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Investigation of Addition Different Fibers on the Performance of Cement Mortar

Abstract- *This work presents an investigation of possibility incorporate of synthetic fibers (glass, nylon and carbon) at two states (short: 1cm, long: 5cm) effects on the mechanical properties of mortars (cement: sand composition (1:3)). Fibers materials used at different weight percentages ranged of (0, 0.4, 0.8, and 1.2) wt%. Density, water absorption, porosity, thermal conductivity, compressive strength and flexural strength experimentally investigated for mortar specimens after curing for (28 days). The results showed that the incorporation of these fiber materials improvement mechanical and physical tests for all reinforced samples with short and long fibers, and that the highest value of the mechanical and physical properties obtained from long fiber (5cm) reinforced cement samples with (1.2%Nylon), reaching the rate of increase in values of compressive strength by (17.74%), flexural strength by (52.8%), and water absorption by (4.54%), while reaching the rate of decrease in values of density by (5.32%). The higher values for short fiber (1cm) reinforced samples reaching the rate of increase in values of compressive strength by (10.92%), flexural strength by (40.65%), and water absorption by (6.65%), while reaching the rate of decrease in values of density by (8.91%). Results of thermal conductivity test showed decrease in values conductivity for all mortar samples with long short synthetic fibers and that the minimum value of conductivity obtained with (1.2%Carbon), reaching the rate of increase in values of thermal conductivity by (41.84%) for long fiber reinforced samples, while the lowest value for conductivity by (75.98%) for short fiber reinforced samples.*

Keywords- *Cement mortar, thermal conductivity, flexural strength, glass, nylon and carbon fibers.*

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1.Introduction

Cement-based materials made with Portland cement is a type of most widely used construction material in the world. It is a composite material containing hydraulic cement as binder, water, 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 known as hydration, then the water reacts with the cement which bonds the other components together [1]. These materials have inherently brittle in its nature and have some disadvantages like poor deformability, weak resistance to crack in the practical usage with tensile strength and flexural strength is relatively low compared to their compressive strength. Many experiments have been done to transform cementitious system to a structural material with desirable physical and mechanical properties [2]. The weakness in tension can be removed by incorporation of fiber materials in cement mortar to increase its toughness, or ability to resist crack growth. The fibers help to transfer loads at the internal micro cracks [3,4]. The fibers reinforce cement-based materials is a family of composite materials that combine the good compressive strength properties of cement based materials with significantly increased flexural, impact and tensile strengths imparted by fiber reinforcement [5]. The most important fibers parameters which influence on the mechanical behavior of the composite materials are geometry, distribution, orientation, and volumetric proportion of fibers in the matrix. Brittle matrices, such as unreinforced mortar, lose their tensile load-carrying capacity.It has been recognized that the addition of fibers in the cement-based materials can raises the toughness of cementitious matrices and serves to arrest cracks significantly. The enhancement on performance of fibers reinforced cement mortar can be attributed to the point where fibers resist cracking generation [6]. Also the use of fibers recalibrates the behavior of the fiber-matrix composite by makes it more homogeneous and isotropic and transforms it from a brittle to a more ductile material. When cement mortar cracks, the randomly oriented fibers arrest the micro-

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cracking and limit the crack progression, thus improving strength and ductility [7]. Presently, a number of laboratory experiments on physical and mechanical properties of using various types of fiber materials in cement-matrix composites have been done. For example, Chung [8], studied that addition of short carbon fiber in a cement matrix composites. The results revealed attractive improvement in the tensile and flexural properties with low thermal conductivity, high corrosion resistance and low drying shrinkage behavior. Ahsan Habib and et al. [9], studied mechanical properties of synthetic fibers (glass, nylon, and polypropylene fibers) reinforced mortars. The results exhibit increase in the compressive strength of mortar composites except glass fiber. Amit Rai and Y.P Joshi [3], studied used steel fiber, glass fiber, natural fiber and polymer fiber as addition to concrete .The results prove that addition of fibers was an effective way to increase the toughness, shock resistance and resistance to plastic shrinkage cracking of the concrete. The aim of the percent work is to study the effect of incorporation of various types of fiber materials such as (glass, nylon and carbon) at different fiber length in cement-based materials performance for enhancing its properties. Hence, this work focuses on the experimental study of physical and mechanical properties of these fiber material embedded in cement mortars.

1. Experimental Work

I. Materials

Ordinary Portland cement was used in this work as the main components of the binder for preparing of cement mortar samples. This cement provided by AL-Mass Bazian factory, and it is conformed 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 (glass, nylon and carbon) were used as additive material in the cement mortar mixtures. Glass fibers used in this work having a density of 2.58 g/cm^3 and it is provided from Mowoling LTD.UK Company as a woven form. Nylon fibers used in this work having a density of 1.27 g/cm^3 and it is provided from China as yarn roll form. Carbon fibers with density of 1.79 g/cm^3 used in this work and it is provided from Sika Wrap®-300 C/60. These fiber materials has been chopped at two length of (1 and 5) cm and then dispersed it by hand in order to easily mix with cement mortar mixtures. Figure (1) shows the different fiber materials (glass, carbon and nylon fiber) at two fiber length (1 cm and 5 cm).

II. Mix Proportion

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

III. Casting and Curing

The cement mortar specimens were casted using cubes of (50 mm), prisms of (40*40*160) mm from steel molds, and a disc of (37.5 mm in diameter and 20 mm in height) plastic mold. The molded specimens were stored in the laboratory conditions and covered with wet burlap for the first 24 hours to prevent moisture loss. After removing from molds, the specimens were cured by submerged in a tap water tank at temperature of ~ (25-30)°C for 28 days. The shapes of some casted specimens are illustrated in figure (2).

III. Specimens Tests

The physical, mechanical and thermal properties of the cement mortar specimens were measured. Density, porosity and water absorption of mortar specimens have been determined by using the procedure specified in accordance to the ASTM C-642. The compressive strength of cubic mortar specimens was calculated according to the ASTM C-109. Flexural strength of the prism mortar specimens was performed using three-point bending method according to the ASTM C-348. Thermal conductivity of the disc specimens shape was measured by the hot disk method.

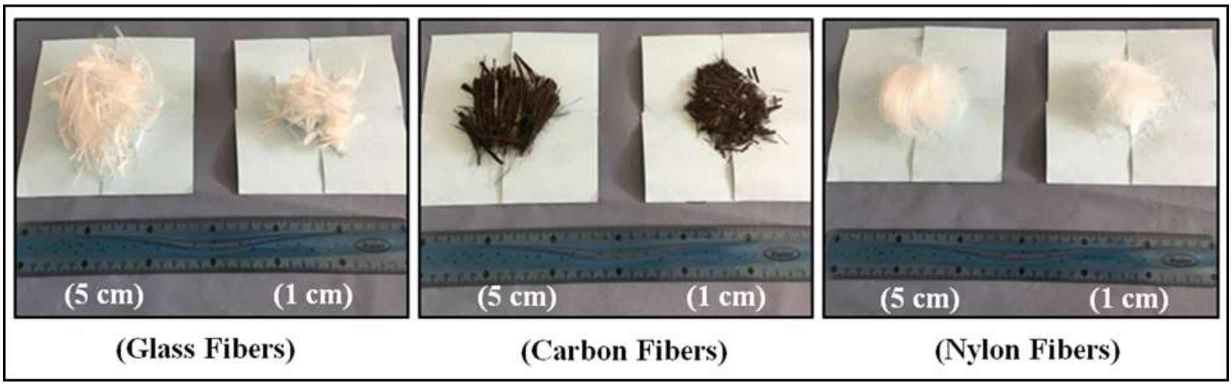

Figure 1: The fiber materials used in this work.

Figure 2: Some of casted cement mortar specimens.

Table 1: Mix proportions of mortar specimens.

Mix	Fiber Materials* (wt %)	Fibers Length (cm)	Fibers (g)	Sand (g)	Cement (g)	Water (ml)
M0	-	-	-	165	55	27.5
M1	0.4 % G*	1	0.22	165	54.78	27.5
M2	0.8 % G	1	0.44	165	54.56	27.5
M3	1.2 % G	1	0.66	165	54.34	27.5
M4	0.4 % G	5	0.22	165	54.78	27.5
M5	0.8 % G	5	0.44	165	54.56	27.5
M6	1.2 % G	5	0.66	165	54.34	27.5
M7	0.4 % N*	1	0.22	165	54.78	27.5
M8	0.8 % N	1	0.44	165	54.56	27.5
M9	1.2 % N	1	0.66	165	54.34	27.5
M10	0.4 % N	5	0.22	165	54.78	27.5
M11	0.8 % N	5	0.44	165	54.56	27.5
M12	1.2 % N	5	0.66	165	54.34	27.5
M13	0.4 % C*	1	0.22	165	54.78	27.5
M14	0.8 % C	1	0.44	165	54.56	27.5
M15	1.2 % C	1	0.66	165	54.34	27.5
M16	0.4 % C	5	0.22	165	54.78	27.5
M17	0.8 % C	5	0.44	165	54.56	27.5
M18	1.2 % C	5	0.66	165	54.34	27.5

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

2. Results and Discussion

I. Porosity

Porosity is considered one of the mechanisms that are directly related to the cement mortar quality, it can provide beneficial information relating to the porous structure, permeation characteristics and durability of the cement mortar surface zone that is penetrated [10]. The addition influence of three different fibers types for both of two fiber states (short and long) respectively on the porosity of the cement mortar samples is shown in the figures (3 and 4). The results showed that the porosity of the mortar specimens is slightly increased with increasing content of the fibers percentages. Essentially, the porosity of mortar specimens which contain carbon fibers was increased about (7.67%) for the short fibers and (5.22%) for the long fibers, comparing with the other fibers (glass and nylon). The increasing in porosity of mortar specimens with addition of these fibers is due to formation of air voids in the microstructure of cement mortar, and the voids content becomes excessively high as fiber volume fraction increases [8]. Besides, the fact that the incorporated fibers in a composite material act to generate air voids in the matrix and lower the density [11]. The results also reveal that the porosity for the short fiber reinforced samples was higher than the long fiber. This is because that the short fiber is more difficult during aligning and packs densely than long fibers. In addition, the weak dispersion of short fibers with cement mortar led to increase the amount of voids and porosity [11, 12].

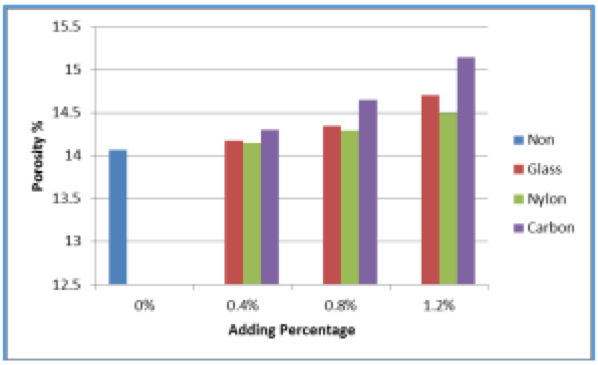

Figure 3: Effect of adding different short fiber on the porosity of mortar samples.

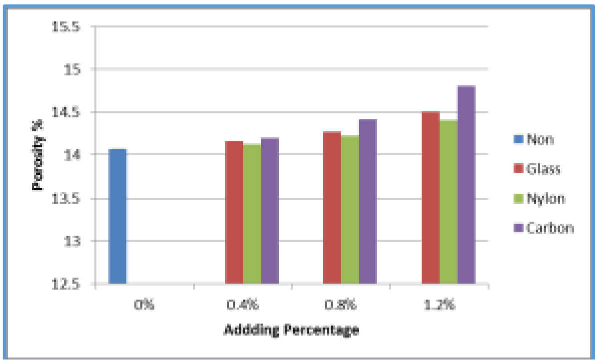

Figure 4: Effect of adding different long fiber on the porosity of mortar samples.

II. Density

The relationship between weight fractions of different fibers types for both of two fiber states (short and long) respectively on density of cement mortar samples including reference samples is shown in figures (5 and 6). It has been shown that the density of cement mortar samples is slightly decreased with increasing of these fibers content. Especially, the density of cement mortar was decrease as carbon fibers content increase in both fiber length states, reaching the rate of decrease in values of density to (17.3%) for short fiber state and (15.22%) for long fiber state. This decreasing appears reasonable can be attributed to the specific gravity of these fiber are lighter than fresh cement mortar mix which reduce the overall density of the cement mortar specimens. From the results, it can be observed that the densities of the short fiber reinforced mortar samples are lower than the long fiber, i.e. the short fibers decrease the densities more. In general, the long fibers are more ease to align and pack densely than the shorter one [10,11]. Hence, the mortar which filled with the short fibers produce an increase in the number of voids and this generates lower in the density [12].

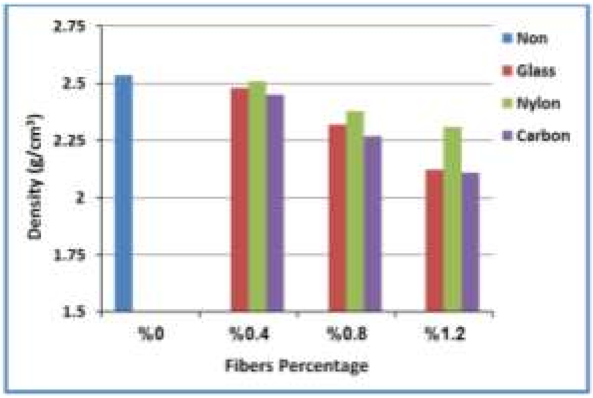

Figure 5: Effect of adding different short fibers on the density of cement mortar samples.

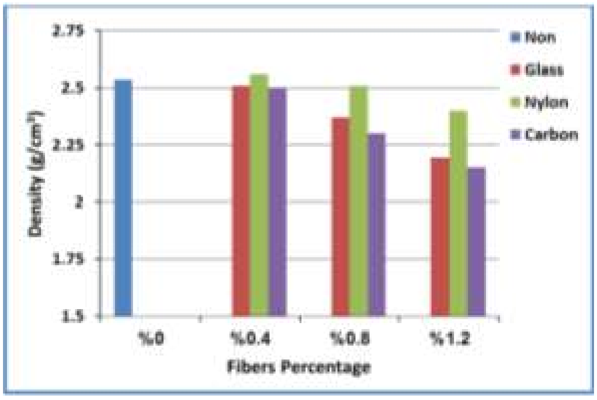

Figure 6: Effect of adding different long fibers on the density of cement mortar samples.

III. Water Absorption

Water absorption property is a measure of the porosity and it supplies advantageous information about the volume of permeable pores inside the samples and possible connectivity between these pores [13,14]. The variation of water absorption of the mortar specimens with addition of three fiber types at two fiber length states (short and long) is shown in figures (7 and 8), respectively. The results show that the water absorption values of the mortar specimens are slightly decreased at addition 0.4 % of three fiber materials and then increased with increasing fibers content more than 0.4 % in the cement mortar mixture. At low fibers content, the water absorption values of the mortar specimens decreased, this may be due to these fibers bonded with the cement and forms same as a network in the mortar structure, which makes to segregate the pores and decreasing the permeability [15,16]. While, with increasing of the fibers content more than 0.4 %, the water absorption values increased. This is because the mortar porosity increases. The reason behind this could be the poor dispersion of these fibers in mortar that consequently increase in void and pore volume with increasing inclusion of the fiber materials in cement matrix [14,15,17]. The results detected that the carbon fibers reinforced mortar specimens have higher water absorption than the other fibers. The results also reveal that the total water absorption for the short fiber reinforced samples was higher than the long fiber. This can be explained in terms of porosity in the main structure of the short fiber reinforced mortar specimens, as the number of pores is much higher than long fiber reinforced mortar specimens [18].

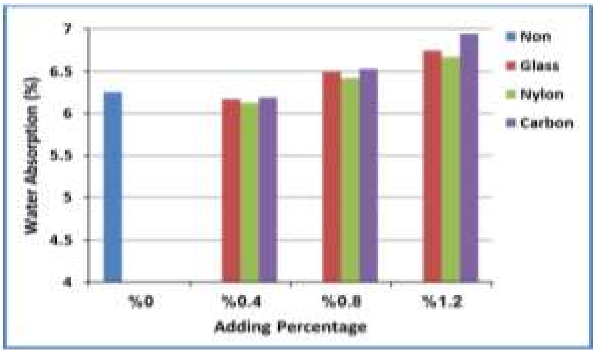

Figure 7: Effect of adding different short fibers on the water absorption of cement mortar samples.

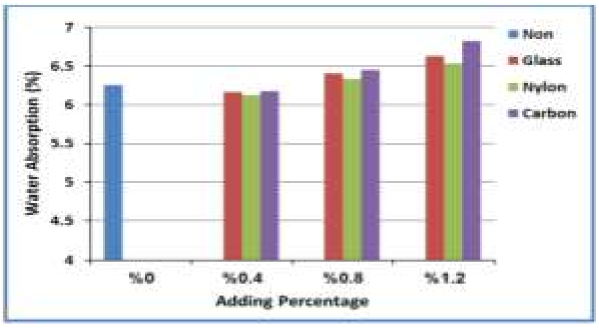

Figure 8: Effect of adding different long fibers on the water absorption of cement mortar samples.

IV. Thermal Conductivity

The purpose of measuring this property is to obtain a mortar for plastering buildings has better thermal insulation, which helps to prohibit the leaking of temperature from inside the building to outside or vice versa [16]. Figures (9 and 10) show the relationship between the weight fractions of different fibers types for both of two fiber length states (short and long), respectively, on thermal conductivity of cement mortar samples including reference samples. It can be seen from these figures that the thermal conductivity of mortar specimens exhibited a continuous decreasing with increasing of the fibers content. This reduction is expected for nylon and glass fibers because these fiber have lower thermal conductivity compared to that of cement mortar matrix. In addition, the fact that the fibers are embedded in composite tends to generate porosity and air in the matrix and reduced the density [12]. The mortar specimens containing on carbon fibers show lower thermal conductivity, although that the carbon fibers are thermally conducting. This behavior is more related to the amount of formed voids and porosity in mortar specimens than the conductivity of this fiber. In general, the size and shape of porosity in structure of ceramic materials is known to play an important role in determining thermal conductivity [23]. Thermal conductivity of the cement mortar decreases as carbon fibers content increased for both fiber lengths, reaching the rate of decreasing in thermal conductivity values of carbon fiber reinforced mortar samples to (75.98 %) for short fibers and to (41.84 %) for the long fibers. The results detect that the thermal conductivity for the short fiber (1 cm) reinforced samples is lower than the long fiber (5 cm) reinforced samples. In general, short fibers are more complicate to align and pack densely than the larger one [11]. Thus, the mortar filled with short fibers produce an increase of the number of voids; this generates lower density and low thermal conductivity of cement mortar [12].

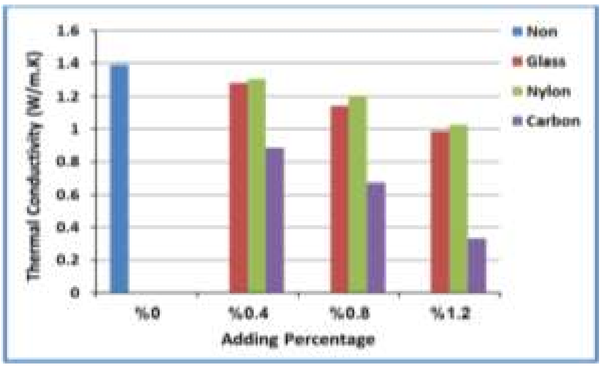

Figure 9: Effect of adding different short fibers on the thermal conductivity of cement mortar samples.

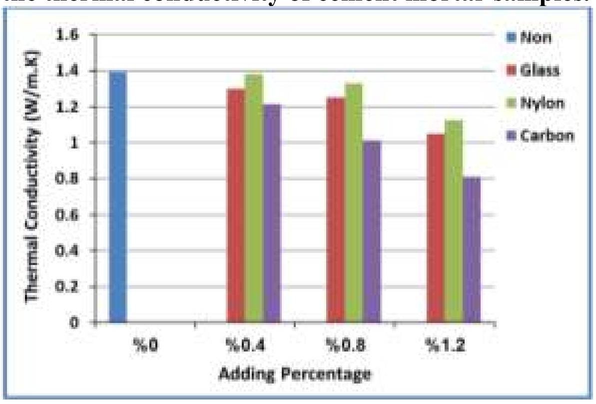

Figure 10: Effect of adding different long fibers on the thermal conductivity of cement mortar samples.

V. Compressive Strength

Compressive strength is ability of a material or structure to withstand axially directed applied forces. Materials are crushed when the limit of compressive strength is reached. The compressive strength is very important for building materials because it refers to the strength of the pillar to resist from fracture [8]. Figures (11 and 12) show the influence of different fibers types percentages for both fiber length states, respectively, on the compressive strength of the mortar specimens. These figures detect that the compressive strength values of the cement mortar specimens is slightly increase up to 0.8 % weight percentage of fibers materials. Nylon fibers reinforced cement mortar offer the higher values of compressive strength comparing with the other fibers. This slightly improvement in compressive strength of cement mortar specimens may be attributed to addition of these fibers lead to increase the toughness of the mortars and make to endurance the composites under stress without breaking through arresting the cracks at both micro- and macro-levels and thus increases the compressive strength of the mortar specimens [16,19]. With increasing fibers content more than 0.8 %, the compressive strength values decreases, this may be attributed to disturbance in the homogeneity of the mortar mix with presence of these fibers, especially at higher percentages. This may be related to an increase in the viscosity during mixing of the matrix at large additions of fiber materials which causing difficulty in matrix fluidity and decreased the ability to penetration between fibers which reduces fiber wetting prior to hardening of the matrix causing a decrease in adhesion (weaker interface) between the matrix and the fibers, and as a result crack propagation will occur. Besides, the reduction in compressive strength is also related to the increase of voids in the samples due to the air entrainment and poorer fibers-matrix adhesion [12,20-22].

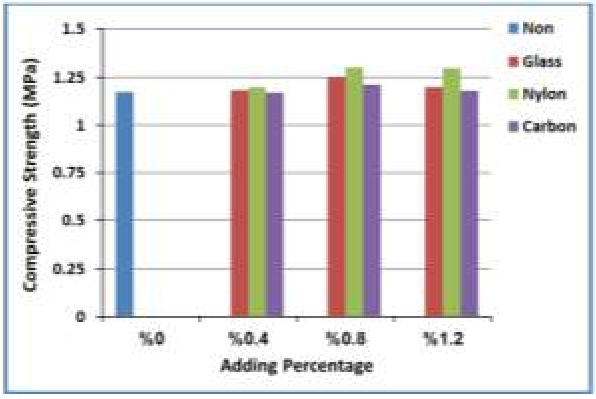

Figure 11: Effect of adding different short fibers on compressive strength of cement mortar samples.

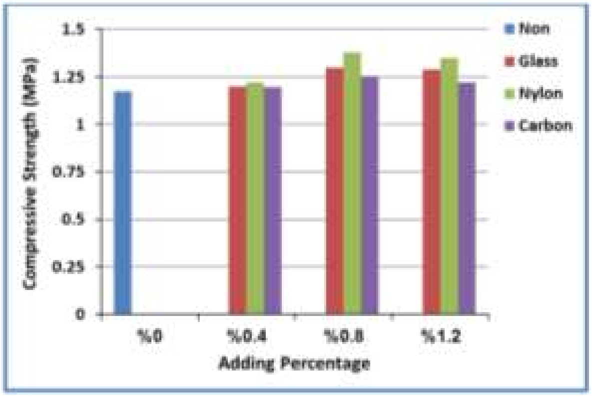

Figure 12: Effect of adding different long fibers on compressive strength of cement mortar samples.

The previous figures exhibited that compressive strength for the long fibers reinforced samples is higher than the short fibers reinforced samples. This behavior is attributed to increasing the fiber length gives good fiber surface adhesion with the cement matrix composite and offer good interlock between the cement mortar components. So this lead to improving in the compressive strength [9].

VI. Flexural Strength

Tensile strength is an important property for cementations materials because its structures are highly vulnerable to the tensile cracking due to various kinds of effects and applied loading itself. However, the flexural test is one measure of the tensile strength of cement-based materials due to difficulty in applying uniaxial tension to cement specimens because the high brittleness with the low tensile strength. Hence, the flexural strength of a material can be defined as its ability to resist deformation under load [7,8,16]. The effect of different fibers types addition at two fibers length states on the flexural strength of mortar specimens are shown in figures (13 and 14), respectively. The flexural strength of mortar specimens have been enhanced with an increase in weight fraction of fibers materials, especially for nylon fiber reinforced. This increasing in the flexural strength was due to the nature of binding of fibers available in cement mortar. When the fibers reinforced mortar forced to split apart in the flexural strength test, the load was transferred into the fibers as pull-out behavior and the mortar matrix began to crack, where it exceeded the pre-crack state. Thus, that the fiber materials are able to resist the fracture strength higher than cement matrix, and that in turn lead to an increase in fracture strength of mortar specimens [7,23,24]. Figure (15-a) depict the mortar specimens that reinforced by long nylon fiber after flexural test. The fracture nature of mortar specimens represent the behavior of the cement matrix with presence of fibers during the crack runs through the entire section. This photograph indicated that the mortar without fiber the fracture is completely brittle and occurs suddenly, while with increasing the fibers content in the cement mortar, the plasticity of the composite mortar increased and the composites will flow under stress without sudden fracture. So, the fibers addition to the cement mortar mix lead to strengthening the composite mortar as resulted to that fibers will absorb part of energy and make the path of crack propagation longer [7,16]. This is clear on the optical microscopic images; figure (15-b), for the mortar specimens which reinforced by long nylon fiber at different fracture points. The mortar specimen which contents on the glass and carbon fibers revealed low mechanical properties compared with nylon fiber reinforced mortar, although that the nylon fiber has low mechanical properties than the glass and carbon fibers. This behavior is related to lack of fibers distribution in the mortar mixture. The optical microscopic images for fracture line of the mortar samples reinforced by glass and carbon fibers are shown in figures (16 and 17), respectively. It observed that most of carbon and glass fibers are clustered in between them and not well distributed in the cement matrix, especially at the higher percentages. This is because these fibers have lower fiber diameters (around 0.01 mm), compared with nylon fiber (0.14 mm), thereby the tangle and interact occurs of these fibers with each other via Van der Walls. This increases the probability of agglomeration of these fibers in the cement mortar mix. Therefore, the higher flexural strength has been observed for the nylon fiber reinforced cement mortar. Beside to the above, this behavior can be also related to the nature of binding of these fibers available in cement mortar matrix [7,22]. Also, these figures revealed that the flexural strength of reinforced mortar samples at different percentages of long fibers state was higher than reinforced mortar with the short fibers. This is due to the increased in length of the fibers lead to increasing the bonding surface area and cohesive strength of these fibers with the cement matrix.

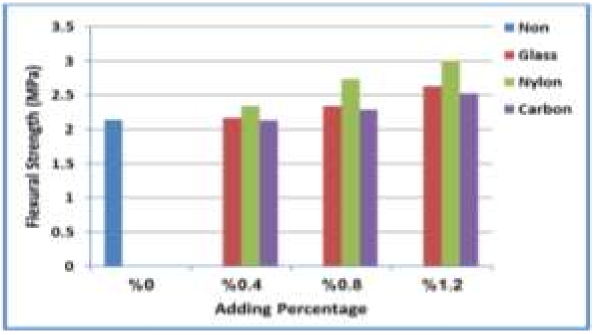

Figure 13: Effect of adding different short fibers on the flexural strength of cement mortar samples.

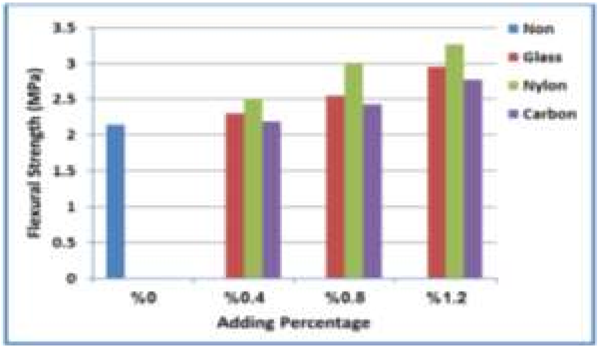

Figure 14: Effect of adding different long fibers on the flexural strength of cement mortar samples.

Figure 15: The mortar samples reinforced by long nylon fibers: (a) Photograph of samples after flexural test; and (b) Optical microscopy images at different fracture points in the mortar samples.

(0.4 %) **(0.8 %)** **(1.2 %)**

Figure 16: Optical microscopy images of the fracture points for mortar samples reinforced by long glass fibers at different percentages.

(0.4 %) **(0.8 %)** **(1.2 %)**

Figure 17: Optical microscopy images of the fracture points for mortar samples reinforced by long carbon fibers at different percentages.

3. Conclusions

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

1) Increasing of the fiber materials content in the cement mortar mix allows lighten the mortar by reducing its density. Decreasing mortar density will make it a better material for building of light-weight structural components.

2) Thermal conductivity of the cement mortar is decreased with increase addition of the fibers by yielding the mortar higher thermal resistance, where the highest decreasing in the values of thermal conductivity was obtained from the short carbon fibers reinforced mortar at addition of (1.2 %), reaching the rate of decrease to (75.98 %).

3) Incorporation of fiber materials in the cement mortar mixture generally enhanced the flexural strength, and resulted slightly increase in its compressive strength. So, the most important contribution of fibers reinforcement cement based materials is not to strength but to increase the toughness of the mortar.

4) The mechanical tests reveal that the cement mortar samples reinforced with long fiber states have higher mechanical properties than mortar samples reinforced with short fiber.

5) The samples of nylon fiber reinforced mortar offer higher mechanical properties than samples with glass and carbon fibers.

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