

Ahmed M. Al-Ghaban

Materials Engineering
Department, University of
Technology, Baghdad, Iraq

Hussein A. Jaber

Materials Engineering
Department, University of
Technology, Baghdad, Iraq
Husseinaj@yahoo.com

Aya A. Shaher

Materials Engineering
Department, University of
Technology, Baghdad, Iraq

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A Comparative Investigation on Mechanical Properties of Various Fibers Reinforced Concrete

Abstract- The present work presents an investigation the effect of adding various fiber materials such as (glass, nylon, and carbon) into the concrete mix for inspecting and compare the mechanical properties of different fibers reinforced concrete. Two different fiber length states of (short=3cm and long=10cm) are used in this work. The concrete of ordinary Portland cement of (1:1.5:3), (cement: sand: gravel), were mixed with each of the fiber materials at four different weight percentages (0, 0.4, 0.8, and 1.2) wt% per cement content. Compressive strength and flexural strength were experimentally investigated of different fibers reinforced concrete specimens after curing for 28 days. The results showed that the incorporation of various fibers with the concrete mix generally improved the strength of concrete by improving the toughness. The flexural strength of concrete with addition of various fibers was strongly enhanced than compression. Addition 0.8% of nylon fiber to concrete resulted in the maximum increase of its compressive strength, reaching the rate of increasing to 11.08% for short fiber and 20.75% for long fiber. Addition 1.2% of nylon fiber to concrete mix resulted in the maximum increase of the flexural strength, reaching rate of increasing to 120.02% for short fiber and 211.49% for long fiber. Increasing the length of fibers increases the strength of the concrete but a little extent. Among these fibers, nylon containing concrete composite exhibits promising mechanical strength that could be easily used as low-cost partitioning wall, false ceiling, and other household purposes.

Keywords- Concrete, compressive strength, flexural strength, glass, nylon and carbon fibers.

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1. Introduction

Cementitious materials in the form of mortars or concrete are attractive for use as construction materials. It is a heterogeneous mix containing hydraulic cement as the binder with fine aggregates and/or coarse aggregates as inert material. It is an affordable, reliable, mouldable, solidifies and hardens when mixing with water and placement due to a chemical process is known as hydration, then the water reacts with the cement which bonds the other components together [1]. Result to their low cost, durability, heavy compressive strength and stiffness. This material is utilizing from a long time ago as building materials. Although their massive use, some drawbacks (brittleness, poor tensile strength, and moisture movements) were observed from a few decades. As a result, scientist and engineers are constantly working to find a solution and to enhance the performance of cement-based materials. There are some alternatives that can be applied on the concrete or mortars to solve the problems but an addition of fibers is a very popular

because of low cost and improves the mechanical properties of cement-based materials [2-4].

The use of fiber reinforcements in cement-based materials is increasing due to the ability to tailor cement and concrete characteristics to specific applications and environments. Addition of fibers in the cement-based products led to improves the ductility, fracture toughness and durability [5].

Fiber reinforced concrete (FRC) is a concrete composite in which discontinuous fibers are dispersed uniformly. The fibers used in FRC may be of various materials like steel, carbon, glass, aramid, asbestos, polypropylene, etc. FRC has found many applications in the civil engineering field. FRC is considered a family of composite materials that combine the high compressive strength properties of cement-based materials with significantly increased flexural, impact and tensile strengths imparted by fiber reinforcement that help to transfer loads at the internal micro-cracks [6-8]. Many factors influence the properties of composite materials reinforced by fibers; include the geometry, properties of the different phases (matrix and fibers), distribution and orientation of

fibers within the matrix, the contact between the fibers and matrix, the shape and size of fibers, mix design, mixing and processing methods, etc. [9]. It has been recognized that incorporated of fibers in cement-based materials can raise the toughness of cementitious matrices and serves to arrest the cracks significantly. Performance improvement can be attributed to the point where fibers resist cracking generation [10]. In addition, using of fibers recalibrates the behavior of the fiber-matrix composite by makes it more homogeneous and isotropic and modifies it from a brittle to a more ductile. When cement-based materials are cracked, the randomly oriented fibers arrest the micro-cracks and limit the crack progression, thus improving the strength and ductility [11, 12].

Many experiments by several researchers have been carried out of using different types of fibers in the cement-matrix composites. For example, Amit Rai and Joshi [7], studied the effect of steel fiber, glass fiber, natural fiber, and polymer fiber as additives to concrete then monitor the properties of fibers reinforcement concrete. From the results discovered that fiber addition improves the ductility of concrete and its post-cracking load-carrying capacity and most important contribution of these fibers reinforcement in concrete is not to strength but to flexural toughness of composites. Prashant Muley et al., [11], studied the effect of using short carbon fibers at different volume fraction (0, 0.25, 0.5, 0.75 and 1) % in structural concrete for enhancing the concrete performance. The resulting exhibit that the workability of concrete significantly decreased as the fibers increases. Split tensile, flexural and compressive strength tests showed that using 1 % of the fiber in concrete increase the strength and help in early strength gain. Thomas and Raguraman, [12], studied the behavior of the glass fiber reinforced concrete. The different glass fiber combinations used in concrete mixes ranged of (0 to 2)% were conducted. It was found that the addition of glass fiber leads to an increase in compressive strength, split tensile and flexural strength with reduction in the workability of concrete. The main role of percent work is to investigate the effect of adding various types of fiber materials such as (glass, nylon, and carbon) in the concrete mix to produce high-quality concrete. Additionally, the effects of the length of the fibers on some of the mechanical properties of fiber reinforced concrete composites were also discussed.

2. Experimental Work

1. Materials

Ordinary Portland cement was used in this work as the main components of binder for preparing of

cement mortar samples. This cement was provided by AL-Mass Bazian factory, and it is confirmed according to the Iraqi specification No.5/1984. AL-Ukhaider natural sand was used as fine aggregate. This fine aggregate was sieved to obtain of <1.12 mm particle size. Different fiber materials of (glass, nylon, and carbon) were used as an additive material in the cement mortar mixtures. The glass fibers used in this work have a density of 2.58 g/cm³ and it is provided from Mowoling LTD.UK Company as a woven form. The nylon fibers used in this work have a density of 1.27 g/cm³ and it is provided from China as yarn roll form. Carbon fibers with density of 1.79 g/cm³ are used in this work and it provided from Sika Wrap®-300 C/60. These fibers have been chopped at two length states: (short = 3 cm and long = 10 cm), and then dispersed it by hand in order to easily mix with concrete mixtures. Figure 1 shows the different fiber materials of (glass, carbon, and nylon) at two fibers length state.

II. Mix Proportion

The concrete mix was prepared with a ratio of (1:1.5:3), cement to sand to gravel. The fibers were added to the concrete mixture at different weight percentages of (0, 0.4, 0.8 and 0.12) wt% per weight of cement. The mixture of concrete with fibers was mixed y hand in a dry condition firstly, and then ordinary tap water was added to produce a uniform concrete mixture with fibers. The water to cement ratio was equal to 0.5 for all of concrete mixtures. Details of mix proportions of the concrete are given in Table 1.

III. Casting and Curing

The concrete specimens were cast using cubes of (100 mm) and prisms of (100*100*400) mm, from steel molds. The molded specimens were stored in laboratory conditions and covered with wet burlap for the first 24 hours to prevent moisture loss. After removing the molds, the specimens were cured by submerged in a tap water tank at a temperature of ~ (25-30)°C for 28 days. The shapes of some casted specimens are illustrated in Figure 2.

IV. Specimens Tests

The mechanical properties of the concrete specimens were measured. The compressive strength of cubic concrete specimens was calculated according to the ASTM C-39. Flexural strength of the prism concrete specimens was performed using three-point bending method according to the ASTM C-78.

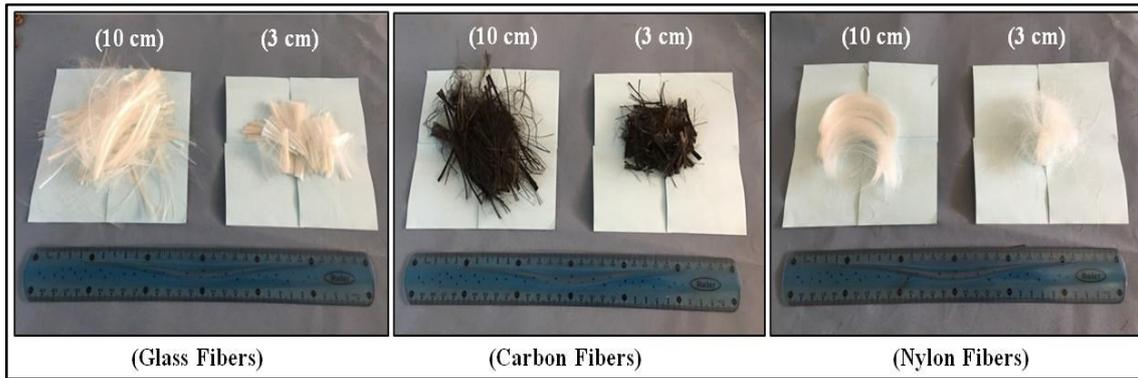


Figure 1: The different fibers used (glass, carbon and nylon) at two fibers length state.



Figure 2: The casted concrete specimens that reinforced by different fibers.

Table 1: Mix proportions of concrete specimens.

Mix	Fiber Materials* (wt %)	Fibers Length (cm)	Fibers (g)	Gravel (g)	Sand (g)	Cement (g)	Water (ml)
C0	-	-	-	1,140	570	380	190
C1	0.4 % G*	3	1.52	1,140	570	378.48	190
C2	0.8 % G	3	3.04	1,140	570	376.96	190
C3	1.2 % G	3	4.56	1,140	570	375.44	190
C4	0.4 % G	10	1.52	1,140	570	378.48	190
C5	0.8 % G	10	3.04	1,140	570	376.96	190
C6	1.2 % G	10	4.56	1,140	570	375.44	190
C7	0.4 % N*	3	1.52	1,140	570	378.48	190
C8	0.8 % N	3	3.04	1,140	570	376.96	190
C9	1.2 % N	3	4.56	1,140	570	375.44	190
C10	0.4 % N	10	1.52	1,140	570	378.48	190
C11	0.8 % N	10	3.04	1,140	570	376.96	190
C12	1.2 % N	10	4.56	1,140	570	375.44	190
C13	0.4 % C*	3	1.52	1,140	570	378.48	190
C14	0.8 % C	3	3.04	1,140	570	376.96	190
C15	1.2 % C	3	4.56	1,140	570	375.44	190
C16	0.4 % C	10	1.52	1,140	570	378.48	190
C17	0.8 % C	10	3.04	1,140	570	376.96	190
C18	1.2 % C	10	4.56	1,140	570	375.44	190

*: G = glass fibers, N = nylon fibers and C = carbon fibers.

3. Results and Discussion

3.1. Compressive Strength

Compressive strength is the ability of a material or structure to withstand axially directed applied

forces. The materials are crushed when the limit of compressive strength is reached. Compressive strength test of concrete is one of the most important properties for building because it refers

to the strength of the pillar to resist from fracture [8]. Compressive strength test was performed on the prepared concrete specimens in order to determine the effect of the different fibers types (glass, carbon, and nylon) at two fibers length states, short (3 cm) and long (10 cm). Figures 3 and 4 show the compressive strength values of concrete specimens which reinforced by different fibers types for both of two fiber states (short and long), respectively, including the reference specimens. These Figures exhibited that the compressive strength values of concrete specimens are slightly increased up to 0.8 % weight percentage of the fibers. This improvement on the compressive strength of concrete could be attributed to that the addition of these fibers lead to increase the concrete toughness and make the composite concrete flows under stress without fracture through arresting the cracks for both of micro- and macro-levels [13,14]. With increasing fibers content more than 0.8%, the compressive strength of concrete decreases. This may be related to difficult packing and disturbance inhomogeneity of concrete mixture in presence of these fibers, especially at higher fibers percentages. Thereby, the viscosity of the concrete mixture increases during mixing of the fibers which causing difficulty in matrix fluidity and decreased the ability of fibers to penetration within concrete mix [15-17]. Thus reduces the fibers wetting prior to hardening of the concrete matrix causing a decrease in the adhesion (weaker interface) between the matrix and fibers. Besides, the reduction in compressive strength is also concerned with the increase the voids in the samples due to the air entrainment and consequently a poor adhesion between the fibers with concrete matrix [9, 15, 18, 19].

From these Figures also can be observed that the nylon fibers reinforced concrete offers higher values in the compressive strength compared with the other fibers types. This may be due to the good mechanical bonding of the nylon fibers with a concrete mixture which increases the plasticity of concrete and flow the concrete specimens under stress without sudden breaking. The compressive strength of the glass fibers reinforced concrete specimens is less than nylon fibers reinforced concrete; this is related to that glass fiber is more rigid than polymeric fiber, as a result when stress is applied concrete cannot resist the cracking, as polymeric fiber does. In addition, the glass fibers could not be distributed properly within the concrete [20].

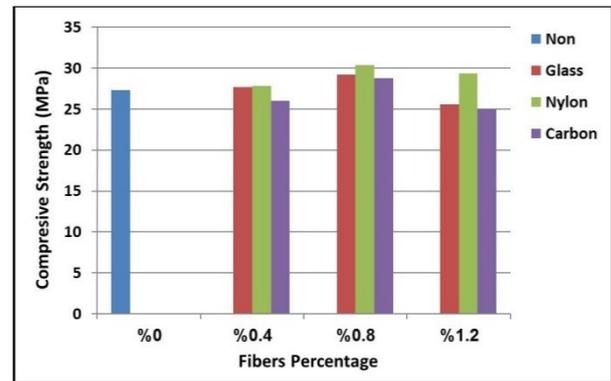


Figure 3: Effect of adding different short fibers on the compressive strength of concrete samples.

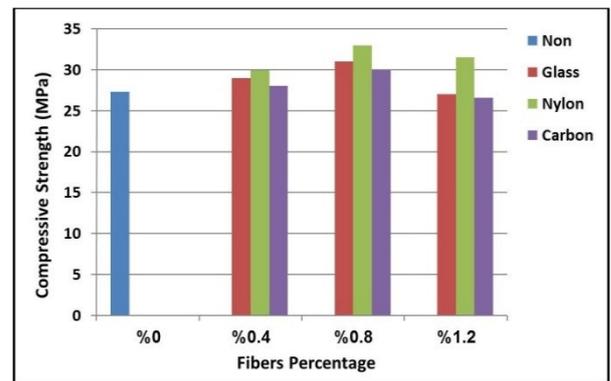


Figure 4: Effect of adding different long fibers on the compressive strength of concrete samples.

It has been seen from the fractured concrete specimens, that the concrete mixtures without fibers appeared a sudden brittle failure. However, the concrete mixtures with the presence of the fibers showed a ductile failure. That is because of the energy absorbing capacity of the fibrous concrete. The presence of fibers in a concrete matrix has been found to increase the ultimate strength, arrest the cracks propagation and increasing the concrete strength with changes in the mode of failure. This is due to their high tensile strength and pull-out strength of the different fibers in the concrete. The fibers stop the cracks propagating by holding the cement matrix together.

Figures 5, 6, and 7 display the comparisons between reinforced samples by the short and long fibers materials for different fibers types (glass, nylon, and carbon), respectively. These Figures revealed to a conclusion of that the compressive strength of long fiber reinforced concrete samples at different percentages is higher than short fiber reinforced samples. This behavior is attributed to increasing in the fiber length produced a network structure within the concrete, which gives a good impact on compressive strength and works as the crack arrestors through a concrete matrix more than the short fibers. Furthermore, the long fibers

have the ability to withstand the entire load that is applied and this leads to enhance the compressive strength of concrete. Thus, it has appeared that the fibers of sufficient stiffness and length can increase the lateral tensile strength of the concrete material which leading to delay the compression failure [20-23].

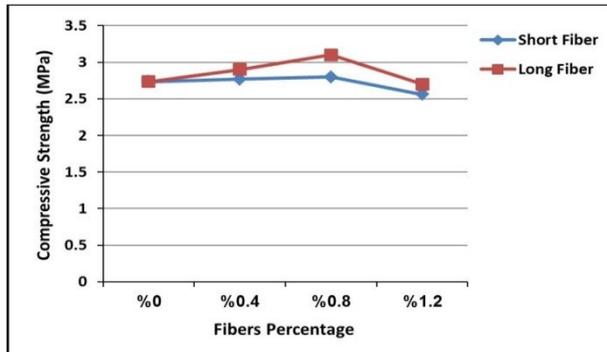


Figure 5: Effect of short and long glass fibers on the compressive strength of concrete samples.

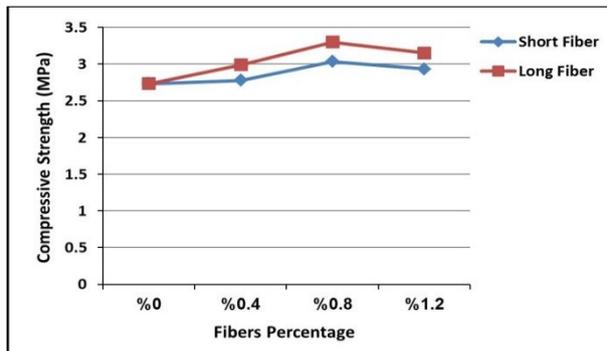


Figure 6: Effect of short and long nylon fibers on the compressive strength of concrete samples.

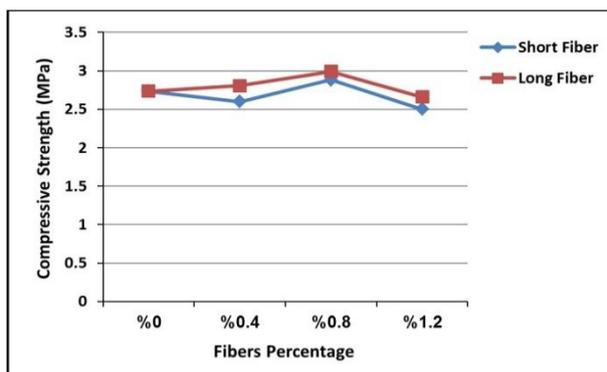


Figure 7: Effect of short and long carbon fibers on the compressive strength of concrete samples.

The previous Figures revealed that the higher values of compressive strength for the reinforced samples with different percentages of short fiber materials (3 cm) was on (0.8 % glass), (0.8 % nylon) and (0.8 % carbon), reaching the rate of increase in values of compressive strength to (6.84%, 11.08%, and 5.37%), respectively. While the higher values of compressive strength of the

reinforced concrete with different percentages of long fiber (10 cm) was on (0.8 % glass), (0.8 % nylon) and (0.8 % carbon), reaching the rate of increasing in the compressive strength values to (13.42%, 20.75% and 9.40%), respectively.

II. Flexural Strength

The additional effect of different fibers types (glass, nylon, and carbon) at two fibers length states, short (3 cm) and long (10 cm), on the flexural strength of concrete specimens are shown in Figures (8 and 9), respectively. These Figures detect interesting that the contribution of these fibers into concrete mixtures have strongly influenced the flexural strength properties. As already mentioned that the fibers increase, the plasticity of the cement-based materials enhances, and hence an increasing trend on the flexural strength could observe. In addition to that, the concrete specimens at the flexural test are exposed to the tension state more than compression. Thus, the fibers are able to resist the tensile strength higher than the concrete matrix, and that in turn lead to an increase in effective fracture energy [24].

The dispersed of these fibers in the concrete strengthened the plastic deformation; a portion of energy it absorbs and makes the crack propagation path longer. Furthermore, these fibers participate to withstand the load and resist the bending of the concrete composite under the applied load. Thereby, increase of the fracture energy and the flexural strength of concrete with increasing of the fibers weight fraction [17,20,25].

Because of high modulus and high strength of the fibers, thus delay failure of the composite concrete specimens after the first cracking. The mechanical behavior is very different from the one observed for the concrete sample. This part is very interesting because it reveals the change in behavior mostly due to the presence of fibers in the composite. The non-reinforced concrete specimen exhibited brittle behavior in bending due to a sudden rupture on access the peak load and separated into two parts. Indeed, no sudden failure and separated into two parts is observed in the fibers reinforced concrete specimens, but many cracks before the failure and continuous fall of the load is recorded [17,21,26,27].

From these Figures also, it can be observed that the concrete specimens which content on the nylon fibers have higher flexural strength values compared with glass and carbon fibers reinforced concrete, although that the nylon fiber has low mechanical properties than the glass and carbon fibers. This may be attributed to a good bonding of the nylon fibers in the concrete matrix. In addition

to the better distribution of these fibers in the concrete matrix that formed as a network. This permits an increase of the flexural strength which associated to raise the displacement of the rupture [17,20].

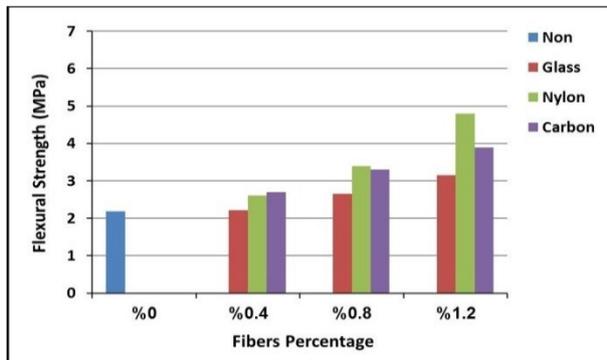


Figure 8: Effect of adding different short fibers on the flexural strength of concrete samples.

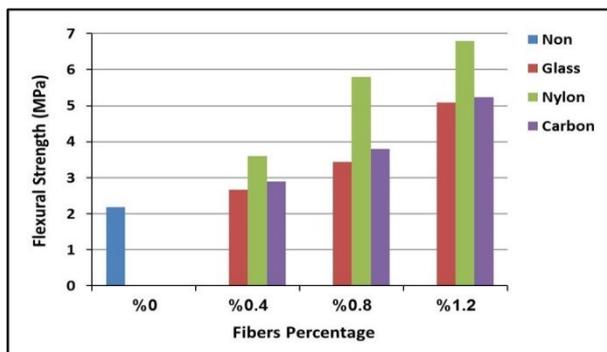


Figure 9: Effect of adding different long fibers on the flexural strength of concrete samples.

Figures 10, 11 and 12 display comparisons between two fibers length states, short (3 cm) and long (10 cm) for different fiber types of (glass, nylon, and carbon) that reinforced the concrete, respectively. The figures revealed to a conclusion that the flexural strength of concrete specimens, which contents on different percentages of long fibers are higher than reinforced concrete with short fibers. Long fibers give the most effective strengthening and better mechanical performance to the concrete. While short fibers offer a lower improvement on the mechanical properties, so the long fibers increase the flexural strength more. This behavior can be explained to that the length of fibers is necessary to resist the load. If the fibers have enough length, this can withstand the entire load and transmitted from the matrix to the fibers. So, increasing the length of the fibers is an indication of bearing load simultaneously of these fibers in the concrete mixtures [25,28].

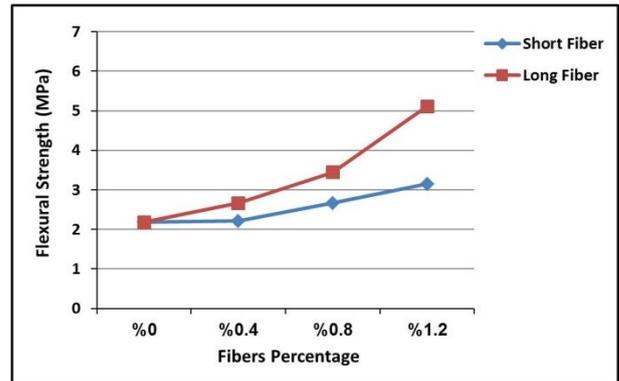


Figure 10: Effect of short and long glass fibers on the flexural strength of concrete samples.

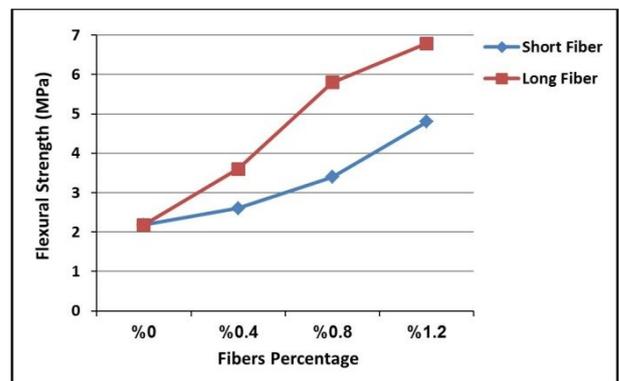


Figure 11: Effect of short and long nylon fibers on the flexural strength of concrete samples.

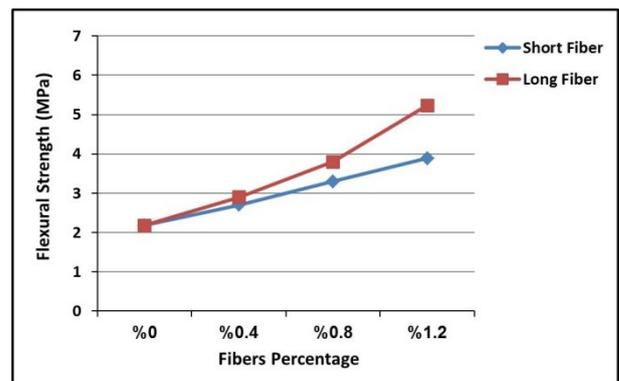


Figure 12: Effect of short and long carbon fibers on the flexural strength of concrete samples.

These Figures detect that the higher flexural strength values of the reinforced concrete samples with different percentages of short fiber materials (3 cm) was on (1.2% glass), (1.2% nylon) and (1.2% carbon), reaching the rate of increase in the flexural strength values to (44.56%, 120.02% and 78.69%) respectively. While the higher flexural strength values of the reinforced concrete samples with different percentages of long fiber materials (10 cm) was on (1.2% glass), (1.2% nylon) and (1.2% carbon), reaching the rate of increase in the flexural strength values to (133.57%, 211.49% and 139.56%), respectively.

Figures 13, 14 and 15 present the optical microscopy images of the fracture surface of concrete samples, after the flexural strength test, which reinforced by long fibers of (nylon, glass, and carbon) respectively, at different fiber weight percentages. These Figures revealed that the nylon fibers had better distribution in the concrete matrix than glass and carbon fibers. This is related to that

the glass and carbon fibers have fewer fiber diameters (around 0.01 mm), compared with the nylon fiber (0.14 mm). Thereby, the tangle and interact had occurred between these fibers via Van der Waals during the mixing and this increases the probability these fibers to agglomerated in the concrete mixture.

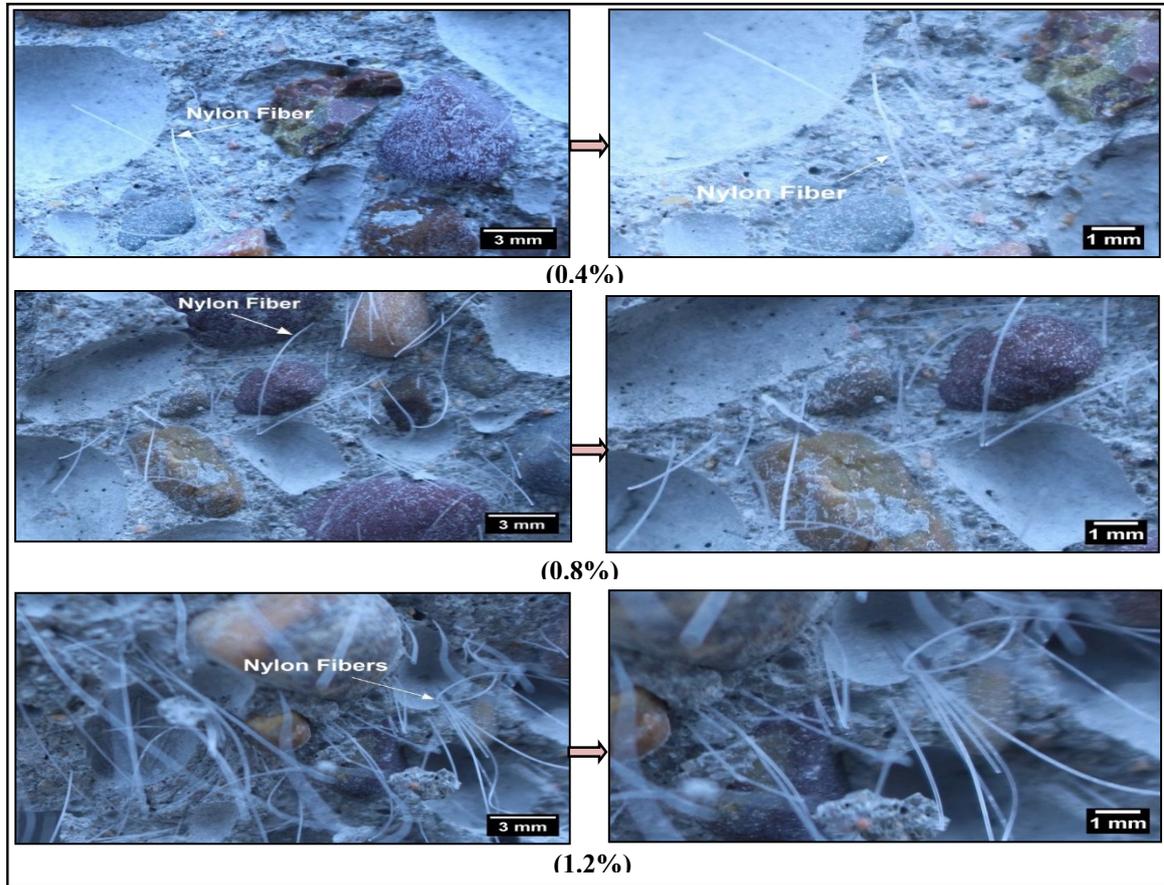


Figure 13: Optical microscopy images of fracture surface of concrete samples reinforced by long nylon fibers at different percentages after flexural test.

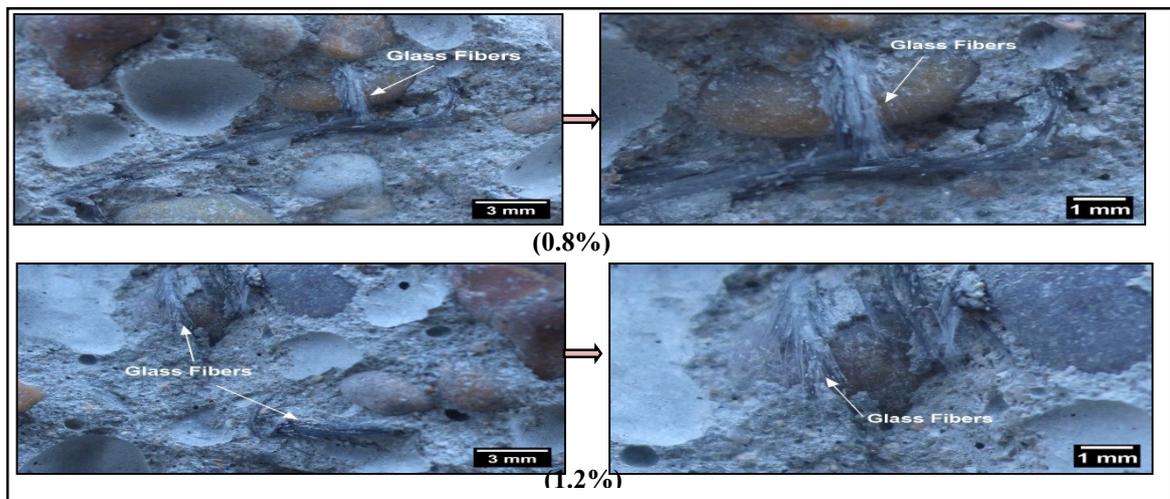


Figure 14: Optical microscopy images of the fracture surface for concrete samples reinforced by long glass fibers at different percentages after flexural test.

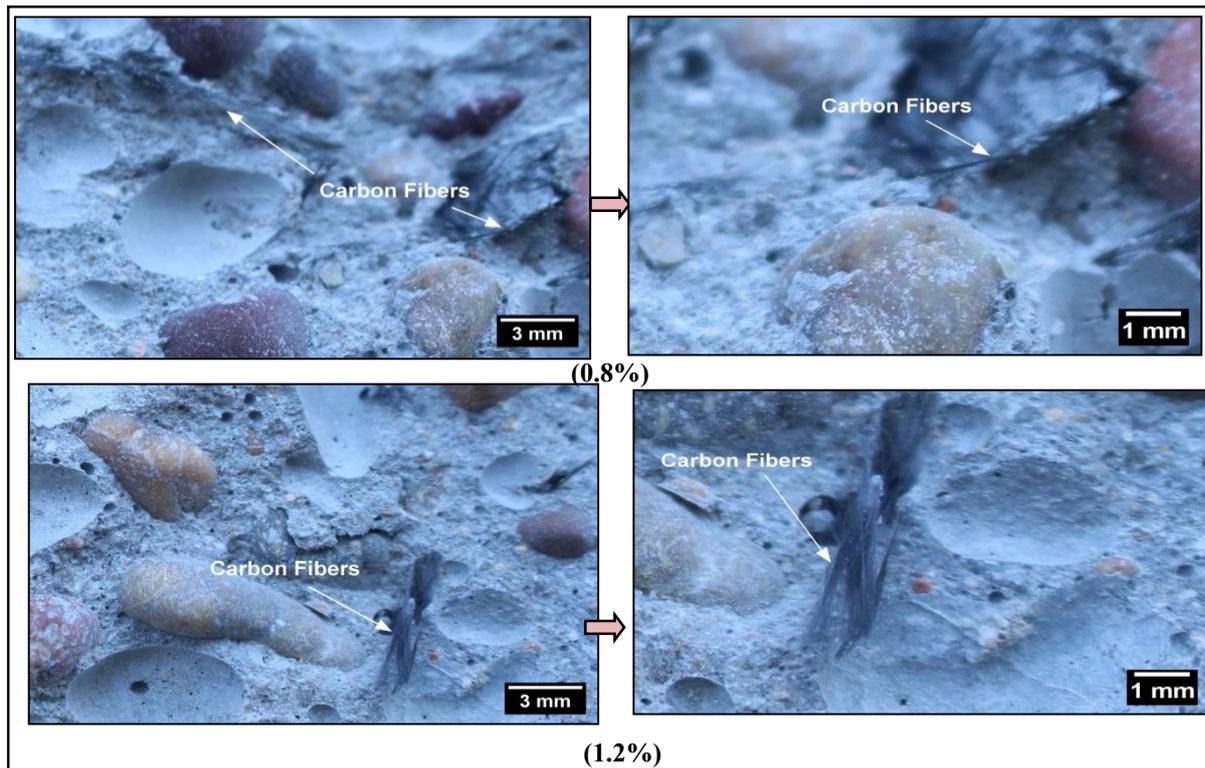


Figure 15: Optical microscopy images of the fracture surface for concrete samples reinforced by long carbon fibers at different percentages after flexural test.

4. Conclusions

In this work, the influence of different fiber types (glass, nylon, and carbon) on the concrete properties was investigated. The main points may be concluded from the results obtained in this work as follows:

1) Incorporation of different fiber types in the concrete mix generally improved the strength of concrete by improves the concrete toughness.

The compressive strength of the concrete with the addition of different fibers was slightly improved.

2) Addition 0.8% of nylon fiber to the concrete mix resulted in the maximum increasing of the compressive strength, reach the rate of increasing to 11.08% for short fiber and to 20.75% for long fiber.

3) The fibers addition provided a clear increment in the strength of the concrete. The flexural strength of concrete with addition of various fibers is strongly enhanced than compression. Addition 1.2% of nylon fibers to concrete resulted the maximum increasing on the flexural strength, reaching the rate of increasing to 120.02% for short fiber and to 211.49% for long fiber.

4) The results of mechanical tests exhibit that the long fibers reinforcement concrete specimens have higher properties than short fiber. Essentially,

nylon fiber reinforced concrete offers higher mechanical properties.

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