Strength of SIFCON- Ferrocement One-Way Ribbed Slabs Contain Steel Fibers

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Abstract. Slurry infiltrated fiber concrete "composites (SIFCON) are a novel type of concrete with improved strength, ductility, and crack resistance. In this study, infiltrating fibers (SIFCON) were used to reinforce specimens of ferrocement one way ribbed slabs. The laboratory work consists of cast and testing of eight specimens with dimensions of 750 mm in length, 500 mm in width and 50 mm in depth. These samples have the same wire mesh reinforcement and the same shape as the ferrocement slabs. Two reference ferrocement slab without ribs contains SIFCON and six ferrocement slabs with ribs contains SIFCON. The variables were the volumetric ratio of fibers in the ribs, which were (2, 4 and 6)\% and type of steel fiber (hook-end and hybrid fiber). Hybrid fibers contain two type of steel fiber (hook-end and micro steel fiber) with equal ratio. All samples were tested under line load up to failure with mid deflections for each test with simple supported. The results of the test showed that the presence of steel fibers in the ferrocement ribs, for both types of steel fibers, improves the resistance to the final loads and the ability to reduce deflection and increases the ductility and stiffness significantly.

Introduction

Due to carbonation, chloride assault, and other reasons, a vast number of civic facilities around the world are fast degrading. In addition, many civil structures are no longer considered safe due to increased load specifications in design guidelines, overloading, underdesigning of existing structures, or a lack of quality control. Older structures must be rebuilt or strengthened to meet the same standards as new ones built today and in the future. Ferrocement has earned a reputation for outstanding performance and adaptability over time. Ferrocement is a type of reinforced concrete that uses many layers of closely spaced mesh and/or tiny diameter rods that are entirely infiltrated with mortar or enclosed in it. Pier Luigi Nervy, an Italian engineer, architect, and contractor, pioneered the use of ferrocement in the construction of aircraft hangars, boats, and houses, among other things, in 1940. It's a long-lasting materials, low-cost, and versatile substance. Ferrocement is a thin-walled reinforced concrete with a continuous, small-scale wire mesh formed of hydraulic cement mortar, The mesh can be made out of metal or other suitable materials [1]. Ferrocement offers a higher tensile strength-to-weight ratio and improved cracking behavior as compared to regular reinforced concrete. Ferrocement has a wide range of applications, including agriculture, construction, and transportation, as well as water supply and sanitation, rural energy and housing, and concrete repair and structural reinforcement. This is due to a number of benefits, including the accessibility of raw materials, the flexibility to make sections of any design, and the low level of expertise required for ferrocement assembly. Delamination of the reinforcement's extreme tensile layer or spalling mortar cover causes flexural failure in ferro cement composites with high reinforcement ratios or high strength meshes. The usage of discontinuous short fibers in matrix can aid in the resolution of these issues. The addition of fibers to the matrix boosted shear capacity while concurrently reduced crack breadth and spacing, according to the researchers. Scientists are interested in fiber-reinforced cement composites (FRC) because of their...
high level of performance, and the addition of different types of steel fibers (hybrid steel fibers) improves the qualities of ferrocement. In terms of ductility, slurry-infiltrated fiber concrete (SIFCON) is the most promising of these composites. SIFCON is a reinforced concrete by a high steel fiber content. SIFCON has (2.5-20) % steel fibers by volumetric ratio, whereas FRC has (0.5-2) percent steel fibers by volumetric ratio. The makeup of the matrix is also an important feature. SIFCON, unlike FRC, employs a cement slurry or a flowing mortar matrix. SIFCON also uses a unique casting procedure. SIFCON is typically manufactured by infiltrating cement slurry into pre-placed steel fibers. The most prevalent infiltration methods are gravity flow with external vibration or pressure grouting. SIFCON possesses tensile stress-strain properties that are up to 10 times stronger in tension strength and a 1000 times tougher than normal concrete (unreinforced). Naaman et al. [2-9].

In an experiment, SIFCON jacketing was employed to fix shear deficient reinforced concrete beams. According to the testing data, the SIFCON converted brittle shear failure to ductile flexural failure and enhanced the ultimate shear of the beams repaired (Sudarsana and colleagues).[10]. From the previous, little research has been done on the structural response of ferrocement members when discontinuous fibers are added to wire mesh reinforcements before cement mortar is poured. As a result, this research aims to create a new type hybrid of ferrocement board in which the reinforcement is made up of steel fibers that are pre-placed in the formwork's in ribs and then poured into a self-compacting cement mortar. The Hybrid specimens with dimension (750 * 500 * 50 mm) contains three ribs with depth 60 mm were bending tested for this purpose.

2. Experimental investigation

SIFCON is used in the experimental program, which comprises of evaluating eight specimens to investigate the flexural behavior of Ferrocement one-way ribbed slabs. The primary factors in the test were the percentage of steel fibers added (2, 4, 6) and the type of steel fiber (hook-end and hybrid), with hybrid including steel fibers two types (hook-end steel fibers with micro steel fibers) in an equal ratio. The cast slabs have dimensions of (750* 500*50)mm and a depth of 60 mm with three ribs as illustrative in figure 1. Table 1 summarizes the Slabs details as well as the primary study parameters. Load – deflection curves, ultimate load and associated deflection at failure, failure pattern, and stiffness were the findings.

| Groups | Slabs No. | Types steel fiber | Volume fraction of steel fiber $V_f$ (%) | Ribs depth |
|--------|-----------|-------------------|----------------------------------------|------------|
| A      | REF1      | -                 | -                                      | 0          |
|        | REF2      | -                 | -                                      | 0          |
| B      | BSFH2     | Hook-End          | 2                                      | 60         |
|        | BSFH4     | Hook-End          | 4                                      | 60         |
|        | BSFH6     | Hook-End          | 6                                      | 60         |
| C      | BSFB2     | Hybrid            | 2                                      | 60         |
|        | BSFB4     | Hybrid            | 4                                      | 60         |
|        | BSFB6     | Hybrid            | 6                                      | 60         |
Figure 1. Flow chart for experimental program.
3. Materials and methods

3.1. Cement
Ordinary Portland cement (Type I) is used. Test results showed that the used cement was complied with “standard specification Iraqi (no.5/1984)” [12].

3.2. Fine Aggregate
The fine aggregate used is natural siliceous sand from Al- NIBAEE region. In all concrete mixes used Sand passing through the sieve 1.18 which is appropriate to be used in casting Ferrocement Concrete and slurry SIFCON matrix [13], as illustrative in Table 2, is satisfies the “Iraqi specification (No.45/1984)”.

Table 2. Fine aggregate grading.

| Sieve size            | Cumulative passing % | Limit of Iraqi specification No.45/1984 |
|-----------------------|-----------------------|-----------------------------------------|
| 4.75 mm(No.4)         | 95                    | 90-100                                  |
| 2.36 mm(No.8)         | 89.5                  | 75-100                                  |
| 1.18 mm(No.16)        | 81.5                  | 55-90                                   |
| 600 µm(No.30)         | 56.7                  | 35-59                                   |
| 300 µm(No.50)         | 21.4                  | 8-30                                    |
| 150 µm(No.100)        | 3.4                   | 0-10                                    |

3.3. Water
All mixes were cast with ordinary tap water, and the specimens were cured with ordinary tap water.

3.4. Wire Mesh
Expended wires mesh layers with diameter 1mm and opening (20*10) mm of wires mesh was used.

3.5. Superplasticizer
Mega Flow 110 has been used to produce high performance concrete is a super plasticizer that improves the workability of ferrocement concrete mixes without adding water and satisfies the requirements for superplasticizer " ASTM-C 494 Types G and F ".

3.6. Steel Fibers
Two types of steel fibers are employed in this project, with varying density, shapes, lengths, diameters and aspect ratios (l/d). The first is a micro steel fiber (straight steel fibers) length of 12 mm, and 0.2 mm diameter with aspect ratio 60. The second type is steel fibers with a hook end with length 30 mm, and 0.5 mm diameter, and aspect ratio 60. ‘ Figure 2 ’ shows sample of used steel fiber, while Table 3 lists the parameters of steel fiber employed in this study.
Figure 2. Sample of Used Steel Fiber (A, C) hook end (B) straight.

Table 3. Steel Fiber Properties.

| Type          | Hook-end steel fibers | Micro steel fibers |
|---------------|------------------------|-------------------|
| Description   | Hook end               | Straight          |
| Length        | 30mm                   | 12mm              |
| Diameter      | 0.5mm                  | 0.2mm             |
| Density       | 7850kg/m3              | 7800kg/m3         |
| Tensile Strength | 1345MPa             | 2600MPa           |

4. Mix Proportion

Many experimental of slurry mixes have been conducted to establish ideal fresh qualities for SIFCON mortars utilizing slump flow and T50 cm test, while also ensuring complete penetration of mortar through the steel fiber network, as shown in ‘figure 3’. the available research on the design specifications of the sifcon mixture has been used because there are no design specifications yet. In most circumstances the weight ratio of (sand: cement) is (1:1) hence ratio was used in study. Many researchers have also used the cement content (800-1000)kg/m3, and it is recommended to use a w/b ratio equal to or less than 0.4 (by weight) to produce the SIFCON matrix [2,6,7]. Therefore after many trails, the mix ratio used in this study illustrated in Table 4.

Table 4. Mix Ratio Used

| Constituent | Fine Aggregates | Cements | Waters | Superplasticizers |
|-------------|-----------------|---------|--------|-------------------|
| Amount (kg/m³) | 969              | 969     | 388    | 19.4              |

In this paper, ferrocement slabs contains three ribs with depth 60 mm that contains steel fibers to strengthen the slabs. Once as a hook-end steel fibers, another is a hybrid steel fiber consisting of steel fibers (hook-end and micro-steel fiber) (50% micro-steel + 50% steel-fibre).
5. Fabrication of Specimens

The dimensions of the wooden molds were (750 * 500 * 50 mm), two without ribs and one with three ribs, with a depth of 60 mm and a width of 50 mm. In each approach, 1 mm diameter expanded metal mesh with an opening of (10*20) mm is utilized as reinforcement in the perimeter faces of the model inside the molds, and after that steel fibers in the necessary volumetric ratio are inserted in the molds. Then, as illustrated in Figure 4, fresh self-compacted mortar mix was poured into the wooden molds. Table 5 shows the fresh self-compacted mortar properties that confirms with EFNARC 2002 specification [14]. Then a steel rod with a tapered head was used to press the steel fibers into the mold to prevent the fibers from clumping that lead to voids or honeycombing. Along with the slabs, a total of twenty one (70 *70*70 mm) cubes mortar and twenty one(160*40*40 mm) mortar prisms were molded. The mortar specimens were used for compressive and modulus of rupture tests with and without steel fibers. The matrix characterized by an average compressive as show in Table 6.molded samples were cured after 24 hours and submerged in the curing tank to 28 days. To achieve clear sight of cracks during testing, the slab was cleaned and painted with white paint on surfaces before the testing day. The slab was set on the minimal supports with care.
Table 5. Properties of self-compacted mortar.

| Test value fresh Mortar | EFNARC Specification (2002) |
|-------------------------|-----------------------------|
| Flow test               | 710 mm.                     | Large than 650 mm          |
| T₅₀ cm                  | 4 sec                       | (3-7) sec                  |

Table 6. Average compressive strength and modulus of rupture for used mixes.

| Specimens | Volume ratio of steel fibers Vₓ (%) | Compressive Strength (f₂₈) 7 day MPa | Compressive Strength (f₂₈) 28day MPa | Modulus Of Rupture MPa at 7 days | Modulus Of Ruptures in MPa at 28 days |
|-----------|--------------------------------------|---------------------------------------|---------------------------------------|----------------------------------|---------------------------------------|
| A₀        | Without                              | 49.1                                  | 57.21                                 | 3.02                             | 5.62                                  |
| A₂        | 2                                    | 51.75                                 | 61.14                                 | 6.56                             | 8.56                                  |
| A₄        | 4                                    | 57.27                                 | 64.69                                 | 8.08                             | 10.85                                 |
| A₆        | 6                                    | 59.12                                 | 69.14                                 | 8.21                             | 12.57                                 |
| AB₂       | 2                                    | 53.19                                 | 66.07                                 | 11.07                            | 15.17                                 |
| AB₄       | 4                                    | 58.50                                 | 68.42                                 | 13.26                            | 15.93                                 |
| AB₆       | 6                                    | 65.48                                 | 71.81                                 | 17.08                            | 19.41                                 |

6. Testing Samples

All samples were subjected to line load with a 650-mm effective span length slabs load capacity of 2.0 Ton was used to apply load and keep the load constant at each load level at the mid-span of the slab. Two steel rods were used to support the slab. Loads were shed and recorded using a calibrated load cell and LVDT was used to measure the deflection. as shown in ‘figure 5’.

A. Specimen in loading mechanie

B. Test

Figure 5. Set-up of ferrocement slabs
7. Results and Discussion

7.1. Load - Deflection Relationships

The load-deflection curves for all the specimens tested are illustrated in Figures (6-11). As can be seen in these figures, all load-deflection curves follow the same pattern. Curves of Load-deflection can be separated into 3 steps in general. In the first stage, the relationship between loading and deflection is linear, and this stage is referred to as the pre-cracking stage. In this stage, the applied load is resisted by the matrix. In the second stage, the curves pass through the relationship where loading and deflection changes and the relationship becomes non-linear. At this stage, cracks begin in the tension region of the samples and gradually increase. The mortar at the cracked section does not carry any tension and the reinforcement (steel fibers) resist the load entirely, and the SIFCON matrix begins to resist the loading, and with the increase in loading, the cracks increase and widen until the loading reaches a value that causes cracking the pressure faces of the samples. The load continues increasing until the maximum load is reached, after which failure occurs it is the third stage. The load-deflection behavior of Ferrocement slabs contains SIFCON is similar to that seen by other studies previously [2,3].
The failure of the normal specimen occurs suddenly when cracking starts in the tension face and then the specimen breaks into two pieces. ‘‘figure 6’’ shows a comparison of the load-deflection curve for ferrocement slabs containing only wire mesh with ferrocement slab containing wire mesh with SIFCON in ribs. It can be seen from these figures that the addition of steel fibers in the ribs has an effect on the bending behavior before the appearance of the first crack and after it until failure occurs. As can be seen from these figures, adding steel fibers can delay crack initiation. Also, during the deformation state after crushing of iron cement plates with steel fibers, the absolute bearing capacity, ductility and energy absorption of the samples were significantly increased compared to the control sample. The increase in the percentage of steel fibers showed a higher toughness for these samples. The use of hybrid steel fibers showed an increase in stiffness and ductility more compared to using steel fibers hooked end and for the same ratio as show in ‘‘figure 12’. When used hook-end steel fibers by ratio (2, 4, and 6)% in SIFCON matrix the ultimate load increases by (283.52, 539.20, 588.92) % respectively As well as used hybrid steel fibers by ratio (2, 4, and 6)% in SIFCON matrix lead to increase the ultimate load by (233.14, 444.36, 700.47) % respectively, as shown in ‘‘figure (6-11) ’’ and Table 7.

7.2. Initial Stiffness

All specimens evaluated in this study have their initial stiffness investigated. The deflection at this point may be computed by taking yield loading and intersected it on the load-deflection curve. The stiffness can then be calculated by dividing the yield load by the corresponding deflection [11]. ‘‘Table 7’’ and ‘‘figure13’’ shows the variation of initial stiffness, for ferrocement slabs specimens. When compared to the reference
ferrocement slabs, the initial stiffness improved for use hook-end steel fibers by (31.11, 60.03, and 61.47) percent for volumetric fractions of steel fibers (2, 4, and 6) percent, and the initial stiffness improved by (69.18, 70.7, 74.17) percent for volumetric fractions of hybrid fibers (2, 4, and 6) percent, when hybrid steel fibers were used.

Through the ‘figures (6-11)’, it can be seen that the addition of hybrid steel fibers in the SIFCON matrix delays the appearance of the first crack and increases its stiffness and effect better than the use of steel fibers hooked ends. The use of hybrid steel fibers in the SIFCON matrix leads to an increase in the bonding between the components of the mixture and between the fibers, which leads to an increase in the strength of the specimens because the hybrid steel fibers contain micro steel fibers. Because the micro-fibers are small, and therefore they work to resist and stop small cracks, and this increases the strength of the specimens.

**Table 7. Test results.**

| Specimens | Yielding load Py in kN | Deflection at Yield load Δy in mm | Initial stiffness in (Py/Δy) kN/mm | Increase in initial stiffness % |
|-----------|------------------------|---------------------------------|----------------------------------|-------------------------------|
| REF       | 6.7                    | 0.43                            | 15.4                             | -                             |
| BSFH2     | 17.6                   | 0.87                            | 20.2                             | 31.11                         |
| BSFH4     | 32.1                   | 1.3                             | 24.69                            | 60.03                         |
| BSFH6     | 34.9                   | 1.4                             | 24.91                            | 61.47                         |
| BSFB2     | 20.1                   | 0.77                            | 26.1                             | 69.18                         |
| BSFB4     | 29.5                   | 1.12                            | 26.34                            | 70.7                          |
| BSFB6     | 43.0                   | 1.6                             | 26.88                            | 74.17                         |

*(REF) average two reference slab (REF1,REF2) used to compared with sample test.*

![Figure 13. Variation of initial stiffness.](image)

**7.3. Failure Modes and Cracks Patterns of the tested Specimens**

All the ferrocement slabs failed in flexural as shown in ‘figure 14’. The breakdown of the two reference ferrocement slabs was sudden. While few flexural cracks appeared at the bottom half of the ribs face of the ferrocement slabs with SIFCON matrix with increasing loading. It was observed that the first crack appeared near the bottom middle of the ribs, which is the region with the greatest bending moment. With the increased loading, all the cracks started in the lower face of the ribs, and with increasing loading, these cracks spread towards the top. The upper layer representing the compression zone was able to withstand the increased loading as no visible cracks appeared on it. All cracks started in the central rib and then the external lateral ribs. Some cracks reached the compression zone before the samples failed to their ultimate loading.
capacity. All the examined ferrocement slabs benefited from the geometry of the central ribs in terms of stiffness and ductility, which led to an improvement in the deflection resistance. Both types of steel fibers in SIFCON matrix in ferrocement slabs held the cracks together and helped the slab endure greater loads, according to the research. This demonstrated that incorporating steel fibers into concrete improves the structure's energy absorption capacity, which improves cracking behavior and load bearing capacity.

**Figure 14.** Failure modes for tested ferrocement slabs.
8. Conclusions

The use of the SIFCON matrix in the ribs of the ferrocement one way ribbed slabs leads to a delay in cracking and the appearance of the first crack and a significant increase in the ultimate loading capacity, ductility and initial stiffness of the ferrocement slabs. Steel fibers in ferrocement slabs ribs can help prevent the matrix cover from spalling. The experimental results clearly show that the fiber type has a substantial impact on compressive strength, modulus of elasticity, and stiffness, with hybrid steel fibers outperforming hooked end fibers. Used hook-end steel fibers by ratio (2, 4, and 6)% in SIFCON matrix the ultimate load increases by (283.52, 539.20, 588.92) % and increase initial stiffness by (31.11, 60.03, 61.47) respectively. The use of micro steel fibers leads to an increase in the number of fibers per unit size and thus leads to the production of a dense network of fibers that improves the properties of SIFCON. Replace the hook-ended steel fibers with micro steel fibres by 50% in SIFCON matrix increased the ultimate load by (233.14, 444.36, 700.47) % and increase initial stiffness by (69.18, 70.7, 74.17) % respectively. We discovered that combining two forms of steel fibers as hybrid fibers had excellent results and improved SIFCON characteristics.

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