Flexural Behaviour of Modified Weight SIFCON Using Combination of Different Types of Fibres

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Abstract. SIFCON is featured construction material has a high strength in addition to large ductility making it convenient for special structural applications. However, the SIFCON unit weight is higher than fibre reinforced concrete due to the heavy weight of the high steel fibre content. This paper aims to investigate the flexural behaviour of Modified Weight Slurry Infiltrated Fibre Concrete (MWSIFCON) by using combination of different types of fibres which are micro steel fibres, macro hooked end steel fibres and polypropylene fibres. For this purpose, 21 prisms and 84 cubes are casted. The volumetric ratios (7%, 4% and 3%) for micro steel fibres, macro hooked end steel fibres and polypropylene fibres respectively are used of each type alone for the purpose of comparison. Moreover, hybrid fibres from combination of two types of these fibres using 50% from ratios above of each type are used to investigate the flexure behaviour of prisms. The other related properties for resulted SIFCON are studied from cube tests. The results indicate that SIFCON of combination macro hook end steel fibres with polypropylene fibres gives a good density for SIFCON with 18.66 KN/m³ and performed adequate flexure strength with 8.09 MPa. Also, it has kindly reduced in the water absorption of SIFCON.

1. Introduction
The concrete named Slurry Infiltrated Fibre Concrete (SIFCON) is a modern special type of high-performance fibre reinforced concrete. SIFCON was first produced in 1979 by Lankard in the USA [1], by forming the steel fibre in the moulds using the large amounts of it to providing very dense network of fibres; it is then infiltrated mortar or cement slurry through the network of fibres without using coarse aggregates in its production.

The fibres percentage by volume can be ranged from 4 to 20% in SIFCON. While, this ratio does not usually exceed 2% in conventional fibre reinforced concrete due to workability and mixing requirements; where the fibres are mixed together with the other ingredients of the concrete: cement, sand and gravel. Because of the high fibre content SIFCON, it offers unique mechanical properties that are superior in ductility and strength [2,3]. SIFCON is relatively new concrete that is used essentially in areas where both high strength and high ductility are required at the same time. For example; plates, shells, pressure vessels, prestressed concrete, underground structures, marine structures, military installations, earthquake resistance structures, airport pavement parking, explosive resistance structures, decks of bridge and other important structures. Also, its used in bridge structures repair, repair of pavements, defense structures and safe vaults because of it has excellent capacities of...
energy absorption [4,5]. But the bad feature of SIFCON is the relatively high density because it contains high ratios of fibres and it is corroded.

Murat et al. [6] have studied the effect of geometry and fibres types, strength of matrix, conditions of water curing and the embedment length on the interface bond of SIFCON. Metin et al. [7] produced a new composite material by using both the reactive powder concrete and the SIFCON together. The flexural strength of composite material was determined using presetting pressure. Sudhikumar et al. [8] investigated the strength properties of the slurry infiltrated fibrous ferrocement with the partial replacement of 1.5% steel fibres by polypropylene fibres in addition to 60% replacement of the natural sand with the manufactured sand. Giridhar et al. [9] investigated the mechanical properties of the SIFCON for many volume fractions for the steel fibres. Two types of steel fibres are used which are of different aspect ratios.

Olutoge et al. [10] studied the comparison between the mechanical properties of the slurry infiltrated fibrous concrete with the discrete bamboo fibres and the short steel fibres. The differences in the properties of the concrete without fibres, concrete with fibres and concrete with the discrete bamboo fibres was examined. The flexural and the compressive strengths of concrete and the slump were also studied. Vijayakumar and Kumar [11] studied properties of SIFCON; cement, sand and fly ash is kept in a constant value. The steel fibres are added in different proportions to reach the optimum value. Elavarasi [12] investigated the behaviour of SIFCON contains different volume fraction of fibres under static loading and developed the regression model from the results reached to estimate the split tensile strength and the compressive strength.

Shashi et al. [13] studied the effect of replacement of the sand partially with the steel slag on SIFCON mechanical properties. It was performed using 2%, 3% and 4% of fibres content by volume in addition to the replacement of the sand by the steel slag with 10% and 20% by weight. Elavarasi [14] investigated the SIFCON flexural behaviour using three different percentages of fibres in addition to used optimum dosage of blast furnace slag replaced by the cement using different percentage of slag to optimize the replacement level.

Parameswaran et al. [15] investigated the flexure behaviour of specimens under cyclic load test that contained high volume percentage of steel fibres in comparison with the conventional fibres content of mortar and ferrocement specimens. Jayashree [16] investigated the flexural behaviour of reinforced concrete composite beams which are included two layers; the bottom layer is SIFCON and the top layer is ordinary reinforced concrete. The short-crimped fibres with small fraction and aspect ratio equal to 50 were used in order to enhance the wear resistance, durability and concrete strength. The effect of different volume of SIFCON used were (20%, 30%, 40% and 50%) of composite beam is studied. Ahmed and Zolfikar [17] presented experimental and numerical studies of slurry infiltrated fibre reinforcement testing twelve specimens with dimensions of height 150 mm, depth 100 mm and 1250 mm length. The longitudinal reinforcements and geometry and stirrups were designed to fail in flexural. The twelve specimens are classified into four as reference and eight specimens casted with steel fibre using percentages of volume fraction different as 8% and 6%. Khaja and Ramavath [18] studied the use of the crimped shaped fibres with different aspect ratio and different volume fraction percentage on compressive and flexural strength of SIFCON.

Shakir et al. [19] examined the hooked ended steel fibres and the mineral admixture replacement the silica fume on the deformation characteristics and the strength of SIFCON specimens. Three percentages of volume fractions of steel fibres were used. The replacement percentage of silica fume was 10% by weight of cement. The toughness characteristic and the flexural strength were tested at seven and twenty-eight days. Olufemi et al. [20] studied the effect of using the miraculous berry fibres as alternative steel reinforcing for economical purposes on flexural behaviour of SIFCON. They were sun-dried, cut in sizes of 400 mm and 80 mm to fit the size of the beam mould into 100 × 100 × 500 mm. The cement slurry was infiltrated into the fibres at the tension zone of the beams to 10, 20 and 30
mm depth and filled up the remainder depth of concrete. Plain concrete control beam without cement slurry and without fibre were cast in order to comparison purposes.

Most of the literature SIFCON researches works interested significantly on the study of the mechanical properties of SIFCON. Also, the studies used one type of fibre in production SIFCON and the used of different types of fibres or combination of them are very limited. Also, an exhaustive literature review shows that there is not much of information available concerning the density of SIFCON; where it has a relatively high density ranging from 21.18 to 30.69 KN/m³ for steel fibres from 5% to 20% volume fraction. [21] This current research aims to investigate the flexural behaviour of modified weight slurry infiltrated fibre concrete by using combination of different types of fibres.

2. Experimental program

2.1. Materials

In this study, ordinary Portland cement named (Kar) is used. The compressive strength of the cement on 7 and 28 days were 20.4 and 27 MPa respectively. The cement specific gravity was 3.15. The Blaine fineness of the cement was 346 m²/Kg. The initial and final setting times of the cement were determined as 180 and 205 min respectively. The chemical analysis was conducted in the Laboratories of Water Resources Engineering College in Al-Qasim Green University is given in table 1.

| No. | Compound of the cement | %   |
|-----|------------------------|-----|
| 1   | Lime Oxide             | 60.92|
| 2   | Silica Dioxide         | 20.25|
| 3   | Alumina Oxide          | 5.30 |
| 4   | Iron Oxide             | 4.60 |
| 5   | Magnesia Oxide         | 2.44 |
| 6   | Free Lime              | 1.33 |
| 7   | Sulfate Trioxide       | 2.11 |
| 8   | Loss on Ignition       | 2.30 |
| 9   | Total                  | 99.25|
| 10  | Insoluble Residue      | 1.0  |
| 11  | Lime Saturation Factor | 0.88 |

Main compounds according to Bogue’s equation %

| No. | Main compounds of the cement | %   |
|-----|-------------------------------|-----|
| 1   | Tricalcium Silicate           | 40.47|
| 2   | Dicalcium Silicate            | 27.50|
| 3   | Tricalcium Aluminate          | 6.26 |
| 4   | Tetracalcium Alumino Ferrite  | 14.00|

It was found that, all the properties of this cement conforming to the Iraqi standard (IQS) No.5/1984 [22]. The sand used in this study is passed through the sieve of 0.60 mm within the zone 4 grading. It has absorption and specific gravity values of 3.28% and 2.55 respectively. The results indicate that the classification is in accordance with the requirements of the limits of Iraqi Standard (IQS) No. 45/1984 [22].
In order to provide the slurry workability in SIFCON, a high range water reducing agent has been used under trade name (Sika Visocrete 5930). The amounts of superplasticizer used in the mixes are 1.76% of the weight of cement. Water potable was used for mixing and curing of SIFCON.

Three types of fibres were used in this study; macro hooked end of steel fibre, micro steel fibre, micro polypropylene fibre as shown in figure 1. The manufacturer properties of macro hooked end steel fibre employed in the SIFCON are presented in table 2. The manufacturer properties of micro steel and polypropylene fibre are presented in table 3 and table 4 respectively.

![Hooked end macro steel fibers](image1.png) ![Micro polypropylene fibers](image2.png) ![Micro steel fibers](image3.png)

**Figure 1. Types of fibres used**

**Table 2. Manufacturer properties of macro hooked end steel fibres**

| No. | Property          | Specifications |
|-----|-------------------|----------------|
| 1   | Length lf         | 35 mm          |
| 2   | Diameter df       | 0.5 mm         |
| 3   | Aspect ratio lf/df| 70             |
| 4   | Tensile strength  | 1300           |
| 5   | Modulus of elasticity | 200 GPa     |
| 6   | Density           | 7500 Kg/m³     |

**Table 3. Manufacturer properties of micro steel fibres**

| No. | Property          | Specifications |
|-----|-------------------|----------------|
| 1   | Length lf         | 13 mm          |
| 2   | Diameter df       | 0.2+ 0.05mm    |
| 3   | Aspect ratio lf/df| 65             |
| 4   | Tensile strength  | 2300           |
| 5   | Modulus of elasticity | 200 GPa     |
| 6   | Density           | 7860 Kg/m³     |

**Table 4 Manufacturer properties of micro polypropylene fibres**

| No. | Property          | Specifications |
|-----|-------------------|----------------|
| 1   | Length lf         | 12 mm          |
| 2   | Diameter df       | 38 µm          |
| 3   | Elongation at break| 12%-14%        |
| 4   | Tensile strength  | 320-400 MPa    |
| 5   | Young modulus     | 3.5 - 3.9 GPa  |
| 6   | Density           | 910 Kg/m³     |
2.2. Mix proportions
A special type of concrete named SIFCON is used in this research. One type of matrix was used for all mixes with cement: sand ratio used is 1:1; the cement content was 886 kg/m³ and the water to cement ratio was 0.31. The superplasticizer is used in the mortar mixtures are 1.76% of the weight of cement in order to get enough workability in mortar.

In current experimental work the maximum possible of fibre volume fraction was used to provide the required performance and to fit the size of the mould used in this experimental work. The ratios of fibres which were slight higher the used limit failed to penetrate the mortar into the fibres network as shown in figure 2.

![Figure 2. Failed samples](image)

Three types of fibres have been used in six SIFCON mixes by using it in single and in combination with each other; micro polypropylene fibres, micro steel fibres and macro hooked end steel fibres in addition to the plain mortar as reference mix. All mix proportions with related symbols are identified in table 5.

| Mix symbol | Micro steel fibres% | Macro hooked end steel fibres % | Micro polypropylene fibres% |
|------------|---------------------|---------------------------------|-----------------------------|
| SM0        | -                   | -                               | -                           |
| SMI        | 7.0%                | -                               | -                           |
| SMA        | -                   | 4.0%                            | -                           |
| SMP        | -                   | -                               | 3.0%                        |
| SMIP       | 3.5%                | -                               | 1.5%                        |
| SMIA       | 3.5%                | 2.0%                            | -                           |
| SMAP       | 3.5%                | -                               | 1.5%                        |

2.3. Mixing, casting, curing of specimens and testing
The internal surfaces of mould, were cleaned and oiled to preclude the adhesion with cement mortar after hardening. While mixing mortar, the dry cement and sand were first mixed together. Then, the superplasticizer was mixed with water and gradually was added to the cement and sand mixture to achieve a homogeneous mixture, so classified as a self-compacting mortar.

The mini flow test and V-funnel test of cement mortar was tested in accordance with EFNARC [23] to ensure the possibility of a link between all the fibres to obtain a homogenous mixture. The workability result for the cement mortar show that the spread diameter in flow test was 26 cm as shown in figure 3.
that is satisfied the required spread diameter for SIFCON mortar (24-26) cm and the flow time in V-funnel test was 8 seconds within the required range of (7-11) seconds [24].

The homogenous mortar was then casted into 50 mm cubes and 40x40x160 mm prisms steel moulds. The casting was done in two layers by filled the mould that contained fibre to half. Furthermore, well vibration was applied to mould by using the vibrated table to ensure that all fibres network are surrounded by mortar from all sides. The Remaining fibre, were put to fill the volume of mould and poured the mortar through it; new vibration must be applied on casted moulds.

The casted samples were kept in the mould for 48 hours: after-that, they were opened and stored in curing water for age of testing; in order to prepare for testing as shown in figure 4. The air dry density, the oven dry density and the absorption at twenty eight days for twenty one cubes are depended on ASTM C642-82 [25]. Also, sixty three of cube compressive strength were tested at 3, 7 and 28 days depended on ASTM C109/C109M-02 [26]. While, twenty one of prisms were tested at 28 days to determining the modulus of rupture (flexural tensile strength) according to ASTM C 348-02 [27]; as shown in figure 5. For each test above the samples are classified into 7 groups, where three samples are used for each SIFCON type.

Figure 3. Mortar flow test

Figure 4. Mixing, casting and curing of specimens
3. Experimental results and discussions

3.1. Air dry density and oven dry density

The results of the air-dry density and the oven dry density tests at 28 days are shown in table 6 for all SIFCON specimens casted by using different types of fibres.

The results indicate that the use of micro polypropylene fibre in SIFCON give the higher percentage in reduction density of SIFCON when use as individual fibres or in combination with the other steel fibres. The air density is reduced by about 9.94%, 3.70% and 9.06% for SMP, SMIP and SMAP respectively and by about 10.44%, 0.47% and 3.64% respectively in oven dry density when compared with control mix SM0.

The use of the micro and macro steel fibre resulted in an increase in air dry density compared to the control mix by about 18.13%, 12.28% and 13.89% for SMI, SMA and SMIA respectively. Whereas the percentage increases in oven dry density was by about 19.27%, 13.66% and 13.82% for the same sequence. These decreases and increases in density can be explained due to the density of the fibres used as listed in tables 2-3-4 which has detailed the properties of fibre used.

Table 6. Air dry density and oven dry density for all SIFCON types

| Mix symbol | Air dry density KN/m³ | % Increase | Oven dry density KN/m³ | % Increase |
|------------|----------------------|------------|------------------------|------------|
| SM0        | 20.52                | -          | 19.25                  | -          |
| SMI        | 24.24                | 18.13      | 22.96                  | 19.27      |
| SMA        | 23.04                | 12.28      | 21.88                  | 13.66      |
| SMP        | 18.48                | - 9.94     | 17.24                  | - 10.44    |
| SMIP       | 19.76                | - 3.70     | 19.16                  | - 0.47     |
| SMIA       | 23.37                | 13.89      | 21.91                  | 13.82      |
| SMAP       | 18.66                | - 9.06     | 18.55                  | - 3.64     |
3.2. Absorption

One of the aims of the research is to examine the water absorption of the different types of SIFCON, which is an important property to evaluate the permeability of SIFCON. The water absorption results of the SIFCON types are shown in figure 6. The figure included also absorption results of the plain mix for comparison purposes. In all SIFCON types it is clear that the inclusion of fibres reduce the ability of absorption.

The water absorption ranged from 9.64 to 16.17 %, according to fibre type while, the absorption of the plain mortar (SM0) was 22.45%. The reason for the reduction of water absorption in SIFCON when used fibres are that the fibres is a non-absorbent material [28]. It can be noted that the SIFCON made with macro hooked steel fibres had higher absorption than the SIFCON made with micro fibres.

![Figure 6. Absorption of SIFCON types](image_url)

The percentage decrease in absorption is 27.93% for SMA and 42.41% for SMI when compared with unreinforced mortar. While, the absorption ratio in SIFCON with polypropylene fibres decrease by about 57.06%, 52.56% and 41.60% for SMP, SMIP and SMAP; respectively, that gave the higher percentage in decreasing of water absorption.

On the other hand, the combination between micro steel fibre with macro hooked steel fibre reduce the ability of water absorption in SIFCON by about 17.94% when compared with SIFCON with macro hooked steel fibre only.

3.3. Compressive strength

The results of the compressive strength at 28 days for SIFCON specimens using different types of fibres are presented in table 7. The results indicate that the compressive strength of SIFCON is more than compressive strength of unreinforced mortar by ranged between 4.49% and 39.89%. This increase in the SIFCON compressive strength can be demonstrated by the fibre ability to restrain the extension of the cracks, change the cracks direction, and delay the cracks growth rate depended upon properties of each fibre type.
The SIFCON compressive strength is higher when micro steel fibres are used; the increase in compressive strength is 39.89%. This is because the possibility of using the micro steel fibre with higher volume fraction value than other types of fibres, which is 7%. The increase in steel fibres lead to reduce the crack numbers, and the crack width by bridging action for the crack in the two sides that led to increasing the strength.

Table 7. Compressive strength for all SIFCON types at 28 days

| Mix symbol | Compressive strength $f_{cu}$ MPa | % increase |
|------------|----------------------------------|------------|
| SM0        | 35.60                            | -          |
| SMI        | 49.80                            | 39.89      |
| SMA        | 46.40                            | 30.34      |
| SMP        | 37.20                            | 4.49       |
| SMIP       | 42.60                            | 19.66      |
| SMIA       | 48.01                            | 34.86      |
| SMAP       | 40.55                            | 13.90      |

The used of hooked macro steel fibre in SIFCON can be increased the compressive strength by about 30.34% which is less than the percentage of increasing when micro steel fibre used. But, if the micro steel fibre used in combination with hooked macro steel fibre slightly improve the compressive strength by about 3.50% when compared with SIFCON with hooked macro steel fibre only.

Polypropylene fibre that used in SIFCON showed less influence in an increasing of compressive strength which is by about 4.49% compared with plain mortar. While, if micro steel fibres and macro hooked end steel fibre used in combination with Polypropylene fibre, give an increase in compressive strength of SIFCON by about 12.68% and 8.26% respectively. The graph in figure 7 showed the development of SIFCON compressive strength with curing age at 3, 7 and 28 days. The results show that the compressive strength increases with the increase of age of curing for all types of mixes.

Figure 7. Development of SIFCON compressive strength with age of curing.
For example, in SMI SIFCON type, the increase in age of curing from 3 to 7 days and from 7 to 28 days leads to increase in compressive strength of SIFCON by about 51.30% and 13.40% respectively. While, in SM0 –control plain mix, the increase in age of curing from 3 to 7 days and from 7 to 28 days makes the compressive strength increasing by about 22.31% and 27.60% respectively. This disparity in the rates of increase between ages in two mixes is due to the presence or absence of steel fibre. However, effect of steel fibre on improving the compressive strength of SIFCON is because of the higher gained bond between fibres and matrix interfaces with increasing curing age. Figure 7 also show the SIFCON mixes that incorporated polypropylene fibres have a lower percentage of increasing in the compressive strength to some extent when compared with SIFCON with steel fibre due to the polypropylene fibres have lower strength.

3.4. Flexural tensile strength (modulus of rupture)

Flexural strength was determined by the results obtained from testing a prism have dimensions (40×40×160) mm and 120 mm clear span under one-point load. Table 8 presents the flexural strength obtained from various types of SIFCON at age of 28 days. For every type of SIFCON, the resulted flexural strength value ranged between 3.11 MPa to 17.61 MPa depends on fibre properties; material manufactured, aspect ratio, geometrical shape, tensile strength and modulus of elasticity.

| Mix symbol | Flexural strength $f_c$ (MPa) | % increase |
|------------|-------------------------------|------------|
| SM0        | 3.11                          | -          |
| SMI        | 6.61                          | 112.54     |
| SMA        | 17.61                         | 466.24     |
| SMP        | 3.73                          | 19.94      |
| SMIP       | 4.46                          | 43.41      |
| SMIA       | 11.22                         | 260.77     |
| SMAP       | 8.09                          | 160.13     |

When comparing the results of SIFCON specimens with control unreinforced mortar, it was concluded that the inclusion of fibre in SIFCON mixes improve its flexural strength. The SIFCON flexural strength is higher when macro hooked end steel fibres are used, it may be 4 times the flexural strength of the plain mortar. The results also show that SIFCON with micro steel fibre have a significant increased flexural strength that is about 112.54%. This positive affect on the flexural behaviour of SIFCON is because of that the micro steel fibre has high surface area which fills in the spaces between mortar components.

The combination micro steel fibre with macro hooked end steel fibre increased flexural strength in SIFCON by about two and a half times the flexural strength of the reference mortar. This obvious increasing in the flexural value of SIFCON when combination these fibres is due to the macro hooked steel fibre. It has length 35 mm that is longer than micro steel fibres by about 3 times; which can extend longer distances inside the mortar. These long fibres bridged the micro and macro cracks by the ability to transfer emerging loads and that increases the maximum applied load and also increase the flexural strength.
As shown in Tab. 8. The use of polypropylene fibres in SIFCON improve the flexural strength of SIFCON by about 19.94% at the age of 28 days compared with reference mix. The reason behind this slight increase compared with other types of fibres used is due to the reality that, the fibres resist the micro cracks formed for a smaller period during the development of cracks and therefore led to a lower flexural strength in addition to lower tensile strength compared with other types of fibre used in SIFCON. However, the benefits of using this type of fibres are shown to reduce the density to a large extent in addition to corrosion resistance. The combination between polypropylene fibres and the micro steel fibre and the macro hooked end steel fibre enhanced the flexural strength obviously by about 43.41% and 160.13% respectively in comparison with control mix. This is due to the fibre material, strength and length effects that enhance the bond between fibres and mortar interface in micro and macro cracks when it will be formed. The flexural strength to compressive strength ratios of all SIFCON types presents in figure 8. The results show that the ratio ranged between 0.09 and 0.38 depended on fibres types used in SIFCON.

![Figure 8. The flexural strength to compressive strength ratio](image)

3.5. Relationship between density and the strength

The relationships between density and other properties are drawn in figures 9 and 10. From figure 9, it's clear that the SIFCON of combination macro hook end steel fibres with polypropylene fibres gives good percentage in reduction of SIFCON density. At the same time, it is performed pretty rising for flexural strength in compression with other combination fibres with 8.09MPa.

![Figure 9. Relationship between flexural strength and air dry density](image)
Also, figure 10 indicates that SIFCON of same combination mentioned in above performed adequate compressive strength by about 40.55 MPa. This combination gives a good density for SIFCON with 18.66 KN/m³ which is less than the lower limit of range SIFCON density produced from using steel fibres (21.18 - 30.69) KN/m³ [20]. This SIFCON can be named as modified weight SIFCON (MWSIFCON) which can be obtained from the combination of polypropylene fibres with steel fibres. This concrete has relatively low density with good flexural and compression strength.

![Figure 10](image_url)

**Figure 10.** Relationship between compressive strength and air dry density

### 4. Conclusions

Conclusions the results obtained from this study have been drawn:

1- As comparing the flexural strength and density of SIFCON, micro polypropylene fibres in combination with macro hooked end steel fibres performed better than other SIFCON types. This is because of the micro polypropylene fibres reduce the density of concrete in addition to the role of macro steel fibres in arresting the growth of macro cracks. This helps to reduce dead load of the structure and benefit to using SIFCON in corrosive environments.

2- The SIFCON of combination micro and macro steel fibres performed better than other combination fibres when their compressive and flexural strength was compared. However, this combination produces heavy type of SIFCON.

3- The micro polypropylene in both individual and in combination using with micro steel fibres was more operative in reducing the SIFCON water absorption compared to other fibre types. This improvement in permeability may be because of the formation denser microstructure and bond strength between the fibres and the mortar matrix.

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