Compressive and Flexural Behaviour of Mortar Infiltrated Fiber Concrete Using Different Types of Fibres

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Abstract. This paper examined the comparison between the mechanical properties of mortar infiltrated fibers concrete with two types of fibers (End hooked steel fiber and Synthetic fiber) with varying fibre volume. The difference in properties of the concrete with steel fiber, concrete without fiber and concrete with Synthetic fiber was determined. Compressive strength and flexural strength (Modulus of rupture) of concrete were determined. The concrete mixing containing [0% control, (2, 4 and 6%)] fibre volume of (End Hooked) and Synthetic fiber were used for compressive and flexural strengths tests. Steel fiber was (30 mm) in length and (0.5mm) diameter, while Synthetic fiber was (60mm) in length and (0.84mm) diameter. the concrete cube used was (100×100mm) for compressive strength test, also beam used for flexural strength test with dimensions (400×100×100mm). The results showed that with increasing volumetric ratio of fiber, the compressive strength and flexural strength increase. The compressive strength and flexural strength of hooked fiber have a much higher extent increasing than that of synthetic fiber.

1. Introduction
Mortar infiltrated fibers concrete is a high-strength, high accomplishment concrete containing high-volumetric ratio of fibre material when compared to usual reinforced concrete. It is also named ‘high-volume fibrous concrete (HVFC)’ [1]. Compared with cement concrete, mortar infiltrated fiber concrete is diverse in mixing, stability of mortar infiltrated fiber concrete and also superior in its energy absorption ability, strength and ductility [2]. These strengths may get distressed; due to the alignment of the fibres [3]. Above the previous twenty years, significant improvements have taken place in the and application and research of mortar infiltrated fiber concrete, that reveals exceptional rheological behaviours that contain workability, self- densifying and self-placing possessions, enhanced in durability act mechanical with significant increase in compressive strength, and behaviour of non- brittleness [4].

Yan et al., (2014) studied the effect of volumetric ratio of fiber and path of loading on the compressive strength of mortar infiltrated fibers concrete, by testing 24 prisms with dimensions (100×100×300mm) and using end hooked fiber with volumetric ratio (6% - 12%) under monotonic load, at age 28 days. The results showed that with increasing of fiber volume fraction, the compressive strength of mortar infiltrated fibers concrete increase. The compressive strength and ductility have a much higher extent increasing than that of steel fiber reinforced concrete (SFRC) [5].

Naser & Abeer, (2020) investigated the (flexural behavior and density) of modified weight mortar infiltrated fiber concrete by chosen combination of different types of fibers and testing 21 prisms with
dimensions (40×40×160mm) at age of 28 days. The volume of fiber used ratios were 7% for micro steel, 4% for hooked end steel and 3% for polypropylene fibers [6].

Three types of fibers have been used in six mortar infiltrated fiber concrete mixtures by using it only and in hybridization with each other, also mortar only as reference mixture. The results indicated that mortar infiltrated fiber concrete had good result in flexural strength (8.09 MPa) (the specimen without fiber recorded 3.01 Mpa) and the combination of hook fibers and polypropylene fibres recorded high density for mortar infiltrated fibers concrete with (18.66 kN/m³), density ranging from (21.18 kN/m³) to (30.69 kN/m³) for hooked fiber [6].

Based on the above quoted literatures, the work has been framed to study the compressive and flexural strengths as the main properties of mortar by using two types of fibres at various volume levels. The results are compared with the full mortar as the controlled specimens.

2. Materials and method

The experimental analysis was approved out in the Babylon University, college of engineering, civil department laboratories. The materials used in casting the specimens were:

2.1 Portland Cement
Portland cement (CEM II / A-L-42.5 R) was used, it was saved in a dry spot, in order to prevent exposure to different atmospheric conditions that mate with the (IQS No. 5/1984) limitations [7].

2.2 Fine Aggregate
Extra fine sand (Natural sand brought from AL - Ukhaider region in Iraq), it has to be small enough to ensure whole infiltration through the dense steel fiber without congestion and which was sieved through (600 μm sieve). It conforms to the limits of Iraq specification No.45/1984 [7].

2.3 High Range Water Reducing Admixture (HRWR)
High range water reducing admixture was needed to advance the (flowability) of the mortar infiltrated fibers concrete which is branded commercially as (Hyperplast PC200) from (DCP) company was used as a HRWR and it is freed from chlorides and complies with (ASTM C494 / C494M, 2017) [8].

2.4 Silica Fume
Micro Silica Fume (SF), It can reveal both pozzolanic and cementitious possessions, size of particle ranges from (0.1 μm) to (1 μm), it improves the cement paste microstructure and increase confrontation of the cement paste more than any kind of exterior effect, which is in the market known as Mega Add MS (D) from chemical company (CONMIX), and the (SF) in this study obeys to the requirement of (C1240-05, 2015) [9].

2.5 Fibers used in the study

2.5.1 Hooked end steel fiber
The first type of fiber was hooked end steel fiber, its length of (30mm) and with diameter of (0.5mm). The hooked fiber was supplied from JATLAS Company in turkey and following ASTM A820/A820M-04 [10]. Plate (1) shows Hooked fiber.
2.5.2 Synthetic fiber
The second type of fiber was (Synthetic) fiber with length of (60 mm) and diameter of (0.84 mm), the synthetic fiber followed (EN 14889-2:2006). This fiber was supplied from Sika company in Zurich, Switzerland. Plate (2) shows Synthetic fiber. Table (1) explains physical and technical properties of fibers used [11].

Table (1): physical and technical properties of fibres used.

| Property          | Hooked fiber                  | Synthetic fiber             |
|-------------------|--------------------------------|-----------------------------|
| Description       | Deformed shape hooked end      | Deformed shape              |
| Appearance        | Bright and clean wire          | White straight fibers with embossing |
| Length (l), mm    | 30                             | 60                          |
| Diameter (d), mm  | 0.5                            | 0.84                        |
| Aspect ratio (l/d)| 60                             | 71.42                       |
| Density (kg/m³)   | 7800                           | 910                         |
| Tensile strength (MPa) | 1100                      | 430                         |

Plate (1): Hooked end steel fiber.

Plate (2): Synthetic fiber.
2.6 Water
Drinking water from the college campus was used for all mixing and specimens curing, free from organic material, salts and turbidity. The temperature of mixing water was maintained at \((25\pm2 \degree C)\).

3. Mix Proportions and Methods

3.1 Mix Proportions
Since there is not any standard specification for mortar infiltrated fibers concrete mix design yet; many trail mortar mixtures were carried out to find a proper mix that has the optimal possessions in the fresh state for fluidity, viscosity and ability of filling without bleeding and pore pockets in the fiber system or segregation, that cause affected drop in the mechanical properties for mortar infiltrated fibers concrete. The literature review findings relieved in the design for mortar infiltrated fiber concrete mixes. It can be seen that the percentage of (sand: cement) by weight in furthermore cases is \((1:1)\), so this ratio was assumed in this study. cement content used range from \((800 \, kg/m^3)\) to \((1000 \, kg/m^3)\) and suggested to use water/cement ratio \((W/C)\) less than 0.4 (by weight) for preparing mortar matrix. Therefor the mix that chosen after these trails was consist of: ordinary Portland cement \((872 \, kg/m^3)\) content, while the water/binder ratio \((w/b)\) equal to 0.32 (by weight). These fiber contents were selected from the experimental work after casting (cubes and prisms) with different percentage \((2, 4\) and \(6\%))

For the mortar infiltrated fibers concrete mixes was produced in a dirt-free pan mixer. The steps of mixing can be listed as follows:

1. The mixer was cleaned off any remaining fresh or hardened materials from the older mixes before mixing operation.
2. The whole amount of Hyperplast was mixed separately with \((1/3)\) of mixing water for nearly \((0.5\) minute).
3. For mortar the binder material (cement and silica fume) was mixed together in mixer for \((1\) minute) to disperse the silica fume particles. The sand then was added and for \((2\) minute) the mixture was mixed to achieve a uniform dry mixture.
4. \((2/3)\) of mixing water has been added to the mixture, and also mixed for \((2\) minute).
5. Feeding the mixture with Hyperplast that mixed with the \(1/3\) of mixing water and mixed for \((2\) minute).
6. Eventually, to get the necessary fluidity, mortar ingredients are mixed for an additional \((0.5\) minute).

3.2 Casting of the specimens
The casting of the mixes of mortar infiltrated fiber concrete was done in three layers, each layer consists of approximately \((1/3)\) quantity of fibers fiber for the specimen and putting the mortar until infiltrated the fiber in this layer. The remained two layers were casted as same as the first layer. Then the specimen’s top surfaces were trowelled level for getting smooth surface.

3.3 Curing of the specimens
The specimens were all saved under sheets of nylon for \((24\) hours), then the specimens were demolded and period of curing beginning till they were tested. The specimens were kept in a tap water tanks.

3.4 Identification of the specimens
To recognized the types of specimens, Table (2) explains the identification of the specimens
Table (2): Identification of the specimens

| Description of the specimens                                      | Symbol of the specimen |
|------------------------------------------------------------------|------------------------|
| mortar without fibers (control)                                  | M                      |
| mortar contained 2% volumetric ratio of Hooked fiber             | H2                     |
| mortar contained 4% volumetric ratio of Hooked fiber             | H4                     |
| mortar contained 6% volumetric ratio of Hooked fiber             | H6                     |
| mortar contained 2% volumetric ratio of Synthetic fiber          | Y2                     |
| mortar contained 4% volumetric ratio of Synthetic fiber          | Y4                     |
| Mortar contained 6% volumetric ratio of Synthetic fiber          | Y6                     |

4. TEST METHODS

4.1 Compressive strength
This test was agreed accordance to (BS1881-116), by using (100×100mm) cubes loaded uniaxially by the universal compressive machine, the loading rate was applied at (0.3 N/mm² per second) as said by (BS.1881: part 116). The three specimens average was recorded for evry variable in this test [12].

4.2 Flexural strength (Modulus of Rupture)
Flexural strength was agreed accordance with ASTM C1609-12(61), The specimens were tested under two-point loads with a constant loading rate about 0.015 Mpa/sec. The three specimens average was recorded for every variable in this test [13].

5. Results and Discussions of Tests

5.1 Results of compressive strength test
Compressive strength results for specimens were summarized in Table (3), and plotted in Figure (1). Plate (3) shows sample of specimens after compression strength test.

Table (3): Summary of results of compressive strength test.

| Symbol of specimens | Compressive strength (MPa) @ three ages |
|---------------------|----------------------------------------|
|                     | 7days | 28 days | 56 days |
| M                   | 41.6  | 50.2    | 61.39   |
| H2                  | 54.7  | 62.19   | 75.47   |
| H4                  | 62.22 | 85.76   | 87.77   |
| H6                  | 66.85 | 89.81   | 93.9    |
| Y2                  | 42    | 52.3    | 65.8    |
| Y4                  | 45.92 | 57.4    | 67.8    |
| Y6                  | 47.5  | 61.2    | 69.6    |
Figure (1): Compressive strength test results.

Plate (3): (H4) specimen after compression strength test.
5.1.1 Effect of fiber volume on results of compressive strength test

From Table (3) and Figure (1), one can see that when comparing (H2, H4 and H6) specimens with M specimen (control), compressive strength increased in ratio ranging from (24% - 79%) in age 28 days (as example). The reason of increasing in compressive strength values was related to the higher bond initiated between fibers and matrix interfaces by fiber volume fraction increasing [14]. While for results of specimens (Y2, Y4 and Y6) when comparing with M specimen, one can concluded that the compressive strength increased in range from (4% - 22%) at age 28 days; due to the increasing in the mechanical bond strength as the fibers allow the capability to delay formation of the micro-cracks and arrest propagation of the micro cracks afterwards up to a convinced extent [15].

5.1.2 Effect of specimen age on results of compressive strength test

From studying the results in Table (3) and Figure (1), it can be observed that increasing in strength with increasing the age of specimens. The results of (56 days) had the highest values in compressive strength test for all mixes.

5.1.3 Effect of fiber type on results of compressive strength test

When comparing the results of compression test between hooked fiber and synthetic fiber one can see that the results of specimens of hooked fiber were higher than the results of specimens of synthetic fiber. The reason of the difference in compressive strength results returns to the hooked fiber has higher values than synthetic fiber in tensile strength and density, that led to get higher results in tests.

5.2 Results of flexural strength test

The results of flexural strength for specimens were summarized in Table (3), and plotted in Figure (2). The Plate (4) shows sample of specimens after flexural strength test.

**Table (4):** Results of flexural strength test

| Symbol of specimens | Flexural strength (MPa) @ three ages |
|---------------------|-------------------------------------|
|                     | 7days  | 28 days | 56 days |
| M                   | 12.4   | 14.03   | 17.5    |
| H2                  | 12.9   | 14.65   | 18.2    |
| H4                  | 23.77  | 25.83   | 28      |
| H6                  | 38.44  | 40.13   | 43.6    |
| Y2                  | 13.01  | 14.37   | 16.97   |
| Y4                  | 17.9   | 22.14   | 23.88   |
| Y6                  | 18.24  | 22.87   | 24.91   |
5.2.1 Effect of fiber volume on results of flexural strength test
When studying the results in Table 4 and Figure 2, one can conclude that when increasing volumetric ratio of fiber, the results of flexural strength increased too. For hooked fiber when increasing volumetric ratio from 2% to (4 and 6%), the results of strength increased in range (4% - 186%) at age 28 days comparing with control specimen (M), while for synthetic fiber the increase was in range (2% - 66%) comparing with M specimen at 28 days.

5.2.2 Effect of specimen age on results of flexural strength test
From studying Table (4) and Figure (2), one can see that the results of flexural strength increased with age specimen increase. The specimens of 56 days were recorded the highest results.

5.2.3 Effect of fiber type on results of flexural strength test
When studying the results of flexural strength test one can see that the hooked fiber mixes have better results than mixes contained synthetic fiber.

6. Conclusions
Conclusions drained based on the tests results of this study:
- The tests of compressive strength specimens of mortar infiltrated fibers concrete (of two types of
fiber with different fiber volume at three ages of test), indicated increasing in the strength value comparing to the control specimens, this increasing of the strength because of the fibers capability to delay the micro cracks development that known with its unstability, and (limiting the spread of that cracks and its influence on concrete).

- The range of increasing of the compressive strength of Hooked fiber is higher when comparing to the Synthetic fiber due the properties of steel fiber higher than the Synthetic fiber.
- The tests of flexural strength concluded clear difference in behavior of steel with and the Synthetic fiber as explained:
  - The value of strength recorded increasing with Hooked and Synthetic fibers specimens when comparing with the control specimens, and the highest strength value at 6% fiber volume.
  - The optimum fiber volume of Hooked and Synthetic fiber with 6% as it ensures accepted infiltration of the mortar through the fibers [the infiltration of mortar and good interpenetration].
  - Hooked and Synthetic fibers could be used in different applications as the strength needed, the existence of the type of fiber in the area of structure and the type of the structure element need to strengthened or repair.

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