Evaluating the Performance of Fibrous Cement Mortar Containing Chopped Carbon Fiber (C.C.F.)

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Abstract. This work presents an investigative study of the influence of adding chopped carbon fiber (C.C.F.) on the performance of two specified properties of cement mortar, namely: The flexural strength and density, for two (W/C) ratios (0.4 & 0.6). Four cement mortar mixtures were casted for this purpose, these mixtures were divided into two groups according to their (W/C) ratios (0.4 & 0.6), and each group was subdivided into two subgroups according to whether C.C.F. is used or not. It was found that, when C.C.F. is added, the flexural strength and density of the cement mortar mass are increased for both (W/C) ratios, and the percentages of these increases are slightly increased with the increase in (W/C) ratios. It was also found that, when (W/C) ratio is enlarged from (0.4) to (0.6), the flexural strength and density are reduced with and without the existence of C.C.F., and the percentage of this reduction is slightly decreased in the existence of C.C.F.

Keywords: Chopped Carbon Fiber (C.C.F.), Flexural Strength, Modulus of Rupture (M.O.R.), Density, Volume fraction of C.C.F. (Vf).

1. Introduction

One of most widely used constructional materials in the world are cementitious materials made with Portland cement. It’s a compound material which contains cement (as binder), water, and inert materials like fine aggregates (sand) and / or coarse aggregates (gravel or crushed stone). It is an available, dependable, moldable material that stiffens and hardens when mixed with water because of a chemical reaction recognized as hydration, then, the interaction of water with cement bond the other ingredients altogether [1]. Cement based material has immanently some shortcomings in the practical life, like brittleness, poor deformability, weak cracking resistance and its flexural and tensile strengths are comparatively low in comparison with its compressive strength. Several experiments have been carried out to turn cement-based materials into a structural system with desired mechanical and physical characteristics [2]. The shortcoming in tension could be compensated by incorporating fiber material inside cement mortar to enlarge its solidity, or capability to withstand cracks evolution. Fibers serve to transmit loads at the interior micro-cracks [3,4]. Fiber-reinforced cementitious materials are a family of compound materials that join the good compressive strength property of cementitious
material with considerably enlarged tensile, flexural and impact strengths induced by fiber reinforcing [5]. Among the various types of fibers used in cementitious compounds, carbon fiber presents distinguished features. The non-corrodible features of carbon fiber, adequate fatigue strength, low repose losses and high (strength-to-weight) ratio are enough characteristics that stimulate any structural engineer to use carbon fiber cementitious compounds in numerous structures and structural elements that are exposed to extreme temperatures and mechanical abrasion [6]. Several investigators have investigated the use of other materials such as steel fibers for strengthening concrete or asphaltic concrete [7-12], or chopped carbon fiber, silica fume, tree glue powder and polyvinyl acetate for strengthening gypsum composites [13-18], or bacteria, glass fibers and nylon fibers for strengthening cement mortar [19,20].

2. Research Objective
This study aims to demonstrate the effect of adding chopped carbon fiber on some of cement mortar properties, namely; the flexural strength and the density.

3. Experimental Work

3.1. Materials

3.1.1. Cement
Ordinary Portland cement Type (I) manufactured in Iraq is used in this research.

3.1.2. Fine Aggregate
In the current work, “AL-Ukhaidher” natural sand is used, it has been chosen to conform with Iraqi specification No.45/1984[21]. In all mixes, sand was dried by exposing in air before being used.

3.1.3. Water
Ordinary tap water is used for all cement mortar mixes.

3.1.4. Chopped Carbon Fiber.
The carbon fibers that was used in this study are chopped by the manufacturer at (8mm) length as illustrated in figure (1), and table (1) displays the characteristics of this carbon fibers [22].

| Property                  | Values       |
|---------------------------|--------------|
| Fiber Length              | 8 mm         |
| Density                   | 1.79 g/cm³   |
| Elongation Percentage     | 1.5          |
| Tensile Strength          | (3.45 – 3.9) Gpa |
| Fiber Diameter            | 166 μm       |
| Tensile Elastic Modulus   | 230 GPa      |
3.2. Cement mortar Mixes

In this study, four cement mortar mixes were casted, the first and the third ones are free of C.C.F. and having (W/C) ratios (0.4) & (0.6) respectively, while the second and the fourth ones contain C.C.F. content of (0.4 %) and having (W/C) ratios (0.4) & (0.6) respectively, as illustrated in the flow chart of figure (2) and figure (3).

Figure 1. Shape of carbon fibers

Figure 2. Plan of Experimental work plan
### 3.3. Mixing procedure

- Sand is well blended with cement in the mixing pan.
- For mixtures containing carbon fibers, sand is manually blended with chopped carbon fibers very well to avoid clumping of fibers until a good dispersal of fibers is achieved, finally cement was added to the mixture.
- Water is added to the dry mixture, and all components are re-blended.
- The well blended mixture is poured into the mould.

### 3.4. Testing program

The experimental work of this research was performed in the lab of construction materials existed in the Faculty of Engineering at Mustensiriyyah University. The above-mentioned lab is a concerted lab that contain several testing machines, and the experimental works of numerous investigators like [23-25] was implemented in this laboratory.

*Figure 3. Groups of the samples*
3.4.1. Flexural Strength Test.
In order to assess the flexural strength of the prismatic (4×4×16) cm samples of the current work (at age of approximately one month), the modulus of rupture (M.O.R.) is used by ASTM C-248 standard (3-point bending test) [26] as an index to the flexural strength of the cement mortar samples using the following equation:-

\[ \text{Modulus of rupture (M.O.R.)} = \frac{3PL}{2bh^2} \]

where \( L, b, h \) are 10cm, 4cm, 4cm, respectively.

![Figure 4. illustrates the testing instrument inside the testing machine of the flexural strength test.](image)

3.4.2. Density
The density of all cement mortar samples were calculated according to the following equation:

\[ \text{Density ( Kg/m}^3 ) = \frac{\text{Weight of sample (g)}}{\text{Volume of sample (cm}^3)} \times 10^3 \]

4. Outcomes & Discussion

4.1. Influence of Chopped Carbon Fiber (C.C.F.) on Flexural Strength of cement mortar with several (W/C) ratios.
Figure (5) and table (2) demonstrate the influence of adding C.C.F. on the flexural strength of cement mortar for the two (W/C) ratios (0.4 & 0.6). One can easily notice that the modulus of rupture (MOR) is increased in the presence of C.C.F., and this behaviour is identical for both (W/C) ratios (0.4 & 0.6). The reason for this behaviour might be because C.C.F. serve to close and resist the growth of the cracks in the cement mortar mass by bridging them, in addition to preventing or at least hindering the initiation of potential ones.

The above mentioned figure (5) and table (2) also illustrate that, when C.C.F. is added, the percentage of increasing in M.O.R. is magnified with the increasing of (W/C) ratio (from 0.4 to 0.6), this behavior may be attributed to the fact that when (W/C) is increased, the cement mortar mass becomes weaker, and hence, the effect of C.C.F. in strengthening the weaker mass is more effective than strengthening stronger mass.
Table 2. Influence of C.C.F. contents (Vf) on Flexural Strength with various (W/C) ratios.

| Mix No. | (W/C) ratio | C.C.F. contents (Vf) | Modulus of Rupture (MPa) | Percentages of Increasing (%) |
|---------|-------------|-----------------------|---------------------------|-----------------------------|
| Mix 1   | 0.4         | 0.0                   | 12.7                      | -----                       |
| Mix 2   | 0.4         | 0.4                   | 15.4                      | 21.3                        |
| Mix 3   | 0.6         | 0.0                   | 10.9                      | -----                       |
| Mix 4   | 0.6         | 0.4                   | 13.3                      | 22.3                        |

4.2. Influence of (W/C) Ratios on Flexural Strength of cement mortar with and without (C.C.F.).

Figure (6) and table (3) display the influence of increasing (W/C) ratios from (0.4) to (0.6) on the flexural strength of cement mortar with and without C.C.F.. They show that M.O.R. is decreased when (W/C) ratio is enlarged, and this behaviour is identical with and without the presence of C.C.F.. This behaviour can be explained by the fact that when the (W/C) increases, the increase in the amount of water causes the cement mortar particles to diverge from each other, which weakens the interconnection between them which leads to the deterioration of all strengths (compressive, shear and flexural) of the cement mortar mass.

Figure (6) and table (3) also reveal that the percentage of reduction in the flexural strength is decreased in the presence of C.C.F. may be because C.C.F. serve to strengthening the interconnection between the cement mortar particles and thus contribute in reducing the rate of deterioration in the flexural strength of the cement mortar mass.

Table 3. Influence of (W/C) ratios on flexural strength with and without C.C.F.

| Mix No. | C.C.F. Contents (Vf) (%) | (W/C) ratio | Modulus of Rupture (MPa) | Percentages of decreasing (%) |
|---------|--------------------------|-------------|--------------------------|-------------------------------|
| Mix 1   | 0.0                      | 0.4         | 12.7                     | -----                         |
| Mix 3   | 0.0                      | 0.6         | 10.9                     | 14.2                          |
Influence of Chopped Carbon Fiber (C.C.F.) on density of cement mortar with several (W/C) ratios.

Figure (7) and table (4) show investigational studies of the influence of adding C.C.F. on the density of cement mortar mass for the two (W/C) ratios (0.4 & 0.6). It can be noticed that the density is increased in the presence of C.C.F., and this behavior is identical for both (W/C) ratios (0.4 & 0.6). The reason may be due to the fact that the C.C.F. filaments of very small diameter (166 μm) slightly increase the surface area of the ingredients that absorb water, and hence slightly reduce the actual (W/C) ratio of the mass, and consequently increases the convergence of the particles and then the density of the mass increases. It could also be seen from the above-mentioned figure (7) and table (4), that the percentage of increase in the density when C.C.F. is added is magnified with the increasing of (W/C) ratio (from 0.4 to 0.6). The interpretation behind this behavior may be explained as follows: - When (W/C) increases, the amount of water that will be absorbed by C.C.F. filaments will increase, causing a more reduction in the actual (W/C) ratio, and consequently causing a more convergence of the particles, and hence leading to an increase in the density.

Table 4. Influence of C.C.F. contents (Vf) on density with various (W/C) ratios.

| Mix No. | (W/C) ratio | C.C.F. contents (Vf) (%) | Density (Kg/m³) | Percentages of Increasing (%) |
|---------|-------------|--------------------------|-----------------|-------------------------------|
| Mix 1   | 0.4         | 0.0                      | 2107            | ------                        |
| Mix 2   | 0.4         | 0.4                      | 2164            | 2.7                            |
| Mix 3   | 0.6         | 0.0                      | 2021            | ------                        |
| Mix 4   | 0.6         | 0.4                      | 2120            | 4.7                            |
4.4. Influence of (W/C) Ratios on density of cement mortar with and without (C.C.F.).

Figure (8) and table (5) present the influence of enlarging (W/C) ratio from (0.4) to (0.6) on the density of cement mortar with and without the presence of C.C.F. They show that the density is decreased when (W/C) ratio is enlarged, and this behaviour is identical with and without the presence of C.C.F. The reason behind this behavior is that when (W/C) increases (i.e. the water increases), it will lead to an increase in the distance between the granules, which will be filled with water, which will turn into voids after its evaporation (i.e. after the hardening of cement mortar mass) and the porosity of the mass increases and thus its density decreases.

Figure (8) and table (5) also illustrate that the percentage of decreasing in the density of the cement mortar mass is reduced in the presence of C.C.F. This behavior may be imputed to the increase in the amount of water that will be absorbed by C.C.F. filaments when (W/C) ratio is increased, leading to a less reduction in the actual (W/C) ratio, and less convergence of the particles, and hence less reduction in the density.

**Table 5. Influence of (W/C) ratios on density with and without C.C.F.**

| Mix No. | C.C.F. contents (Vf) (%) | (W/C) ratio | Density (Kg/m³) | Percentages of decreasing (%) |
|---------|------------------------|-------------|-----------------|-----------------------------|
| Mix 1   | 0.0                    | 0.4         | 2107            | ------                      |
| Mix 3   |                        | 0.6         | 2021            | 4.1                         |
| Mix 2   | 0.4                    | 0.4         | 2164            | ------                      |
| Mix 4   |                        | 0.6         | 2120            | 2.1                         |
5. Conclusions

- When C.C.F. is added, the flexural strength of the cement mortar mass is noticeably increased for both (W/C) ratios, and the percentage of this increase is slightly higher at (W/C = 0.6) than at (W/C = 0.4).
- When (W/C) ratio is enlarged from (0.4) to (0.6), the flexural strength is reduced with and without the presence of C.C.F., and the percentage of this reduction is slightly decreased in the existence of C.C.F.
- When C.C.F. is added, the density of the cement mortar mass is slightly increased for both (W/C) ratios, and the percentage of this increase is slightly magnified with the increase in (W/C) ratios.
- When (W/C) ratio is enlarged from (0.4) to (0.6), the density of the cement mortar mass is slightly reduced with and without the existence of C.C.F., and the percentage of this reduction is slightly decreased in the existence of C.C.F.

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