The Effect of Using Fan Palm Natural Fibers on the Mechanical Properties and Durability of Concrete

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***Abstract*—Many published researches have been conducted worldwide to investigate the advantages of using Natural Fiber Reinforced Concrete (NFRC), few of them use in their study fibers extracted from Fan Palm trees. This study was performed to investigate the effect of using Fan Palm fibers in concrete. Mechanical properties and resistance to plastic shrinkage cracking for Palm Natural Fiber Reinforced Concrete (PNFRC) were determined. The mechanical properties were determined from experimental program comprising of testing compressive strength, indirect tensile strength, flexural strength, and static modulus of elasticity, as well as Flexural toughness tests. To produce representative results about performance of the new composite, three parameters in the mix design were taken into consideration. The parameters are the percentage of fiber volume fraction (0, 0.5, 1.0, 1.5%), fiber aspect ratio L/D (60, 100), and concrete strength (30, 40, 60MPa). The results show that adding palm fibers help the concrete in gaining more strength at early stages. Most of the concrete mechanical strength increased by about 10% to 15% with more elastic deformation. In addition, adding 1% by fiber volume fraction reduced the plastic shrinkage cracking in concrete slabs in about 70%. It is concluded that Fan Palm Fibers can be used as an additive in concrete to improve its performance and open a new opening to a more sustainable composite.**

***Index Terms*—fiber reinforced concrete, fan palm, natural fiber, shrinkage cracking, strength, toughness**

I. Introduction

Concrete is a brittle material that has high compressive strength, but of relatively low tensile strength. The addition of fibers in concrete mix will improve the mechanical properties of concrete material in terms of tensile and bending strength, enhance its ductility, and result in greater resistance to cracking and hence improving impact strength and toughness [1], [2].

Natural fibers were used in some applications in the construction field early in the 19th century. Later, interest goes toward synthetic fibers because of their superior properties. However, due to scarcity in raw material and energy consumption, the attention is drawn again towards natural and renewable resources like vegetable fibers. Nowadays, Natural Fiber Reinforced Concrete (NFRC) is one of the main research topics in structural engineering applications [3].

The primary advantage of using fibers in the concrete mix is represented by the significant improvement in concrete properties and its relative low cost [4], [5]. Out of the commonly used and easily available low cost natural fibers are renewable source materials. In this study, attention is focused on the use of natural fibers, particularly Natural Fibers from Fan Palm Leaves. The distinctive properties of Natural Fiber Reinforced Concretes (NFRC) are recently undergoing significant improvement although historically many fibers have been used to reinforce various building materials, until recently many scientific efforts have been devoted to the use of Fan Pan Natural Fibers in concrete production and cement paste. Furthermore, using NFRC can increase the greenness of concrete, contributing to a more healthy and sustainable environment [6].

For that, an intensive experimental program was performed to investigate the effect of adding Fan Palm Natural Fibers on the mechanical properties of concrete. The properties investigated are compression, split tension, and flexural strengths. In addition, flexural toughness, modulus of elasticity, and plastic shrinkage cracking has been investigated. To give a more realistic performance for the new composite, three main parameters that affect the behavior of FRC have been studied. The parameters that will be included in this study are: three fiber volume fractions (0, 0.5, 1, and 1.5%) with control mix, two Aspect ratios (L/D = 60, 100), and three Concrete Strengths (30, 40, 60MPa).

II. Materials and Methods

A. Materials

The natural fibers used in this research (Fig. 1b) have been extracted from Fan Palm Tree Leaves (Fig. 1a). Fan Palm species are commonly cultivated across the United States, the Middle East, southern Europe, and North Africa, where they have greatly hybridized [7]. Production of fibers from these leaves will convert the unused wasted leaves to a renewable source material and low cost natural fibers that will be incorporated in concrete mixes. The natural fibers used in this research

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are from the leaves of the Fan Palm trees. After trimming the leaves from Palm trees, they were air dried then cut into fibers of width 1mm each. A handmade machine was used to cut leaves into fibers according to the required size. Then, the fibers were treated using Alkali treatment chemical method to improve their performance in the cement matrix [8].

The mechanical properties of Fan Palm Fibers were determined as shown in Table I.

TABLE I. MECHANICAL PROPERTIES OF FAN PALM FIBERS

Property	Lower–Upper
Fiber Dimensions: Thickness[mm] Width [mm]	 0.25-0.35 0.60-0.90
Bulk Density [Kg/m^3]	500-800
Absorption [%]	100-200
Modulus of elasticity [GPa]	4.5-6.5
Tensile strength [MPa]	70-120
Elongation [%]	1.5-2.0

a. b.

Figure 1. Fan palm trees and fibers

The cement used is PA-L 42.5, Conforms to EN 197 European norms (CEM II/A-L) and to Lebanese standards (LIBNOR), manufactured by HOLCIM Company for cement production, Chekka, north Lebanon. The Super plasticizer Sikament NN (High Range Water-Reducing), Sika brand, was used in the concrete mix. Sikament NN is a highly effective dual action liquid super plasticizer. The Dosage specified is between 0.8-3% by weight of cement depending on desired workability and strength. The Silica Fume is brought from SODAMCO Company, Beirut-Lebanon. Natural sand from the mountain of Lebanon area was used as fine aggregate. The coarse aggregate is a crushed stone also taken from the Mountain of Lebanon. Both aggregates were sieved and graded according to the ASTM requirements [9]. Aggregates' properties are shown in Table II.

TABLE II. COARSE AND FINE AGGREGATES' PROPERTIES

Aggregate	Type	Bulk Relative Density	Absorption %	FM
Fine Aggregate	Natural sand	2.61	0.9 %	2.4
Coarse Aggregate	Crushed stone	2.58	1.6 %	

B. Mix Proportions

Three mix designs were prepared for the three required strengths of concrete as shown in Table III. The absolute volume method was used in the design, and then trial mixes were performed and tested to check the workability and the required strength of the concrete. Twenty-four mixes were conducted according to the parameters used in the study.

TABLE III. MIX PROPORTIONS FOR THE CONCRETE GRADES USED IN THE STUDY

Index	Cement Kg/m^3	Silica Kg/m^3	Water Kg/m^3	SP Kg/m^3	W/C	Sand Kg/m^3	C.A. Kg/m^3
G30	326	24	208	2.25	0.6	589	1110
G40	370	30	152	8.4	0.4	740	1050
G60	465	35	138	12.5	0.3	733	1000

C. Specimen and Curing Condition

Different sizes of specimens were required for every mix of the twenty-four selected mixes as detailed in Table IV. The specimens were removed from the molds after 24 hours and cured in saturated limewater at room temperature until testing day, except for the slabs where no curing was required to monitor the plastic shrinkage crack propagation.

TABLE IV. SPECIMEN SHAPES AND DIMENSIONS FOR STRENGTH TESTS CONDUCTED IN THE STUDY

Test Required	Number and type of specimens	Specimen dimension [mm]	Date of tests
Compression tests	9 Cylinders	100*200	@ 7, 28, 90 days
Indirect tensile test	6 Cylinders	100*200	@ 7, 28, 90 days
Flexural Tests & Toughness	9 Beams	100*100*500	@ 7, 28, 90 days
Modulus of Elasticity	3 Cylinders	150*300	@ 28 days
Plastic shrinkage cracks	1 Slab	1000*1000*30	Inspection for 7 days

D. Testing Program

All experimental tests were conducted at civil engineering labs, at Beirut Arab University. The Universal crushing machine was used in the compression strength test according to ASTM C 31, C 39, C 192 and C 617. Flexural strength test and flexural toughness specimens were tested in The Universal Testing machine. The flexural strength of FRC was determined under third-point loading using ASTM C78 and C1018 [9]. Toughness is a measure of the energy absorption capacity of a material and is used to characterize the material's ability to resist fracture when subjected to static strains or to dynamic or impact loads. A dial gage with accuracy of 0.01mm was used to measure the deformation at the mid span when subjected to a deflection control rating. The loading rate is 0.05mm/min. To determine the splitting tensile strength of cylindrical concrete specimens, splitting tensile strength was conducted according to ASTM C 496.

Modulus of elasticity (ASTM C 469): The purpose is to determine the Modulus of Elasticity of concrete under longitudinal compression using the chord modulus to define elasticity. This test to measure the modulus of elasticity is applicable to Fiber Reinforced Concrete [10].

Resistance to plastic shrinkage cracking: The lack of a standard test for plastic shrinkage cracking resistance of concrete at an early age has prompted the proposal of several methods. These have involved the measurement of the length and width of concrete cracks. In this study, a slab of 1m*1m was prepared for every mix with a thickness of 30mm. The slabs used to investigate the plastic shrinkage cracking propagation were subjected to an environment of hot dry climate to encourage the spreading of cracks. The slabs were exposed to a fan with an electric heater directly after being mixed without curing. This environment increases the possibility of cracks due to the increase in the process of water evaporation in the plastic phase of concrete. Then, the length and the opening of the cracks were monitored and registered daily for the next week to be compared to the different mix designs.

III. Tests Results and Discussions

A. Compressive Strength

The results for compressive strength, at grade 30MPa, show that adding fibers has no significant effect on compression strength at 7 and 28 days, but show a slight improvement at 90 days when using 3cm fiber length (Fig. 2).

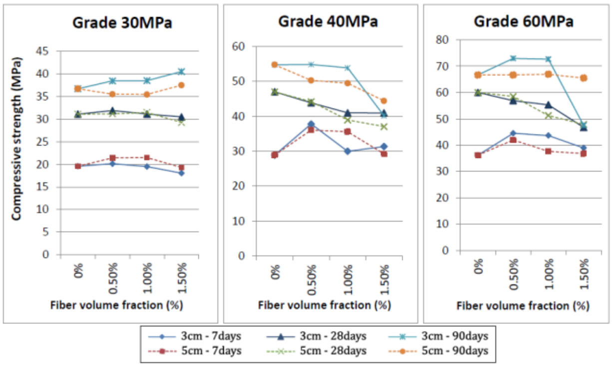

Figure 2. Results for compressive strength for the three grades of concrete with fiber volume percentage

The results for compressive strength, at grade 40MPa, show an increase for some mixes of about 20 to 30% in the strength of concrete after 7 days upon adding fibers. The increase in concrete strength resulted from the moisture content of the fibers that was distributed all over the concrete specimens. This moisture content increases the hydration process of the concrete as if it is cured from the inside [11]. At 28 days, the addition of fibers decreases the compressive strength by about 6 to 20%, especially for volume fraction larger than 1%. The compressive strength at 90 days shows that adding fibers more than 1% volume fraction results in serious reduction in the strength. Fiber length has no remarkable effect on the compressive strength of concrete.

The results for compressive strength, at grade 60MPa, show that adding fibers increases the strength of concrete at 7 days as for 40MPa. Using 5cm fiber length reduces compressive strength more than 3cm. As a result, using fibers with fiber volume fraction more than 1% causes a significant reduction in the concrete compressive strength by about 25%. However, using low percentage fiber volume fraction may improve or have no effect on the compressive strength of the concrete.

B. Split Tensile Strength

The results for splitting tensile strength at grade 30MPa show that adding fibers improve significantly the indirect tensile strength of concrete at 7days (Fig. 3). The improvement varied between 10% and 70% for the different mixes. For Grade 40MPa and 60MPA, the splitting tensile strength was not affected significantly by the addition of fibers, especially at 90 days.

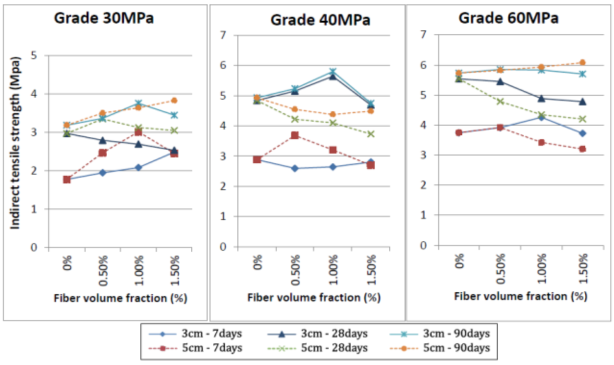

Figure 3. Results for Indirect tensile strength for the three grades of concrete with fiber volume percentage

C. Flexural Strength

Using Fan Palm fibers in concrete improves the flexural strength of concrete with different percentages depending on the different parameters tested (Fig. 4). For concrete grade 30MPa and 40MPa, adding fibers results in improvement between 20 to 30% for almost all the mixes at 7days. However, there is no significant effect of fibers at 28 and 90 days. In fact, attention must be taken for high percentages of fibers. For grade 60MPa, where the used cementing materials are 500Kg/m^3, the bond between the fiber and the cement matrix results in an improvement in the flexural strength between 30% and 40% for approximately all the mixes and different ages of concrete specimens.

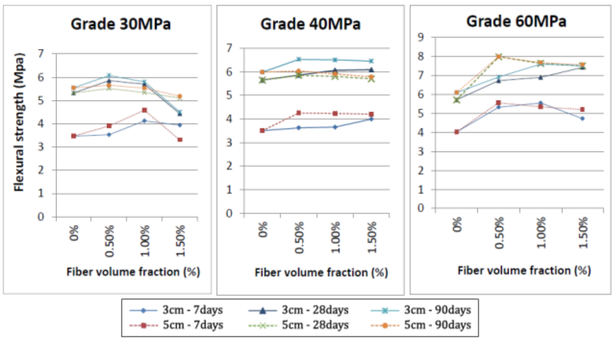

Figure 4. Flexural strength results for the three grades of concrete with fiber volume percentage

D. Flexural Toughness

In the study, toughness was evaluated by computing the area under the load deflection curve (P-) that represents the energy absorption capacity of the new composite. The obtained results were compared with the results of the conventional concrete to conclude the effect of tested parameters on the flexural toughness results. For that, Fig. 5 shows the result for conventional concrete as 100% compared to the relative flexural toughness for the other mixes.

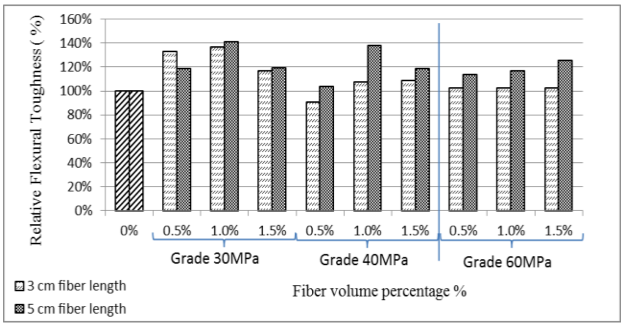

Figure 5. Relative flexural toughness for all grades of concrete, fiber volume fraction, and fiber length

We can conclude from the results of flexural toughness shown in the figure that: using 5cm fiber length increases the toughness of the concrete for most of the selected mixes. For grade 30MPa and 40MPa, 1.0% fiber volume fraction gives the best results for toughness where the values increase by about 40%. However, the results decreased for higher fiber volume percentage. On the other hand, for grade 60MPa, the toughness still shows improvement for 1.5% of fiber especially for 5cm fiber length. The improvement for grade 60MPa was due to the increase in bond between fiber and cement matrix where the high cement content allows more bonding agents.

E. *Modulus of Elasticity*

The results show that the modulus of elasticity for fiber reinforced concrete decreased by about 5% to 15% (Fig. 6) compared to that of conventional concrete.

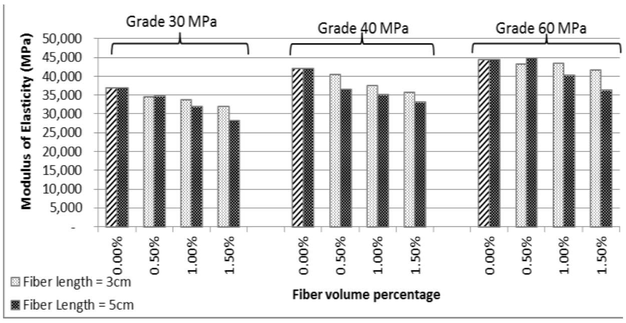

Figure 6. Experimental results for the modulus of elasticity for all grades of concrete, fiber length, fiber percentage.

The reduction in the modulus of elasticity is the result of concrete specimens with fiber allowing more deformation when subjected to the same values of compression loads. As a result, Fiber reinforced concrete is a more ductile material than ordinary concrete. In fact, this property is an advantage for many concrete applications, especially those subjected to dynamic or impact loads. In addition, concrete with 5cm fiber length allows more deformation for its specimens than those with 3cm fiber.

F. *Resistance to Plastic Shrinkage Cracking*

The inspection of slab specimens showed that using natural fibers reduces the propagation of plastic shrinkage cracks significantly. Moreover, the reduction was more effective when using more fibers. In fact, Using 0.5% fiber volume fraction reduced cracks by about 50% than that of conventional concrete. With 1% fiber, the reduction decreases to 70%. Moreover, with 1.5% fiber volume fraction, the plastic shrinkage cracking disappeared 90%.

IV. Conclusions

The experimental study on the incorporation of Fan Palm fiber in concrete at various fiber volume fraction, fiber length, and concrete strength shows significant effect on the investigated properties of the new composite. From the test results, the following conclusions are drawn:

- The compression strength was not affected by the addition of low percentage of fibers for concrete grade 30MPa. For Grade 40MPa and 60MPa, the compressive strength increases significantly at 7 days by about 20% compared to the conventional one (Normal concrete). After that, at 28 and 90 days, the results show a slight decrease in the results between 5 and 20%.
- The splitting tensile strength for grade 30MPa increases significantly by about 40% at 7days. For the rest of the mixes, adding fibers has no major effect on the splitting tensile strength of the new composite. However, some improvement did not happen until the concrete age of 90days.
- The flexural strength for grade 30 and 40MPa resulted in significant improvement at 7days where the strength increases between 10 and 20%. At 28 and 90 days, the improvement in flexural strength was insignificant. However, for grade 60, the improvement in the flexural performance was more significant. In fact, an increase of 30% to 40% was shown in most of grade 60MPa tested specimens.
- The flexural toughness of the concrete when using fan palm natural fiber increased especially for concrete with low strength relatively, where the values of improved strengths when using 1.0% fiber volume was about 40%. In addition, using 5cm fiber length results in more toughness than using 3cm.
- The Modulus of elasticity decreases when using fibers in concrete. Moreover, the elastic deformation of concrete increased with the fiber length increase.
- The resistance to plastic shrinkage cracking increased significantly with increasing the percentage of fiber volume in concrete, and tends to eliminate this defect in concrete at 1.5% fiber.

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