Study the behavior of Slurry infiltrated fibrous concrete (SIFCON) under impact loading

Dr. Manolia abed Al-wahab Ali 1, Dr. Shakir Ahmed Salih 2 and Dr. Qais Jawad Frayyeh 3

1 Al-Mustansiriya University, Iraq.
2 University of Technology, Iraq.
3 University of Technology, Iraq.

E-mail: manoliaalim@gmail.com

Abstract. SIFCON, as a type of fiber reinforced concrete (FRC), has a unique and superior properties in the areas of both ductility and energy absorption and the impact resistance is recognized as one of the significant properties of SIFCON.

The main object of present study is to determine the influence of SIFCON mortar type and fiber volume fraction on the behavior of SIFCON under impact loading. For SIFCON mortar, supplementary cementitious materials [Class F fly ash (FA) and silica fume (SF)] were used as a partial replacement by weight of cement. The percentage of FA replacement was (20%) and of SF replacement was (10%). Hooked end steel fibers were used with different fiber volume fraction (6, 8.5, and 11) %, the test was carried out using disc specimen (152 mm diameter by 63 mm thick). The test results were compared with those of fiber reinforced mortar (FRM) containing 2% fiber volume fraction, as a reference (control) mix. The test results show that in general, there is a significant improvement in impact resistance of all SIFCON mixes with increasing fiber volume fraction. SIFCON mix containing SF and FA and 11% volume fraction exhibited the highest impact resistance, and the energy required for completing failure was increased by 11.87 times, when compared with the control mix at 90 days.

Keyword
SIFCON, fly ash, silica fume, hooked end fiber, impact resistance

1. Introduction
Slurry infiltrated fiber concrete (SIFCON) is one of the recently developed construction material and could be considered as a special type of fiber reinforced concrete (FRC). Generally, the conventional (FRC) contains fibers (1–3) % by volume, whereas SIFCON contains (4–20) % of fibers, Even though the current practical ranges from (4 - 12) %. SIFCON is found in application area of pavements repairs, repair of bridge structures, structures subjected to impact loading and defense structures due to its excellent energy-absorption capacities [1,2,3,4].

Giridhar et al[5] investigated the mechanical properties of SIFCON for volume fraction of steel fibers(4,6,and 8%). Two types of hooked ends fibers were used with length (50mm and 35 mm). The slurry mix proportion was 1:1 cement sand ratio with water cement ratio of 0.4, and 2% of Superplasticizer. The researchers found that the mechanical properties of SIFCON increase with increasing the fiber volume fraction. For (4%, 6%, 8%) volume fraction, the compressive strength of 35 mm steel fiber after 28 days of water curing were (90, 110, 120 MPa) while The flexure strength were (4.47, 6.84 and 8.90 Mpa), respectively. The splitting tensile strength for 8% fiber volume fraction of...
length 35mm was found to be 3.08MPa after 28 days of curing. Also the compressive strength was more for smaller length fibers than higher length fibers.

A very little information is available about the impact strength of SIFCON; the only available information was from Parameswaran et al [6], who studied behavior of SIFCON specimens due to impact loads. The tests results were compared with those of plain mortar and fiber reinforced mortar with (1 to 4) % fiber volume fraction. The slurry consisted of cement and fine sand (passing through a 1.18-mm sieve) mixed in the proportion of 1:1 by weight. Straight round steel fibers of 0.4 mm diameter were used. Two fiber volume percentages (6 and 8)% were used in making the SIFCON specimens with aspect ratios (75 and 100), the impact test was carried out using the weight of drop of 50 N, and the drop height was varied from 250 to 1000 mm. The test results show that, SIFCON specimens reinforced with fibers of 100 aspect ratio exhibited greater impact resistance than those reinforced with fibers of 75 aspect ratio.

Therefore, producing different SIFCON mixes containing silica fume (SF), fly ash (FA) and studying the influence of fiber volume fraction and mortar type on SIFCON behavior under impact load is the main object of the research.

2. Research significant
Recently, there has been a growing interest in the use of SIFCON for explosive-resistant containers, security blast-resistance vaults, and repair of structural components. Which have high impact resistance and high energy absorption properties. Since SIFCON is a relatively new construction material, a little information on SIFCON characteristics subjected to impact load is known from published previous researches. From this point of view, this investigation was suggested to provide experimental data on the behavior of SIFCON under impact load by studying the effect of different volume fraction of steel fiber and SIFCON mortar type, which considered the most important factors that influenced on the properties of SIFCON products.

3. Experimental works
The experimental program used throughout the work involves the properties of the materials, mix proportion, preparation, mixing, casting procedures, and the test on SIFCON specimens.

3.1 Materials used
3.1.1 Cement. Ordinary Portland cement was used in this study. Its chemical and physical properties conformed to ASTM C150-04 [7].
3.1.2 Natural sand. Al-Ekhaider natural sand, passed through sieve (1.18 mm), was used as a fine aggregate throughout this work. It is conformed to ASTM C33-03[8].
3.1.3 Water. Tap water was used for mixing and curing all SIFCON mixes.
3.1.4 Chemical admixtures. High performance concrete superplasticizer (Glenium 54), from BASF company, was used as a high range water reducing admixture (HRWR). It is free from chloride and complies with ASTM C494-05 Type F[9]. The use of (Glenium 54) is important to enhance the workability of SIFCON slurry.
3.1.5 Mineral admixtures. Two types of mineral admixtures were used in this work. The first type was densified silica fume (SF), and the fineness was (21000 m²/kg) , it conforms to ASTM C1240-05 requirement [10]. The second type of admixture was fly ash Class (F), with fineness of (773 m²/kg) and fly ash (FA) used conforming to ASTM C 618-2005 requirement [11].
3.1.6 Steel fiber. Hooked-end steel fiber with (35mm) length and (0.7 mm) diameter is used in the present work. It is conforming to ASTM A820-04 [12] requirements.

3.2 Mix proportion
Many trail slurry mixtures were carried out to obtain a mixture which has the optimum fresh properties with suitable fluidity and filling ability without bleeding or segregation in the dense fiber bed. Three types of SIFCON mortar $M_1$, $M_2$ and $M_3$ were prepared with different mix compositions, as shown in Table 1. The proportion of (sand: cement) by weight, (1:1), was adopted in this investigation, ordinary Portland cement content ($885$ kg/m$^3$) was used, each of SIFCON mix was prepared and reinforced with different volume fraction (6%, 8.5% and 11%) of hooked steel fiber. The fiber volume fraction of 6% was a minimum practical content that could fill the mold without using vibration. While fiber volume fraction of 11% was the maximum practical value that fills the mold with using vibration to obtain complete penetration of the mortar into the fiber network, and fiber fraction of 8.5% was used as an intermediate value. Conventional fiber reinforced mortar with volume fraction of (2%) as a reference mix was also prepared for comparison with SIFCON mixes.

### 3.3 Tests on fresh properties of SIFCON

Testing of the fresh SIFCON mortar is important for SIFCON production. It must be liquid to penetrate enough into the dense fiber bed, for SIFCON mortar, only two tests have been proposed by EFNARC [13] which are V-funnel and mini slump flow. The mini slump flow test uses a cone with a height of 60 mm, top diameter of 70 mm and base diameter of 100 mm. The spread diameter required for SIFCON mortar is between (240-260) mm, while the flow time required for V-funnel test is between (7-11) seconds [13], the mini flow test measures the mortar flowability while the V-funnel test was used to evaluate the mortar viscosity. The results of fresh properties for SIFCON mortars are presented in table 2.

### Table 1. Detail of SIFCON mixes.

| Group No. | Mix Symbol | Cementitious | Sand kg/m$^3$ | Water kg/m$^3$ | w/binder by wt. | Fiber Vf. (%) |
|-----------|------------|--------------|---------------|----------------|----------------|--------------|
| Ref.      | $M_1$-F2   | 885          | 0.00          | 885            | 265.5          | 0.3          | 2            |
| 1         | $M_1$-F6   | 885          | 0.00          | 885            | 265.5          | 0.3          | 6            |
|           | $M_1$-F8.5 | 885          | 0.00          | 885            | 265.5          | 0.3          | 8.5          |
|           | $M_1$-F11  | 885          | 0.00          | 885            | 265.5          | 0.3          | 11           |
| 2         | $M_2$-F6   | 796.5        | 88.5          | 885            | 265.5          | 0.3          | 6            |
|           | $M_2$-F8.5 | 796.5        | 88.5          | 885            | 265.5          | 0.3          | 8.5          |
|           | $M_2$-F11  | 796.5        | 88.5          | 885            | 265.5          | 0.3          | 11           |
| 3         | $M_3$-F6   | 619.5        | 88.5          | 177            | 265.5          | 0.3          | 6            |
|           | $M_3$-F8.5 | 619.5        | 88.5          | 177            | 265.5          | 0.3          | 8.5          |
|           | $M_3$-F11  | 619.5        | 88.5          | 177            | 265.5          | 0.3          | 11           |
### Table 2. Results of fresh SIFCON mixes.

| Mix symbol | Mini slump flow (mm) | The V-funnel (sec) | (HRWR) by weight of cement (%) |
|------------|----------------------|--------------------|-------------------------------|
| M₁         | 258                  | 8                  | 1.2                           |
| M₂         | 257                  | 9.5                | 2.4                           |
| M₃         | 260                  | 7                  | 2.0                           |

3.4 **Preparations, casting, and curing of the test specimens**

For preparing SIFCON specimens, the steel fiber was incorporated into the SIFCON matrix in two-layers, the procedure consisted of placing fibers in the mould to the half of its depth, then filling the mould with the mortar to this level and repeated this process until the required volume fraction filled the mould, as shown in figure 1. Light and intense vibrations were required in case of (8.5% and 11%) fiber volume fraction, respectively, after that, the specimens were kept in the laboratory for 24 hours, and then they were de-molded, and immersed in tap water tank to be cured till the age of 90 days.

![Figure 1. Preparation and casting of SIFCON mixes](image)

3.5 **Tests on hardened SIFCON specimens (Impact resistance)**

The conducted impact test was the drop-weight test, according to ACI committee 544 [14], with some changes in the equipment used as a result of higher volume fraction of steel fiber in SIFCON specimens, which required higher drop weight and drop height. This test was carried out using disc specimen (152 mm diameter by 63 mm thick), the equipment used for impact test consists of manually operated compaction hammer contact with hardened steel ball; the weight of the drop was 7.4 kg instead of 4.54 kg (the weight in the original equipment), also the drop height was 1000 mm instead of 457 mm (the original drop height) as shown in Figure 2, the hammer is dropped freely and repeatedly from a height of 1000 mm and recorded the number of blows required to cause the first crack and failure of SIFCON specimen. The specimens were tested at age of 90 days; the impact energy of each specimen used in this test was calculated using Equation (1):

\[
E_{\text{imp}} = N \cdot m \cdot g \cdot h \\
\text{Where:} \\
E_{\text{imp}} \text{ impact energy, (N} \cdot \text{m)} \\
m \text{ mass of drop hammer, (kg)} \\
g \text{ acceleration due to gravity, (9.81 m/s}^2) \\
h \text{ releasing height of drop hammer, (m)} \\
N \text{ number of blows.}
\]
4. Results and Discussion

4.1 Properties of fresh SIFCON

The test results of the fresh SIFCON mortars are shown in Table 2, it can be seen from the results of the (M₁) that using HRWR is very important to prepare homogenous mixture with lower water/binder ratio, to obtain the optimum dosage of HRWR needed for M₁, slump flow test was carried out first with various dosage of HRWR until reaching to the dosage with slump flow diameter range between (240-260) mm, after that the V-funnel test was carried out to check the mortar viscosity, the incorporation of HRWR in cement mortar causes a reduction in viscosity, thus improving flowability, this is due to their long lateral chains of carboxylic ether polymer which when adsorbed on cement particles, they imparts a strong negative charge and that minimize the surface tension of the surrounding water molecules and enhances the fluidity of the system [3,4], also the addition of 10% SF to the (M₂) mortar cause increase in water demand and decrease in workability, and that require increase the HRWR dosage, because SF particles have high surface area, that was solved when using (20%) FA with (10%) SF in (M₃) and that improves the workability and decrease HRWRA dosage; this is due to the effect of FA particles, which have the spherical shape, in reducing the friction between particles and hence increasing the workability [3].

4.2 Impact resistance

The impact resistance test results of control mix (M₁-F2) and SIFCON mixes at age of 90 days are presented in Table 3 and plotted in Figure 3. The test results show that in general, there is a significant improvement in impact resistance for all SIFCON mixes at first crack and failure compared with the reference mix, SIFCON mix (M₃-F₁₁) has the highest impact resistance and the energy required for complete failure was (109471.8 N. m) which is increased by 11.87 times, when compared with the reference mix. This superior behavior of SIFCON mixes is due to the inclusion of steel fiber with high volume fraction (6-11%) in mixes. Other factors that effect on the impact resistance of SIFCON mixes are mentioned and discussed below.
Table 3. Impact resistance for various mixes of SIFCON specimens at 90 days age.

| Group No. | Mix symbol | Number of blows to cause | Impact energy (N. m) |
|-----------|------------|--------------------------|---------------------|
|           |            | First crack (N1)         | Failure (N2)        | First crack | Failure     |
| reference | \(M_1\)-F2| 33                       | 127                 | 2395.6      | 9219.4      |
| 1         | \(M_1\)-F6| 75                       | 271                 | 5444.6      | 19673.0     |
|           | \(M_1\)-F8.5| 161                     | 510                 | 11687.6     | 37023.0     |
|           | \(M_1\)-F11| 200                     | 923                 | 14518.8     | 67004.3     |
| 2         | \(M_2\)-F6| 149                      | 405                 | 10816.5     | 29400.6     |
|           | \(M_2\)-F8.5| 251                     | 766                 | 18221.1     | 55607.0     |
|           | \(M_2\)-F11| 365                     | 1385                | 26496.8     | 100542.7    |
| 3         | \(M_3\)-F6| 216                      | 658                 | 15680.3     | 47766.9     |
|           | \(M_3\)-F8.5| 375                     | 1116                | 27222.8     | 81014.9     |
|           | \(M_3\)-F11| 470                     | 1508                | 34119.2     | 109471.8    |

Figure 3. Number of blows required to cause first crack (N1) and failure (N2) on SIFCON.

4.2.1 Influence of fiber volume fraction on the impact resistance of SIFCON. It is clear from the test results that the increase in fiber volume fraction for SIFCON in groups (1, 2, and 3), causes a significant increase in impact resistance both at first crack and at failure as compared to control mixes \(M_1\)-F2, this is due to the higher capacity of hooked end steel fiber in SIFCON specimens to absorb higher amounts of energy prior to undergo failure, therefore; the energy input required to initiate first crack and to produce failure in SIFCON mixes is much higher than that for control mix \(M_1\)-F2, the increase in energy at failure ranges between (113.4% -1087%), as shown in Table 3 and Figure 4. When fiber fraction increase from 6% to (8.5% or 11%) in group (1), the impact energy of SIFCON mixes (\(M_1\)-F8.5 and \(M_1\)-F11) increase to (114.6% and 166.6%) for first crack, and to (88.2% and 240.6%) for failure, respectively compared to the SIFCON mix \(M_1\)-F6. While, when the fiber fraction is increased from 6% to 8.5% or 11% in group (2), the impact energy increased to (89.1 and 242%) for failure when compared with the \(M_2\)-F6 mix.
4.2.2 Influence of mortar type on the impact resistance of SIFCON. The results indicate that, the mortar type has a considerable effect on the impact resistance of SIFCON specimens. Table 3 and Figure 5 show that the incorporation of (SF) in SIFCON mixes in group (2) causes increase in the first crack and failure impact resistance compared to corresponding mixes in group (1) without (SF), this is attributed to the pozzolanic reactivity of silica fume, which contribute in the densification of the microstructure of the matrix, therefore increases the bond between the matrix and the fibers leading to increase in the energy absorption [16]. The increase in impact energy reaches to about (49.4%, 50.2%, and 50.1%) at failure for SIFCON mixes (M2-F6, M2-F8.5 and M2-F11) at 90 days compared with mixes in group (1), while Figure 6 shows that, SIFCON specimens in group (3) have another increase in impact resistance compared with specimens in group (2), the increase in impact energy reaches to about (62.5%, 45.7%, and 8.8%) at failure for SIFCON mixes (M3 - F6, M3 -F8.5 and M3 - F11) at 90 days as compared to their corresponding mixes in group (2).

Figure 4. Influence of fiber volume fraction on the impact energy at failure of SIFCON mixes.

Figure 5. Influence of silica fume on the impact energy of SIFCON specimens at first crack and failure.
Figure 6. Influence of silica fume and fly ash combination on the impact energy of SIFCON specimens at first crack and failure.

Figure 7 shows an example of the failure mode of SIFCON specimens under impact loads, it can be seen that the steel ball had shown deeper local damage in the specimens due to the higher No. of blows before failure compared to the control mix specimens M1-F2.

5. Conclusions
Depending upon the experimental results of the present study, the following conclusions can be drawn:

1- The incorporation of silica fume in SIFCON mortar increases its viscosity, while using (20 %) fly ash in with silica fume, improves the workability and reduces the HRWR dosage.
2- SIFCON mixes exhibit superior impact resistance, with energy for complete failure higher by (11.87) times in comparison with the reference mix at age of 90 days.
3- Increasing the fiber fraction from (6% to 11%) increases the impact energy to failure of SIFCON mixes containing silica fume and fly ash to (129.2%) at age of 90 days.
4- The incorporation of silica fume in SIFCON mortar increases impact energy to about (50.1 %) with fiber content 11%, while SIFCON specimens containing (10%)silica fume and (20%)fly ash, have additional increase in their impact energy to about (63.4%) at age of 90 days.

References
[1] Yazıcı H, Aydı̇n S, Yiğiter H Yardı̇mcı̇ M Y and Alptuna G 2010 Improvement on SIFCON performance by fiber orientation and high-volume mineral admixtures Journal of materials in civil engineering, Vol. 22, Issue 11, November, pp 1093-1102
[2] Mahadik S A, Kamane S K and Lande A C 2014 Effect of steel fibers on compressive and flexural strength of concrete International Journal of Advanced Structures and Geotechnical Engineering , Vol. 03, No. 04, pp 388-392, October 2014
[3] A A Manolia, A S Shakir and J F Qais 2018 The effect of fiber and mortar type on the freezing and thawing resistance of Slurry Infiltrated Fiber Concrete (SIFCON) IOP Conference. Series: Materials Science and Engineering

[4] Shakir S, Qais F and Manolia A 2018 Fresh and some mechanical properties of SIFCON containing silica fume MATEC Web of Conferences 162, 02003, https://doi.org/10.1051/matecconf/201816202003, 2018

[5] 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 1366-1368, March-2015

[6] Parameswaran V S, Krishnamoorthy T S, Balasubramanianv K and Gangadar S 1993 Studies on slurry-infiltrated fibrous concrete (SIFCON) Structural Engineering Research Center, National Academy of Sciences, Issue No. 1382, part 2, India, pp 57-63

[7] ASTM C150-04, 2004 Standard Specification for Portland cement, American Society for Testing and Material International

[8] ASTM C33-03, 2003 Standard Specification for Concrete Aggregates, American Society for Testing and Material International

[9] ASTM C494-05, 2005 Standard Specification for Chemical Admixtures of Concrete, American Society for Testing and Material International

[10] ASTM C 1240 – 05, 2005 Standard Specification for Silica Fume used in Cementitious Mixtures American Society for Testing and Material International, Vol.04.02

[11] ASTM C 618, 2005 Standard Specification for fly ash Used in Cementitious Mixtures, American Society for Testing and Material International

[12] ASTM A820-04, 2004 Steel fibers for fiber-reinforced concrete, American Society for Testing and Material International

[13] EFNARC "Specification and guidelines for self-compacting concrete", 2005 European Federation for Specialist Construction Chemicals and Concrete Systems, Norfolk, U.K., pp 1-32

[14] ACI committee 544.2R, 2009 Measurement of properties of fiber reinforcement concrete.

[15] Ashish K G and Prakash K B 2012 A Study on the effect of alternate wetting and drying on the strength properties of SIFCON produced from waste coiled steel fibers. NBMCW Technology Belgaum, Karnataka