Upgrading of normal concrete service life by using SIFCON layers

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Abstract. Slurry infiltrated fibrous concrete (SIFCON) is a form of superior performance fiber reinforced concrete made by penetrating steel fiber bed with an exceptionally designed slurry of cement-based. Researches have demonstrated that SIFCON is an imaginative building material having both extensive ductility and high strength. In the current study, the use of SIFCON has been investigated as a strengthening layer for conventional concrete section. The effects of the SIFCON layer position (bottom, top & bottom, and jacket), thickness (1.5, 2.5, and 3.5) cm, and steel fiber volume fraction (6, 7.5, and 9) % on the flexural strength, toughness, and ductility of hybrid prisms were reported. The results showed that the increase in thickness of the SIFCON layer and the steel fiber volume fraction improves the load bearing capacity, toughness, and ductility of the composite sections. The maximum ductility and load carrying capacity is achieved from the jacketing case. Also, the toughness enhanced greatly in the case of jacketing composite section, it was 23 times higher than that of control prisms.

Keyword: SIFCON, slurry infiltrated fiber concrete, composite section, strengthening of concrete, defect concrete repair.

1. Introduction

The most common defects of relatively old standing reinforced concrete structures are low quality concrete and insufficient ductility, especially in the countries in seismic areas [1]. Recently, the worthiest challenge in civil engineering have been repair and retrofitting of existing building like bridges, dams, etc. There are many traditional ways for repairing and strengthening defected reinforced concrete members, epoxy bonding the steel plates, shotcrete jacketing, and external post tensioning [2–4]. Amongst these techniques, strengthening by using advanced composites such as Slurry infiltrated fiber concrete (SIFCON).

SIFCON is a kind of high-performance fiber reinforced concrete. Slurry infiltrated fiber concrete is made by distributing short discrete fibers in the mold to the full volume or designed volume fraction, and then infiltrated by a fine liquid cement-based slurry or mortar. The fibers can be splashed by hand or by using fiber-dispensing techniques for big sections [5]. SIFCON might be produced by a combination of steel and polypropylene fiber [6]. The flexural strength was reached 41.23MPa with the steel fiber at length of 60 mm steel and 50 mm polypropylene fiber combination. On the other hand, the using of the polypropylene fiber provides lower density and cost compared with SIFCON produced only
from steel fiber. Waste steel fiber extracted from tires used successfully to produce SIFCON [7]. The highest percent of steel fiber in investigation was 5% by volume. It was observed that the compressive strength was not affected by the using of waste steel fibers. However, a significant increase was achieved in the flexural and splitting strength as the waste steel fiber increased. Much research has been done to assess the effectiveness of SIFCON retrofitting technique during the last years.

Balaji and Thirugnanam studied the effect of SIFCON layers on the behavior of conventional reinforced concrete beams under flexural loads [8]. They concluded that the ultimate load of composite beams was about 50% higher than control beams without SIFCON layers. Also, they found that the behavior of both bottom face layer and the top and bottom layers was nearly similar. The energy absorption capacity and ductility factor was enhanced by 90% and 185%, respectively.

Researchers have tried to cast fresh SIFCON jackets as external shear reinforcements and found that the brittle failure has eliminated and the maximum shear strength of the retrofitted beams increased up to 50% [9]. The behavior under flexural load of plain and SIFCON composite beams have been studied by some researcher. They educated that the composite beams with SIFCON have clearly enhanced the energy absorption capacity and flexural strength compared to conventional RC beams, and the behavior improved with increasing the SIFCON layer thickness [10]. Ipek with other researchers have examined the fracture toughness and flexure behavior of reactive powder and SIFCON concrete composite beams. According to control beams, flexural strength improved by 43.21%. Also fracture toughness was improved about 32.03% [11].

The current study is an attempt to study the location effect of fresh layer of SIFCON according to plain concrete prisms, the thickness of the fresh SIFCON layers, and the steel fiber percent of SIFCON. The behavior of prisms with SIFCON fresh layers were investigated. The parameters like flexural strength, load-deflection curves, toughness, ductility and failure pattern are studied.

2. Experimental Program

2.1 Materials and Mix Proportion

The mix proportion for normal concrete (25 M) and SIFCON are shown in Table 1. Ordinary Portland cement commercially known as “Kar” produced in Al-Najaf city is used and the maximum size of aggregate is 19 mm. Hook end steel fibers with 0.6 mm diameter and aspect ratio of 50 are used to cast SIFCON layer. Three volume fraction of steel fiber (6, 7.5, 9)% and three thickness layer of SIFCON (15, 25, 35) mm are adopted. The sand used for all mortar SIFCON mixes, was screened on a sieve 1.18 mm.

| mix      | Cement (kg/m³) | Sand (kg/m³) | Gravel (kg/m³) | w/c | Steel fiber (%) by vol. of concrete | HRWR (% of cement weight) |
|----------|----------------|--------------|----------------|-----|------------------------------------|----------------------------|
| normal   | 425            | 718          | 966            | 0.4 | -                                  | -                          |
| SIFCON1  | 900            | 900          | -              | 0.3 | 6                                  | 1.6                        |
| SIFCON2  | 900            | 900          | -              | 0.3 | 7.5                                | 1.6                        |
2.2 Test specimens and cast procedures

Firstly, the normal concrete prisms were casted with varying dimensions depending on the thickness and position of the repairing layers of SIFCON and cured for 28 days. The composite section of SIFCON and normal concrete should form a constant cross-section dimension for all cases which is \((100 \times 100)\) mm. Table 2 shows the specifics of normal concrete prisms and the fresh layers of SIFCON.

| SIFCON3 | 900 | 900 | - | 0.3 | 9 | 1.6 |

### Table 2. The dimensions details of normal concrete prisms and SIFCON layer

| Normal concrete prism size (height × widths × length) mm |
|---|---|---|
| **Bottom** | Top + Bottom | Jacketing |
| 85×100×400 | 70×100×400 | 85×70×400 |
| 75×100×400 | 50×100×400 | 75×50×400 |
| 65×100×400 | 30×100×400 | 65×30×400 |

| Fresh SIFCON layer size (height × widths × length) mm |
|---|---|---|
| **Bottom** | Top + Bottom | Jacketing |
| 15×100×400 | 2* | 2* |
| 2* | (15×100×400) | (15×100×400)+(15×70×400) |
| 25×100×400 | 2* | 2* |
| 2* | (25×100×400) | (25×100×400)+(25×50×400) |
| 35×100×400 | 2* | 2* |
| 2* | (35×100×400) | (35×100×400)+(35×30×400) |

2* number of laminates for each prism

2.3 Strengthening of prisms with fresh SIFCON layers

The location of the fresh layer SIFCON for each case (bottom, top and bottom, jacketing) are shown in table 3. The bonding face of normal concrete prisms were roughed by angle grinder and then they were cleaned to remove any dust. The prisms are put in the molds to cast a fresh layer of SIFCON after applying two-parts epoxy adhesive to bond the new concrete (SIFCON layers) with the old concrete (normal concrete prisms), which meets the (ASTM C881, type V) requirements. After casting the SIFCON strengthen layers, the molds are removed. The composite prisms are put in curing tank for 28 days. Figures (1-4) shows the strengthening procedures of normal concrete prisms.

Table 3. Location of fresh SIFCON strengthen layers

| Reference | Bottom | Top + bottom | Jacketing |
|---|---|---|---|
| Normal concrete | SIFCON |
2.4 Test Setup
A two-point simply supported flexural loading system according to BS 1881: part 118 [12] is adopted. The rate of load increasing was 200 N/sec. The deflection of the prism at the midpoint is recorded by the testing machine.

3. Results and Discussion
3.1 Loading and Load Deflection Behavior
The results showed that the repaired prisms had a positive effect on the load-deflection behavior as will be explained later. The figures (5-a) to (7-c) illustrated the results for all cases. For each SIFCON strengthening case (top, top and bottom, and jacket), the flexural load increases with increasing the percent of steel fiber and the thickness of strengthened SIFCON layers. Also, it was noticed that the higher the steel fiber, the lower deflection at the corresponding load level and the higher the first cracking load, which reflects the higher potential of strengthened composite prisms to resist the flexural stresses because of the fiber bridging action. The best results of the ultimate load were achieved in the jacking case at 9% steel fiber which were (87.36, 97.8, and 134.34) kN for (15, 25, and 35) mm thickness, respectively. The small deflection reflects the higher elastic stiffness of SIFCON strengthened prisms compared to reference. The slope of the ascending pats of curve was approximately similar for (top, and top and bottom) case while in the jacketing case the slope was higher which indicates a higher stiffness.
Figure 5. Load-deflection curves for strengthened prisms using of (a) 6% (b) 7.5% (c) 9% SIFCON(BOTTOM)
Figure 6. load-deflection curves for strengthened prisms using (a) 6% (b) 7.5% (c) 9% SIFCON (TOP & BOTTOM)

7 (a)

7 (b)
3.2 Mode of failure

It was observed that the control prisms had a brittle failure and they were totally divided into two segments instantly after cracking. Figures (8), (9) and (10) show the crack pattern for cases (bottom, top & bottom, and jacketing), respectively. After strengthening the prisms with SIFCON layer, the failure mode changed where the first crack did not cause a sudden failure. The prisms in all strengthening cases show a ductile flexural failure. The propagation of cracks arrested by the randomly distributed steel fiber. At the early stages of loading, the formation of cracks does not occur. However, in the jacket strengthening case the high load results in the formation of multiple cracks in the lower face of the prisms and some of these cracks are propagated towards the top of prisms. The biggest crack opening was recorded in the bottom case while the lowest width was in the jacketing case. This behavior leads to increased stiffness and enhanced serviceability.

3.3 Toughness

It is representing the area under the load-deflection curve [13]. For control prisms the toughness was very low since it is known that concrete is a brittle material. Table 4 shows the toughness value for all
strengthened prisms. It was clear that as the volume of steel fiber and SIFCON layer thickness increase, the toughness improves. The highest toughness is achieved in the jacketing case which reached 23 times higher than plain concrete. All the strengthened prisms fall due to steel fiber pull out rather than fiber breaking. The high toughness can be useful in special application involving impact blasts and seismic loading.

![Figure 9](image1.png)

**Figure 9.** crack pattern of Top and bottom SIFCON layers specimens (a) 6% steel fiber (b) 7.5% steel fiber (c) 9% steel fiber

![Figure 10](image2.png)

**Figure 10.** crack pattern of Jacketing with SIFCON layers specimens (a) 6% steel fiber (a) 7.5% steel fiber (c) (a) 9% steel fiber

3.4 Ductility

The ratio of maximum deflection at any load level to the first yield deflection is known as the ductility factor [14]. The ductility of the repaired prisms increased significantly compared with reference. Table 4 shows the results of ductility factor. The maximum improvement is achieved in the case of jacketing which reached about 3.22. The ductility of strengthened prisms increased as the SIFCON occupies more area of the prism cross-section, the reason being the ability of steel fiber to tie the cracks in micro and macro level. In micro level, the steel fiber prevents initiation of cracks, while at macro level; steel fiber act as bridges and provides a source for ductility and toughness [15].

| References | Toughness = 5.68 kN.mm | Ductility= 0 |
|------------|------------------------|--------------|
| Bottom     |                        |              |
| Top & Bottom|                        |              |
| Jacketing  |                        |              |
| Layer thickness (mm) | Toughness kN.mm | Ductility | Toughness kN.mm | Ductility | Toughness kN.mm | Ductility |
|---------------------|-----------------|-----------|-----------------|-----------|-----------------|-----------|
| 6 % steel fiber     |                 |           |                 |           |                 |           |
| 15                  | 18.689          | 1.81      | 13.925          | 1.98      | 30.287          | 2.01      |
| 25                  | 21.063          | 2.01      | 26.393          | 2.12      | 46.701          | 2.21      |
| 35                  | 42.638          | 2.34      | 45.326          | 2.45      | 50.490          | 2.71      |
| 7.5 % steel fiber   |                 |           |                 |           |                 |           |
| 15                  | 23.92           | 2.00      | 24.466          | 2.28      | 27.050          | 2.55      |
| 25                  | 40.161          | 2.05      | 42.004          | 2.45      | 64.575          | 2.84      |
| 35                  | 49.628          | 2.42      | 53.034          | 2.53      | 95.091          | 2.92      |
| 9 % steel fiber     |                 |           |                 |           |                 |           |
| 15                  | 26.86           | 2.51      | 27.019          | 2.52      | 89.257          | 2.71      |
| 25                  | 48.028          | 2.39      | 64.762          | 2.61      | 105.835         | 2.98      |
| 35                  | 73.933          | 2.64      | 87.07           | 2.75      | 130.334         | 3.22      |

4. Conclusion

1. SIFCON can be used as a repair technique to improve the properties of defect normal concrete.
2. Repairing with SIFCON can enhance flexural strength of the prisms, it was increased by (646.67, 735.89, and, 1048.97) % of control prisms for (15, 25, and 35) mm, respectively.
3. The toughness of the repaired prisms in the cases of (bottom, top and bottom) are nearly close, while in the jacketing case the improvement in the toughness is too significant. It was about (9, 17, and 23) times of control prism for 9% steel fiber and (15, 25, 35) mm thickness.
4. The ductility improved for all repaired prisms, the higher value was obtained in jacketing case, which is 3.22 for 9% steel fiber and 35 mm layer thickness.
5. All repaired prisms showed a slow failure, which provides a chance to save lives.

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