of electricity in ISKENment-Turkey power station. The FA used have fineness of (773 m²/kg) and contain less than 20% CaO. It conforms to the requirement of ASTM C 618-2005[12].

2.1.6. High range water reducing admixture (HRWR)
A high-range water reducing admixture which is commercially known as (GLENIUM 54) From BASF Construction Chemicals Company was used throughout the experimental work. The using of HRWR is necessary to enhance the workability of SIFCON mortar, which must be liquid enough to infiltrated into the dense fiber bed without leaving honeycombs. This type of admixture conformed to the requirement of ASTM C494 type F[13].
2.1.7. Steel fiber
Two types of steel fiber were used in this investigation, which are different in shape and aspect ratio. The first type was Hooked end steel fiber having a length of 35 mm, diameter of 0.7 mm with aspect ratio of 50 and tensile strength of 1100 MPa. The hooked fibers were supplied from ATLAS Company in Turkey, and random orientation of fiber in the matrix was carried out. The second type was straight steel fiber (micro steel fiber) with a nominal length of (15 mm), diameter of (0.2 mm), aspect ratio of 75 and tensile strength of 2850 MPa, manufactured by Jingjiang Hangtu steel fiber Factory. Figure 1 shows the hooked end and micro steel fiber used in this research.

![Figure 1. Hooked end and micro steel fibers used](image)

2.2 Mix proportion
In this work, many trail slurry mixes were carried out to produce SIFCON mix with suitable fresh properties that satisfies the criteria of filling ability, flowability, fluidity and viscosity without segregation or bleeding through the dense fiber bed. After that, the minimum and maximum steel fiber content were selected to be used with the obtained slurry. Three types of SIFCON mortars (M₁, M₂, and M₃) were prepared with the same mix proportion of cement: sand (1:1) by weight, depending on many researchers used the proportion of (cement to sand) equal to 1 in their researches[4,5,14,15]. Ordinary Portland cement with content of (885 kg/m³) and water/binder ratio of 0.3 were used for the three SIFCON mixes (M₁, M₂ and M₃). The first type (M₁), which consider as a reference mortar, were produced by adding (HRWR) which is Glenuim (54), the second type of mortar was produced from the reference mortar with partial replacement of cement by 10% of silica fume (SF) to improve the mechanical properties of SIFCON, while the third type of SIFCON mortar was produced from the reference mortar with partial replacement of cement by 10% of silica fume (SF) and 20% of fly ash (FA) to increase the workability of SIFCON slurry, with regulate the dosage of HRWR to obtain similar viscosity and flow diameter without bleeding or segregation. So a new SIFCON mixture was produced called (ternary mixture) incorporating Portland cement, silica fume and fly ash which has high strength and greater workability at lower cost. The details of the mix proportion for the three mixes of SIFCON are presented in Table 1.

| Mix symbol | Cement kg/m³ | Sand kg/m³ | SF (10% rep.) kg/m³ | FA (20% rep.) kg/m³ | Water L/m³ | w/b ratio | HRWR (° by wt. of cement) |
|------------|--------------|------------|---------------------|---------------------|------------|-----------|-------------------------|
| M₁         | 885          | 885        | 0.0                 | 0.0                 | 265.5      | 0.3       | 1.2                     |
| M₂         | 796.5        | 885        | 88.5                | 0.0                 | 265.5      | 0.3       | 2.4                     |
| M₃         | 619.5        | 885        | 88.5                | 177                 | 265.5      | 0.3       | 2.0                     |

* b = binder = (cement + silica fume + fly ash)
* HRWR dosage was regulated to obtain similar viscosity and flow diameter without bleeding and segregation

The three SIFCON mixes were prepared with three different contents of steel fiber (6%, 8.5% and 11%). The fiber content of (6%) was a minimum practical content of steel fiber that could fill the mold
without needing to use the vibration table, while the fiber content of (11%) was the maximum practical value that fills the mold with using vibration to obtain complete penetration of the mortar through the fiber network. The fiber content of (8.5%) was taken as an intermediate value which can be used to produce SIFCON specimens with only light vibration.

A conventional fiber reinforced mortar, with 2% fiber content, was also prepared as a comparison (control or reference) mix with SIFCON mixes.

The next step of this study includes producing two new types of SIFCON, the first type was by using mortar (M₃), which have the optimum fresh and hardened properties compared with the other mortars (M₁ and M₂), as shown later, with micro steel fiber. The volume fraction of (6%) was founded as the maximum practical limit that the mortar (M₃) can be infiltrated through its network without clogging.

The second type of SIFCON is (Hybrid SIFCON) which was produced by using mortar (M₃) with both the hooked end steel fiber and micro steel fiber with volume fraction of (8.5%). This procedure lead to twelve different SIFCON mixes which every mix represent a certain combination of mix type, fiber type, and fiber content, as show in Table 2.

| Mix symbol | The description |
|------------|-----------------|
| M₁-F₂      | Ref. mortar with 2% volume fraction (Vf.) of hooked end steel fiber |
| M₁-F₆      | SIFCON mortar with 6% Vf. of hooked end steel fiber |
| M₁-F₈.₅    | SIFCON mortar with 8.5% Vf. of hooked end steel fiber |
| M₁-F₁₁     | SIFCON mortar with 11% Vf. of hooked end steel fiber |
| M₂-F₆      | SIFCON mortar with 6% Vf. of hooked end steel fiber and 10% silica fume replacement, by weight of cement |
| M₂-F₈.₅    | SIFCON mortar with 8.5% Vf. of hooked end steel fiber and 10% silica fume replacement, by weight of cement |
| M₂-F₁₁     | SIFCON mortar with 11% Vf. of hooked end steel fiber and 10% silica fume replacement, by weight of cement |
| M₃-F₆      | SIFCON mortar with 6% Vf. of hooked end steel fiber and (10% silica fume + 20% fly ash) replacement, by weight of cement |
| M₃-F₈.₅    | SIFCON mortar with 8.5% Vf. of hooked end steel fiber and (10% silica fume + 20% fly ash) replacement, by weight of cement |
| M₃-F₁₁     | SIFCON mortar with 11% Vf. of hooked end steel fiber and (10% silica fume + 20% fly ash) replacement, by weight of cement |
| M₃-MF₆     | SIFCON mortar with 6% Vf. of micro steel fiber and (10% silica fume + 20% fly ash) replacement, by weight of cement |
| M₃-HF₈.₅   | SIFCON mortar with (6% Vf. of hooked end steel fiber+2.5% Vf. of micro steel fiber) and (10% silica fume +20% fly ash) replacement, by weight of cement |

2.3. Tests on fresh properties of SIFCON

SIFCON concrete differs from conventional (FRC) in that its fresh properties are critical to its ability to be placed satisfactorily. The mortar must be flowable enough to penetrate through the dense fiber network. Filling ability, viscosity and passing ability are the key properties of workability which need to be carefully controlled to ensure successful production of SIFCON concrete. According to EFNARC [16] the mini slump flow and V-funnel test were used to determine these properties of the mortar. The mini flow test represents the flowability and segregation resistance of the mortar. The apparatus used for the mini slump flow test was a mold in the shape of a cone with internal dimensions of 100 mm base diameter, 70 mm top diameter, and a height of 60 mm And a spread
diameter between (240-260) mm is required for SIFCON mortar. V-funnel test was the other test to determine the viscosity of the mortar and a flow time between (7-11) seconds is considered appropriate for the mortar[16]. The procedures of these tests could be obtained from the references[16,17]. The fresh properties results of the three SIFCON mortars are given in Table 3. and shown in figure 2. and figure 3.

### Table 3. Properties of fresh SIFCON mortars

| Mix symbol | Mini slump flow (mm) | V-funnel (sec) | HRWR (%) by wt. of cement |
|------------|----------------------|---------------|--------------------------|
| M₁         | 258                  | 8.0           | 1.2                      |
| M₂         | 257                  | 9.5           | 2.4                      |
| M₃         | 260                  | 7.0           | 2.0                      |

![Figure 2. Mini slump flow test for SIFCON mortar](image)

![Figure 3. Mini V-funnel test for SIFCON mortar](image)

2.4 Preparing, casting, and curing of SIFCON specimens

At the beginning of preparing SIFCON specimens, the steel fibers were preplaced into the molds and then cement mortar was poured to infiltrate thorough the dense fiber-filled mold. After many trials of casting technique in the laboratory, two-layer technique was used for incorporating the steel fiber into SIFCON matrix. It proved its effectiveness during casting of SIFCON specimens and found out to be easier and simpler in actual practice than the single layer-technique especially when using high volume fraction of steel fiber.

The two-layer technique involved placing and packing the fibers which were oriented, in random manner, only to the half depth of the mold, followed by filling the mold by the mortar up to this
level (half depth). The contents in the mold were then vibrated to avoid honeycombing or voids. This process was repeated (for the second layer) where all the mold was filled with the required volume fraction of fiber. The vibration was not applied with the minimum volume fraction of 6%, while a vibration for (7-15) seconds by table vibrator was required for (8.5% and 11%) volume fraction of steel fiber, to ensure complete penetration of SIFCON mortar through the fiber pack, as shown in figure 4. The steel fiber weight to be placed in each mold depends on the dimension of the mold, the required fiber fraction and on the density of steel fiber itself.

After casting, the specimens were covered with nylon sheet to eliminate the risk of shrinkage cracks caused by evaporation of mixing water, and left for 24 hours in the laboratory. Then they were demolded, marked and immersed in top water until the age of 28 days.

Figure 4. Preparation, Casting, and demolding of SIFCON Specimens

2.5 Tests on hardened properties of SIFCON
2.5.1 Freezing and Thawing test
This test method was carried out to find the resistance of SIFCON specimens to repeated freezing and thawing cycles by using the procedure A: Rapid Freezing and Thawing in Water, according to ASTM C- 666/C666M-03[18]. The Freezing thawing cabinet used in this test contains a suitable chamber where the specimens exposed to the specified freezing and thawing cycle together, with the necessary refrigerating and heating equipment and controls to produce continuously and automatically reproducible cycles within the specified temperature requirements, figure 5 shows the freezing thawing cabinet. After 28 days of water curing, the specimens were removed and divided into two groups; the first group was stored in a dry place inside the laboratory as reference specimens, while the second group was kept in the cabinet with water saturated conditions. The initial weight of SIFCON specimens was taken before beginning the test. The nominal freezing thawing cycle for this test procedure shall consist of alternately lowering the temperature of the specimens from (4 to -17.8 °C) and raising it from (-17.8 to 4 °C) in 2 hours. The 100 cycles of repeated freezing and thawing cycles were applied on two prismatic specimens of 100 x 100 x 400 mm for each mix. After that the two groups were weighted and tested for flexural strength.
2.5.2 *Flexural Strength Test*

This test was performed in accordance with ASTM C1609[19], using prismatic specimens of 100 x 100 x 400 mm simply supported beam. The specimens were tested under two point loads with a constant rate of loading about 0.015MPa/sec. The flexural strength was calculated using the following formula:

\[ f_r = \frac{PL}{bd^2} \]

where

- \( f_r \): Flexural Strength or modulus of rupture, (MPa).
- \( P \): maximum applied load, (N).
- \( L \): Span length of specimen, (mm).
- \( b \): the width of the specimens, (mm).
- \( d \): the depth of the specimen, (mm)

3. Results and discussion

3.1 Properties of fresh SIFCON

Many trail mixes were investigated to satisfy the requirements needed for SIFCON mortars under this work. Table 3 shows the mini slump flow and V-funnel test results which satisfied the criteria of flowability, filling ability and a suitable viscosity for the three SIFCON mortars (M1, M2, and M3). It is clear from the results of reference mortar (M1) that the using of HRWR is important to obtain a mortar with lower (w/c) ratio and also satisfying the homogeneity and the other mentioned requirement.

The method followed to determine the HRWR dosage required for M1 is by checking first the slump flow with various dosage of HRWR until reaching the required value which is between (240-260) mm, then checking the two other requirements by V-funnel test. This is because the slump flow test is the simplest and the fastest one.

The positive effect of HRWR on cohesiveness and fluidity of SIFCON mortar was because the polycarboxylate superplasticizer absorbs onto the cement particles and disperses them; and that enhancing the workability and reducing the friction. These particles remain frictionless, therefore
keeping the effect of dispersing for longer time after mixing [17]. The influence of adding silica fume (SF), as a partial replacement (10%) by weight of cement, to reference mortar (M1) is shown in table 3 as a mortar (M2). It is clear that this addition causes reduction in workability which making SIFCON mortar more cohesive and sticky. To obtain similar viscosity and fluidity, the dosage of HRWR must be increased. Inadequate viscosity or fluidity was observed when using HRWR dosage lower than that shown in Table 3, while using higher HRWR dosage caused bleeding and segregation in SIFCON mortar. This reduction in workability and the stickiness of the mortar is due to large surface area of SF particles. [17]. It is obvious from the results that the using of SF replacement decreases the spread diameter of mini slump test and increases the time of V-funnel test.

The experimental work showed that the addition of (10%) SF alone to the SIFCON mortar causes increase the HRWR dosage to a mount reach to (2) times the amount used in (M1). This problem was overcome with the addition of (20%) FA to SF and mixed together, which improve the workability and reduce the dosage of HRWR as possible. This great effect is due to the spherical shape of the fly ash particles which serves to increase workability by decreasing friction between particles and that permit the HRWR in the mixture to be reduced for a given workability.

3.2 Properties of hardened SIFCON
3.2.1 Freezing and thawing test
The main aim of this investigation is to find out the performance of different SIFCON mixes subjected to freezing and thawing cycles, and comparing them with the behavior of the control mix (M1-F2) which is tested under the same conditions. The method used to determine the deterioration of SIFCON and control mix due to freezing and thawing cycles was by measuring the loss or change in flexural strength and the weight of the specimens. The results of the tests are presented in Table 4.

Table 4. The change in flexural strengths and weights of SIFCON specimens subjected to freezing and thawing cycles

| Group No. | Mix symbol | Flexural strength (MPa) | Percentage of reduction in strength (%) | Percentage of reduction in weight (%) |
|-----------|------------|-------------------------|----------------------------------------|--------------------------------------|
|           |            | 0 cycle | 100 cycle |                          |                                      |
| control mix | M1-F2      | 10.34    | 8.08      | 21.8                   | 2.50                                 |
| 1          | M1-F6      | 21.00    | 16.9      | 19.57                  | 1.90                                 |
|            | M1-F8.5    | 27.43    | 22.4      | 18.34                  | 1.74                                 |
|            | M1-F11     | 31.00    | 26.23     | 15.4                   | 1.36                                 |
| 2          | M2-F6      | 24.65    | 20.26     | 17.80                  | 1.68                                 |
|            | M2-F8.5    | 28.50    | 24.15     | 15.26                  | 1.33                                 |
|            | M2-F11     | 32.38    | 27.92     | 13.77                  | 1.17                                 |
| 3          | M3-F6      | 26.53    | 22.10     | 16.70                  | 1.53                                 |
|            | M3-F8.5    | 30.25    | 25.74     | 14.90                  | 1.19                                 |
|            | M3-F11     | 33.20    | 28.78     | 13.30                  | 0.95                                 |
| 4          | M3-MF6     | 25.10    | 21.10     | 16.00                  | 1.27                                 |
|            | M3-HF8.5   | 32.8     | 28.28     | 13.78                  | 1.05                                 |

3.2.1.1 The loss in flexural strength
Flexural strength test was carried out for both the reference specimens of SIFCON which is stored in a dry place inside the laboratory (exposed to 0 cycles of freezing and thawing) and for SIFCON specimens exposed to 100 cycles of freezing and thawing, and the relative flexural strength with respect to the reference specimens was considered. The changes in flexural strength of SIFCON mixes are shown in Table 4. In general, all SIFCON specimens have less reduction in flexural strength as compared with the control mix (M1-F2), and shown (13.3-19.57)% loss in flexural strength after 100 freeze-thaw cycles. This is due to the superior bond ability between steel fiber and cement paste, therefore the plasticity of the concrete increased, reducing the cracks of the concrete due to its inside contraction, reducing its strength loss and improving its frost resistance accordingly.

3.2.1.1.1 Effect of volume fraction of steel fibers on flexural strength loss in SIFCON specimens

It is obvious from the table 4 and figures 6 and figure 7, that the incorporating of steel fibers in SIFCON mixes, with high content, show a positive effect on decreasing internal damage that may happen due to freezing and thawing, and reducing the loss in flexural strength. The lower loss in flexural strength occurred when using higher volume fraction of steel fiber, and hence lower deterioration. This was true for all SIFCON mixes in groups (1,2, and 3). In group (1), the increase in fiber fraction from 6% to (8.5 and 11)% decrease the loss in flexural strength from 19.57% to (18.34 and 15.4)%, respectively. This behavior is due to the effect of steel fibers in arresting the microcracks produced in SIFCON specimens by the internal pressure which built up due to the frost action.

![Figure 6](image)

**Figure 6.** Flexural strength of SIFCON mixes after and before exposing to freezing and thawing cycles

![Figure 7](image)

**Figure 7.** The Effect of fiber fraction and mortar type on flexural strength loss in SIFCON specimens

3.2.1.1.2 Effect of mortar type on the flexural strength loss of SIFCON
Also figure 7 present the influence of mortar type and the mineral admixture used in SIFCON mixes on freeze-thaw resistance of SIFCON specimens and the percentage of reduction in flexural strength. It can be concluded from the results that, the addition of silica fume (SF) as a partial replacement of cement, in SIFCON mixes in group (2) decrease the loss in flexural strength caused by freezing and thawing cycles. The percentage of reduction in strength was (17.8%, 15.26%, and 13.77%) for SIFCON mixes (M2-F6, M2-F8.5 and M2-F11), respectively, which is lower than the reduction (19.57%, 18.34%, and 15.4%) of their corresponding mixes in group (1) (M1-F6, M1-F8.5 and M1-F11), respectively. This is due to the effect of silica fume in reducing the pore size and number in SICON mortar and hence decrease the water absorption capacity of SIFCON specimens, also makes water unable to freeze at ambient temperatures, thus indicates a good durability nature of SIFCON and increase SIFCONs freeze-thaw resistance.

While SIFCON specimens in group (3), where the mortar containing a combination of silica fume and fly ash, show no significant difference in their resistance to freeze and thawing cycles, as compared with SIFCON specimens in group (2), and the flexural strength loss for the two SIFCON mortar types were very close to each other, with slightly better performance recorded in SIFCON mortar in group (3) over SIFCON mortar in group (2), as can be seen in Figure 7. The percentage of reduction in strength was (16.7%, 14.9%, and 13.3%) for SIFCON mixes (M3-F6, M3-F8.5 and M3-F11), compared with (17.8%, 15.26%, and 13.77%) for SIFCON mixes (M2-F6, M2-F8.5 and M2-F11), respectively.

It can be seen from the test results in table 4 and figure 8 that, both micro steel and hybrid fiber show positive effects on reducing the loss in flexural strength.

![Figure 8](image_url)

**Figure 8.** The effect of fiber type on the flexural strength loss of SIFCON mixes

### 3.2.1.1.3 The effect of fiber type on the flexural strength loss of SIFCON

Figure 8 shows the percentage of reduction in flexural strength for the SIFCON mixes (M3-F6, M3-MF6, M3-F8.5 and M3-HF8.5) made with hooked fibers (F), micro steel fiber (MF) or hybrid fibers (HF). It is clear from the figure that, there is a small difference in the percentage of reduction in flexural strength between the two mixes (M3-F6 and M3-MF6), with slightly better behavior of micro steel fiber over hooked fibers.

While using hybrid fibers in SIFCON specimens (M3-HF8.5) reduce its flexural strength loss comparing to hooked fibers specimens (M3-F8.5). This agrees with Faming et al. [20], who studied the frost resistance of hybrid fiber concrete and compared with single fiber concrete and found that hybrid fiber in the concrete enhances three-dimensional random distribution and adhere with each other. This can effectively inhibit the generation of cracks of concrete. Also hybrid fiber can be used to squeeze the capillary inside the mortar, and mortar water area will be greatly reduced. By improving the compactness of cement, water infiltration is reduced from the external environment to the internal porosity of concrete, and reduce the effective freezing of free water, this can accordingly improve the frost resistance of concrete.
3.2.1.2 The loss in weight
Measuring the weight of SIFCON specimens, after exposing to freezing and thawing cycles and determines their weight losses with respect to the initial weight before starting the test, is another important indicator to evaluate the deterioration due to freezing-thawing cycles. The loss in weight is due to the cracks and surface scaling in specimens as a result of the damage effect caused by repetitive freezing and thawing.

3.2.1.2.1 The effect of volume fraction of steel fiber on weight loss of SIFCON specimens
The test results show that the volume fraction of steel fibers had a good effect on decreasing the weight loss of SIFCON mixes compared with control mix M₁-F₂, the loss in weight reduced from about 2.5% to less than 1%, as illustrated in table 4 and figure 9. And the loss in weight decrease with increasing the volume fraction of steel fiber, the weight loss results of the specimens with the highest volume fraction (11%) showed the smallest value. This is due to the effect of steel fiber in restraining the cracks caused by freezing and thawing cycles.

![Figure 9](image_url)

**Figure 9.** The reduction in weight for all SIFCON mixes after 100 cycles of freezing and thawing

Also, it is noticed that SIFCON specimens containing highest volume fraction of steel fiber showed relatively more corrosion products on their surfaces than the other specimens, as shown in figure 10. This is due to the fact that the amount of steel fibers in the surface layers is proportional to fiber volume fraction, therefore, higher amount of fibers will be present near the surfaces of the specimens, and that making them susceptible to corrosion by the effects of freezing and thawing cycles and the fibers will have corrosion products formed on specimens surfaces. This will cause some increase in the initial volume of fibers, and creating internal pressures on the matrix, leading to more scaling at the specimens. In spite of the higher corrosion and scaling occur on specimens with high fiber content compared with the other specimens, but their weight losses are still show lower value. This is due to the fact that the initial weight is higher in SIFCON specimens reinforced with more fibers, therefore the loss occurred due to the surface scaling did not affect much with respect to the initial weight of specimens. Also, the steel fiber inside the specimens did not show any corrosion after freezing and thawing cycles, as shown in figure 11.
Figure 10. Formation of corrosion products on specimens of SIFCON mixes (a: M3-F6), (b: M3-F8.5) and (c: M3-F11) after 100 cycles of freezing and thawing.

Figure 11. The situation of steel fiber in SIFCON specimen (M3-F11) after 100 cycles of freezing and thawing.

3.2.1.2 The effect of mortar type on weight loss of SIFCON specimens

The test results show that the type of SIFCON mortar effects on the weight loss of specimens after exposing to freezing and thawing cycles. Using (10%) silica fume replacement by weight of cement in SIFCON mortar in group (2), reduces the weight loss in specimens as compared with the specimens in group (1), table 4 and figure 12 illustrate this behavior. The reason is related to the permeability of SIFCON mortar, and due to the effect of silica fume in reducing the permeability of mortar, therefore SIFCON mortar (M2) in group (2) is less permeable than reference mortar (M1) in group (1), and the effects of freezing and thawing will be higher on SIFCON specimens in group (1).

More reduction in weight loss was observed in SIFCON specimens in group (3), where SIFCON mortar containing both silica fume and fly ash, as a partial replacement by weight of cement. This is also due to the effect of these mineral admixtures in reducing the permeability of mortar and hence reducing the deterioration caused by freezing and thawing cycles.
3.2.1.2 The effect of fiber type on weight loss of SIFCON specimens

Figure 13 shows the weight loss of SIFCON specimens made with hooked fiber(F), micro steel fiber (MF) and hybrid fiber (HF). It is indicated that, weight loss by freeze-thaw cycles decreased when using micro steel fiber in mix (M3-MF6) compared with hooked fiber in mix (M3-F6).

Also using hybrid fibers in SIFCON specimens (M3-HF8.5) reduces its weight loss comparing to hooked fibers specimens (M3-F8.5). This is in agreement with Faming et al [20] who found that addition of hybrid fiber can control the weight loss of the freeze-thaw cycles more than single fiber in concrete and this can enhance the frost resistance of concrete.

4. Conclusions

The test results show that the use of (20 %) fly ash in combination with (10%) silica fume, as a replacement of cement, improves the workability, decreases the viscosity of SIFCON mortar, and reduces the dosage of HRWR as possible. Therefore, SIFCON mortar, having proper flow ability and filling ability properties, can be produced with silica fume and/or fly ash replacement by using proper dosage of HRWR. The results also show that all SIFCON specimens have less reduction in flexural strength and weight after 100 freeze-thaw cycles, it reaches to (13.3% and 0.95%) loss in flexural strength and weight, respectively compared with (21.8% and 2.5%) loss in strength and weight of the control mix (M1-F2). The increase in fiber fraction from 6% to 11% decreases the loss in flexural strength and weight of SIFCON mixes after 100 freeze-thaw cycles. The loss in flexural strength
It reduces from 19.57% to 15.4%, and the loss in weight decreases from 1.9% to 1.36%, when the fiber fraction increases from 6% to 11%, respectively for mixes M1-F6 and mix M1-F11. It is obvious that the using of fly ash and/or silica fume reduces the percentage of reduction in flexural strength and weight of SIFCON mixes after exposing to 100 cycle of freezing and thawing. And the use of micro steel fiber or hybrid fiber in specimens decreases the loss in flexural strength and weight by freeze-thaw cycles when compared with hooked fiber specimens.

References

[1] Kani M A and Raj B J 2016 Investigation on strength and durability of slurry infiltrated fibrous concrete “International Journal of Emerging Technologies in Engineering Research (IJETER) Vol. 4 Issue 5 India pp.26-30.
[2] Shanthini D and Mohanraj E K 2015 Mechanical behavior of SIFCON beams International Journal of Science and Engineering Research (IJOSER) Vol. 3, Issue 10 p.3.
[3] Deepesh P and Jayant K 2016 Study of mechanical and durability properties of SIFCON by partial replacement of cement with fly ash as defined by an experimental based approach International Journal of Innovative Research in Science Engineering and Technology Vol. 5 Issue 5 p7.
[4] Krishman M G and Elevarasi D 2014 Experimental study on Slurry Infiltrated Fiber Concrete with sand replacement by Msand International Journal of Engineering research and technology Vol. 3 Issue5 pp.534-37.
[5] Yardimici M Y Aydin S ,Yigiter H and Yazici H 2010 Improvement of self-compacting cement slurry for autoclaved SIFCON containing high volume class C fly ash Dokuz Eylul University Engineering Faculty Department of Civil Engineering, Buca - Izmir/Turkey pp.1039-1102.
[6] Gilani A M 2007 Various durability aspects of slurry infiltrated fiber concrete Ph.D. thesis, the graduate school of natural and applied sciences of middle east technical university ,Turkey, p209.
[7] Armagan K and Canbaz M 2016 Effect of fiber type on freeze thaw durability of SIFCON International Journal of Advances in Mechanical and Civil Engineering Vol.3 Issue 5 pp.56-59.
[8] Canbaz M and Armagan K 2016 Effect of binder type on freeze thaw durability of SIFCON International Journal of Advances in Mechanical and Civil Engineering Vol.3 Issue 5 pp.16-20.
[9] Iraq Standard Specification (IQS) No.5 1984 Portland cement Iraq pp.1-8.
[10] Iraq Standard Specification (IQS) No.45 1984 Natural sources of aggregate used in building and concrete Iraq pp.1-13.
[11] ASTM C 1240 – 05 2005 Standard specification for silica fume used in cementitious mixes American Society for Testing and Material International Vol.04.02 pp.1-7.
[12] ASTM C 618 2005 Standard specification for fly ash used in cementitious mixes American Society for Testing and Material International Vol.04.pp.1-3.
[13] ASTM C 494-05 2005 Standard Specification for Chemical Admixtures for Concrete American Society for Testing and Material International pp1-5.
[14] Yan L, Zhao G and Qu F Compressive properties of slurry infiltrated fiber concrete under monotonic and cyclic loading the Hong Kong institution of engineers, Dallan , Vol.6 No.1 pp.67-69.
[15] Giridhar R, Rama P and Rao M 2015 Determination of mechanical properties of slurry infiltrated concrete (SIFCON) International Journal for Technological Research in Engineering Vol. 2, Issue 7 pp.1366-68.
[16] EFNARC 2005 Specifications and Guidelines for Self-Compacting Concrete EFNARC UK (www.efnarc.org) pp. 1-32.
[17] Mahdi B S 2009 Properties of Self-Compacted Reactive Powder Concrete Exposed to Saline Solution Ph.D. thesis Building and Construction Engineering University of Technology Iraq p.223.
[18] ASTM C 666/C 666M-03. 2003 Standard test method for resistance of concrete to rapid freezing and thawing American Society for Testing and Material International pp. 1-6.
[19] ASTM C1609M–12 2012 Standard Test Method for Flexural Performance of Fiber-Reinforced Concrete (Using Beam with Third Point Loading) American Society for Testing and Material International pp.1-10

[20] Faming L, Lisha Z and Jie M 2015 Frost resistance test research on hybrid fiber concrete based on range analysis The Open Construction and Building Technology Journal China pp.292-97.