SELECTED PROPERTIES OF CONCRETE CONTAINING PALM FIBERS

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Abstract

Durability of concrete is one of the main concerns to improve its performance and efficiency. Furthermore, concrete durability is mainly related to concrete permeability that could be tested by its capillarity and water absorption. This study presents an experimental investigation on the mechanical and permeability properties at different ages for adding Natural Palm fibers to improve concrete properties. The compressive strength, density, UPV, total water absorption, and capillary water absorption tests were performed to evaluate the effect of fiber incorporation into the concrete on these properties at 7, 28, and 91 days. The volume percentages of fibers added to the concrete mix were 0% (Control mix), 0.5%, 1.0%, 1%, and 1.5% with water cement ratio equal to 0.5 for all concrete mixes. The results indicate that adding natural palm fibers to concrete improves most of the investigated properties especially those related to durability as water absorption and capillarity. Precisely, the water absorption of concrete decreases about 17%, 26%, 51% When using 0.5, 1, 1.5 % fiber content respectively. In addition, capillarity also decreases 16%, 24%, 32% When using 0.5, 1, 1.5 % fiber content respectively. It is concluded that adding Natural Palm fibers to concrete is a feasible strategy to produce more durable, eco-friendly material especially when adding 1.5% fiber (by volume).

Keywords:

Bio-Fiber, Capillarity, Concrete, Durability, Natural, Palm Fibers, Sorptivity, Water Absorption.

1 INTRODUCTION

Concrete is one of the most used materials worldwide in construction field, especially in the field of buildings construction. Consequently, improving concrete greenness and sustainability will result more green and sustainable products in the word and ecofriendly construction [El-Darwish *et al., 1997;* El-Kurdi *et al*., 2014; Hadjsadok *et al*., 2012; Herki and Khatib, 2013; Herki and Khatib, 2016; Khatib *et al*., 2008; Khatib *et al*., 2009; Khatib *et al.* 2013a; Khatib *et al.* 2013b; Khatib *et al.* 2014; Khatib *et al*., 2015a; Khatib, 2016 ; Khatib *et al*., 2016b; Mangat *et al*., 2006; Okeyinka *et al*., 2015; Sonebi *et al*., 2016; Wright and Khatib, 2016].

One of the main concerns to produce sustainable concrete is to concrete its durability [Ghanem et al., 2010a; Ghanem et al., 2010b, Ghanem et al., 2012a, Ghanem et al., 2012b]. For that, many new researchers have been investigating new ecofriendly materials that can be used to improve concrete durability [Machaka 2017].

On the other hand, the durability of concrete depends mainly on the ability of the concrete to resist the penetration of external aggressive agents that reduce its durability and sometime could be destroyable. The ability of this material to withstand the intrusion of these aggressive agents (i.e., chloride ions, sulfate, oxygen, carbon dioxide, etc.) is mainly characterized by permeability [Amriou 2017; Ghanem et al. 2008].

In this regard, this study Investigated the percentage of total water absorption and the capillary absorption of concrete which are of the important factors to assess the durability of concrete because the pore network in the cement paste matrix or microcracks can provide transport path for water or aggressive agents [Wang 2016, Hall 1989]. Precisely, one the used parameter that evaluates the water absorption property by capillary suction is the sorptivity coefficient [Wang 2016]. In detail, sorptivity is an index of moisture transport into unsaturated specimens, and recently it has also been recognized as an important index of concrete durability [Dias 2000, Wang 2016]. For that, looking for an ecofriendly, natural, and cheap material that can reduce the concrete absorption is the objective of this study.

Using fibers in concrete is a strategy that result a significant improvement in concrete properties with low cost materials. Nowadays, due to scarcity in raw material and energy consumption, the attention is drawn towards natural and renewable resources like vegetable fibers. Fibers extracted from natural plants are one of the preferred resources environmentally. Recently, Natural Fiber Reinforced Concrete (NFRC) is one of the main research topics in structural engineering applications [Machaka 2014].

One of the natural fibers that had been investigated in many previous researches was fibers extracted from the leaves of Fan Palm trees. On the other hand, the durability of these fibers and its compatibility with cement matrix is one of the main concerns that discouraged the expansion of using these materials on a large scale [ACI 544.1 2010, Faruk 2012].

Therefore, in a previous research, an experimental study was performed on Fan Palm fibers to overcome these obstacles [Machaka 2014, Machaka 2017]. As a result, alkali treatment by soaking these fibers in 1% Sodium Hydroxide solution for a duration of 24 hours was the optimal selection to Improve the compatibility between these fibers and the cement matrix and to overcome the durability failure of these fibers when lives in the concrete alkali environment [Hashim 2012, Machaka 2014]. On the other hand, environmentally, Euro chlor reported that because sodium hydroxide is neutralized in the environment, the substance is not persistent, and it will not accumulate in organisms or in the food chain. Bioaccumulation will not occur. In addition, Emissions from the Alkali treatment to air are also not a concern because sodium hydroxide will be rapidly neutralized in air due the presence of carbon dioxide in air; briefly, alkali treatment is not harmful to the environment [Euro chlor].

Consequently, the investigation extended to examine the effect of adding Fan Palm fibers on the fresh concrete properties (unit weight and workability), mechanical concrete properties (compression, tension, and flexural strength, modulus of elasticity); In addition, the effect on adding Palm Fibers on the reduction of plastic shrinkage cracking. The study performed on different fiber aspect ratios and volume fraction percentages to choose the best performance in improving most of the concrete properties. As a result, the study shows that using 1% fiber volume fraction with 3 cm length resulted in the optimized mechanical properties for this new composite [Machaka 2014]. Moreover, Machaka & ElKordi conducted an experimental study to investigate the effect of adding these fibers on the volume stability of the concrete when exposed to different severe environments such as Sodium Sulfate, Magnesium Sulfate, Alkali solutions such as sodium hydroxide, and sea water solution. This study showed that Adding Fan Palm Fibers to concrete improve its performance significantly in the length change when exposed to different severe environments [Machaka 2017].

Therefore, more concrete properties that affect its durability were investigated in this study using these fibers by testing its permeability by the mean of absorption, capillarity, and sorptivity with different percentages of fiber volume inclusions.

The fibers used were extracted from Fan Palm leaves as shown in Fig. 1, splited into 1 mm width, cured for 24 hours in 1% NaOH solution, washed, dried, and stored in polyethylene bags to be ready for concrete mix.

2 MATERIALS AND MIX PROPORTIONS

2.1 Materials

The natural fibers used in this research have been extracted from Fan Palm tree leaves shown in Fig. 1. Then, the fibers were treated using Alkali treatment chemical method to improve their performance in the cement matrix as shown in Fig. 2. The mechanical properties of Fan Palm Fibers were determined as shown in Tab. 1 [Machaka 2014]. The fiber width after chemical treatment decrease from 1mm to a range between 0.60 and 0.90 mm. The Bulk density of the fibers about 550 Kg/m^3, and their tensile strength between 70 and 120MPa.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 C33 and C136 requirements. The physical properties for fine and coarse aggregates are shown in Tab. 2. The cement used is PA-L 42.5, Conforms to EN 197 European norms (CEM II/A-L) and to Lebanese standards (LIBNOR).

Fig. 45 Fan Palm tree.

Fig. 46 Treated Fan Palm fibers.

Tab. 4 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]	500-600
Absorption [%]	100-200
Modulus of elasticity [GPa]	4.5-6.5
Tensile strength [MPa]	70-120
Elongation [%]	1.5-2.0

Tab. 5 Aggregate's properties.

Aggregate (Type)	Bulk R. Density	Abs. %	FM
Fine Aggregate (Natural sand)	2.51	1.56 %	2.7
Coarse Aggregate (Crushed stone)	2.60	1.35 %	

2.2 Mix proportions

To study the effect of adding Fan Palm fibers on concrete strength, density, and permeability four mixes were prepared. The first mix was the control one without fibers to compare with the others with 0.5,1, and 1.5 % fiber volume fraction. Tab. 3 showed the concrete mix design proportions. The absolute volume method was used in the design. The aggregate weights are in dry condition. In addition, Palm fibers were added to the mixer with the coarse aggregates.

Tab. 6 Mix proportions.

Mix	W/C	Cement Kg/m^3	Water Kg/m^3	Sand Kg/m^3	C.A. Kg/m^3	Fiber Kg
Control 0%	0.5	420	210	585	1050	0
0.5% fiber	0.5	420	210	585	1050	2.75

3 EXPERIMENTAL PROGRAM

All experimental tests were conducted at civil engineering labs, at Beirut Arab University. Specimens were prepared in the lab using steel molds and compacted using vibrating table. In detail, to determine the compressive strength six 150*300mm cylinders were casted; eight cylinders 100*200mm were prepared for density, UPV, and total water absorption tests; finally, eight Cubes of 100*100*100 mm were casted for capillarity tests. Tests were performed during the curing process at the ages of 3, 7, 28, and 91 days.

3.1 Permeability study

The evaluation of concrete permeability was investigated based on the percentage of water absorption with time at different curing ages by immersion and by capillarity. Moreover, a comparison for the rate of water absorption by capillarity for different fiber inclusion percentages was also investigated by the function of sorptivity. Practices from ASTM C1585 were used in this study. To clarify, sorptivity is an index of moisture transport into unsaturated specimens, and recently it has also been recognized as an important index of concrete durability [Dias 2000, Zhang 2014]. During sorptivity process, the driving force for water ingress into concrete is capillary suction within the pore spaces of concrete, and not a pressure head [Hall 1989].

The Comparison of testing results for total water absorption, capillary water absorption, and sorptivity obtained in this experimental program aim to study the effect of adding fiber to get properties of the new composite Palm Natural Fiber Concrete (**PNFC**) compared to control concrete mixes (without fiber) for the fiber volume fractions.

3.2 Testing methods

For the compressive strength tests, The Universal crushing machine was used in the compression strength test according to ASTM C 31, C 39, C 192, & C 617.For the total water absorption test, the specimens were casted, demolded, and then cured in water at room temperature to the date of testing at 3, 7, 28, 91 days. In the day of testing, specimens were removed from water, dried in the oven for 48 hours at 80° until specimens reach a constant weight. At this time, the weight registered as dry weight assigned by **A** (dry weight). After that, the specimens have been immersed totally in the water for 5 minutes then removed, wiped with a towel to remove any excess water at the concrete surface. At this point, the specimen weight is registered to get the first reading at 5 minutes assigned by **B** (wet weight) then the specimens were re-immersed in water directly and the procedure are repeated at 10 min, 20 min, 60 min, 120 min, 240 min , 1 day, 2 days, and finally 3 days. The increase in the weight of the specimens at different time intervals indicates water absorption represented by the percentage of total water absorption = **(B-A)/A*100**

For the capillary water absorption, cubes 100*100*100 were used in this test. The cubes cured for the same ages as before then dried. On the other hand, after removing the specimen from the oven, the cubes were sealed at their four sides to prevent absorption other from the bottom sides that is in contact with water. The sealing was higher 2 mm from the bottom as ASTM C1585 specify. Weight of the specimen was recorded and assigned as **W1** (dry weight). The specimens were put in a bottle filled with water to cover the concrete sides from 3 to 5 mm as shown in Fig. 3. After 1 minute from immersion, the cubes were removed, wiped, and weighted to record the first weight at 1 minute with water absorbed by capillarity and assigned as **W2**. The procedure repeated at minutes 3,5,10,20,30,60, 120,240, then 1 day, 2 days, and finally 3 days. From these results, the capillary water absorption at each reading was obtained by dividing the cumulative water absorption over the surface area of the cube through which water penetrates (100 mm^2) as shown in the following relationship:

$$I(\text{mm}) = \frac{\Delta W}{A.d} = \frac{W2 - W1\ (in\ grama)}{A.d} \quad (1)$$

A = surface area of the cube through which water penetrates (mm^2).

d = density of water (g/mm^3).

To determine the sorptivity, using strategies from ASTM 1585, Standard Test Method for Measurement of Rate of Absorption of Water by Hydraulic-Cement Concretes, this test method is used to determine the rate of absorption (sorptivity) of water in hydraulic cement concrete by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. The sorptivity that was obtained is the initial slope for the curve between the cumulative absorbed volume of water per unit area of inflow surface and the square root of time in minutes. In short, sorptivity is based on the rate of absorption, which is proportional to the surface area exposed to moisture and time [Vimal 2009, ASTM 1585]. The Sorptivity can be calculated from the following relationship:

$$I = S\sqrt{t} \quad (2)$$

I = the cumulative water absorption over the surface area in mm.

t = time of taking the weight in minutes.

S =Sorptivity in mm/$\sqrt{t}$

4 RESULTS AND DISCUSSION

4.1 Compressive strength

Fig. 4 shows the average compressive strength of concrete for all mixes at days 7,28, and 91. The tests are performed on 150mm*300mm cylinders. The averages of two specimens for each mix and curing age are computed for comparison. The results for compressive strength show that after 7 days of curing adding 0.5% and 1.0% Palm fibers decreases slightly the strength to about 16% and 8% respectively; in contrary, when adding 1.5% of fibers the strength increases about 10%. On the other side, the strength increases for concrete with fibers at 28 and 91 days for the different used fiber volume fractions. The compressive strength at 28 days was not affected by adding 0.5% and 1.0% fibers where it remains approximately constant compared to an increase of 10% when we use 1.5% fiber. In similar at 91 days, the improve in the performance of concrete strength when adding fibers was also observed where adding 0.5% and 1% fibers increase the strength 10% and adding 1.5% showed higher values that reaches about 20%. In general, adding Natural Palm fibers improve the concrete strength for all the used replacement percentages.

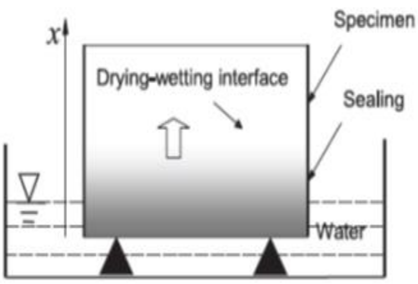

Fig. 47 The schematic diagram of capillary absorption.

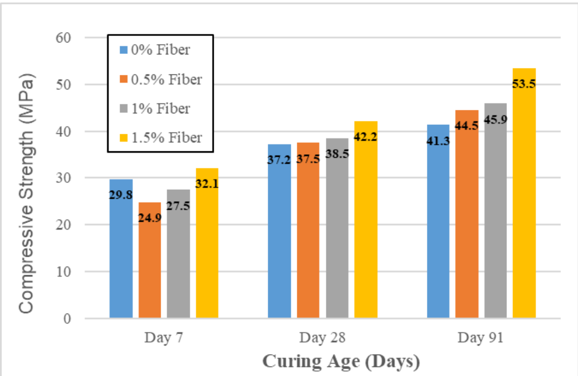

Fig. 48 The effect of adding different percentages of Palm fibers on the compression strength of concrete at curing ages 7,28, and 91 days.

4.2 Density

Fig.5 shows the dry density of concrete for the different mixes for curing ages 7,28, and 91days.The weight used to calculate the density are dry weight where the cylinders removed from water and put in the oven for 48 hours at 80°C so that a constant mass of the specimens is reached, then cooled down for 3 to 5 minutes before weighting.

The results show that adding fibers with percentages of 0.5%, 1.0%, and 1.5% decrease slightly the concrete unit weight. The decrease was between 2% and 4% taking into consideration that the density of the fibers is low compared to other concrete ingredients.

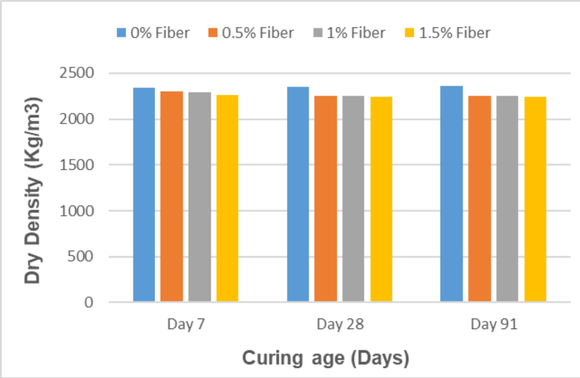

Fig. 49 The effect of adding different percentages of Palm fibers on the dry density of concrete at curing ages 7,28, and 91 days.

4.3 Ultra-Pulse Velocity (UPV)

Ultrasonic pulse velocity testing of concrete is based on the pulse velocity method to provide information on the uniformity of concrete, cavities, cracks and defects, presence of voids, honeycombing or other discontinuities [Rehman 2016, No 2002]. Tab. 4 shows the guidelines for qualitative assessment of concrete based on UPV test results.

Tab. 7 Quality of concrete based on UPV value.

Pulse Velocity	Concrete Quality
> 4.0 km/s	Very good to excellent
3.5 – 4.0 km/s	Good to very good, slight porosity may exist
3.0 – 3.5 km/s	Satisfactory but loss of integrity is suspected
< 3.0 km/s	Poor and loss of integrity exist.

Fig. 6 shows the readings of the UPV tests for all the mixes after curing ages of 7, 28 & 91 days. The represented results are the average of two readings. All in all, as all the reading are above 4 Km/s for control and concrete with different fiber volume inclusion, we conclude the quality and the uniformity of the concrete was maintained and remain in the very good to excellent category.

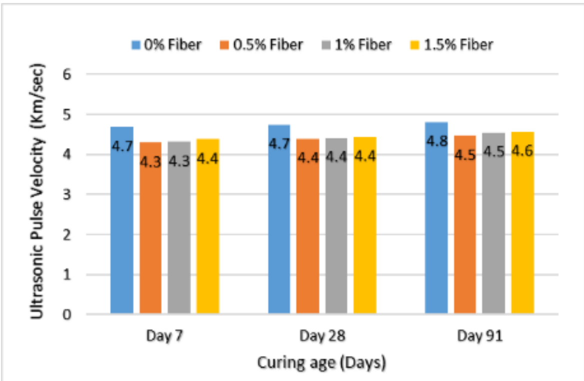

Fig. 50 The effect of adding different percentages of Palm fibers on the UPV of concrete at curing ages 7,28, and 91 days.

In details, adding fibers 0.5%, 1.0%, and 1.5 % reduces slightly the Ultra Pulse Velocity between 7% and 10%. The UPV results decreases even that the compressive strength increases slightly as shown in the compressive strength tests previously, but the density decreases in the same way as the UPV. The UPV results increases with time, the velocity increases about 4% from day 7 to day 91 when adding 1.5% fibers.

4.4 Total Water Absorption

Fig. 7 shows the average of the total water absorption for the concrete specimens after 91 days of curing for different mixes depending on the percentage of fibers added to the concrete. The specimens were totally immersed in water for 72 hours and the readings recorded at time intervals as specified previously.

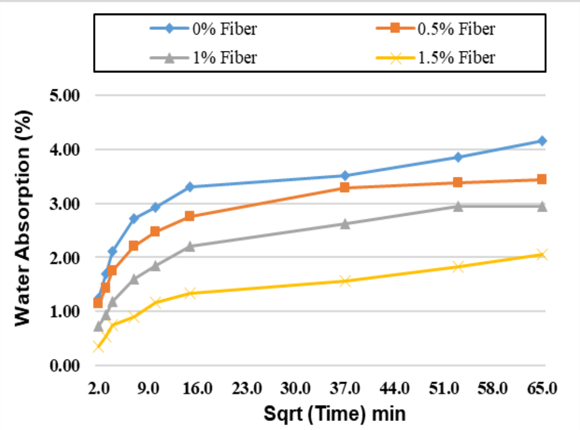

Fig. 51 Average water absorption at day 91 for 72 hours of specimen immersion in water for different fiber volume fraction.

The results show that adding Palm fibers to the concrete decreases the rate of total absorption with time. At square root of time in minutes where the value is 7.7 (60 minutes), the percentages of absorption were 2.71%,2.2%,1.6%,0.9 % for the concrete specimens with 0%(control), 0.5%,1.0%,1.5% of fibers respectively. It was noted the adding 1.5% fibers effectively reduced the total water absorption to approximately the third for the amount of absorbed water.

After 72 hours ($\sqrt{t} = 65$) ,adding 0%, 0.5%, 1.0%, 1.5% fibers recorded 4.16%, 3.45%, 2.94%, 2.05% for the total water absorption respectively as shown in Fig. 8.

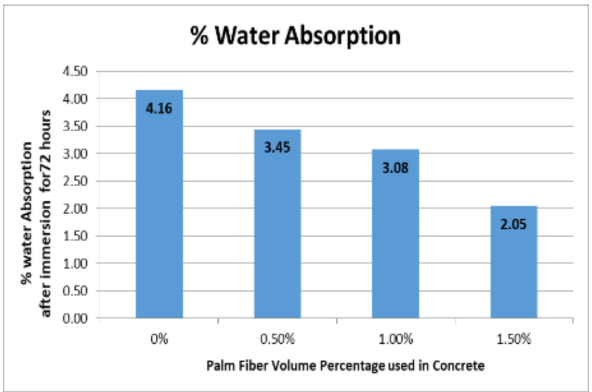

Fig. 52 Percentage of water absorption after 72 hours of specimen immersion in water for different fiber volume fraction at the age of 91 days.

In detail, adding 0%, 0.5%, 1.0%, 1.5% fibers decrease the absorption of the concrete after 72 hours after 91 days of curing to the ratios 17%, 29%, 51% respectively. Consequently, the decrease in the percentage of total water absorption increases the durability of the concrete concerning the external agents attack that are harmful to concrete.

Moreover, as shown in Fig. 9, the absorption results for the all mixes were recorded at different curing ages (3, 7, 28, and 91 days) to monitor the effect of using 0%, 0.5%, 1.0%, 1.5% of Palm fibers at these ages.

The percentage of water absorption resulted after 91 days of curing are 4.16%,3.45%,2.94%, and 2.05% when adding 0%, 0.5%, 1.0%, and 1.5% respectively for 72 hours of water immersion. The results show that at three and seven days adding fibers increases the rate of absorption from 4.35% to 5.48% and 5.07%.on the other hand, the percentage of absorption decreases with time for concrete with fibers especially when we use 1.5% the reduction was about 50% comparing the absorption results between 3 days and 91 days of curing.

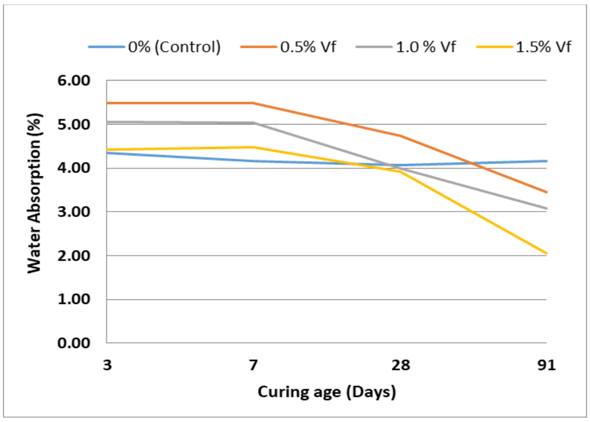

Fig. 53 Percentage of water absorption for concrete specimens after 72 hours for different fiber volume fraction at ages 3,7,28, and 91 days.

4.5 Capillary water Absorption

Fig. 10 shows the results for the capillary water absorption test for the concrete specimens after 91 days of curing for different fiber volume fraction used in concrete mix. The results plotted for the capillary water absorption per square area (I in mm) vice-the square root of time in min. Three fiber volume fraction of Palm fibers were used in the concrete mix in addition to the control one without fiber that are 0%, 0.5%, 1.0%, and 1.5% to investigate the effect of adding Palm fibers on the capillarity and sorptivity of concrete.

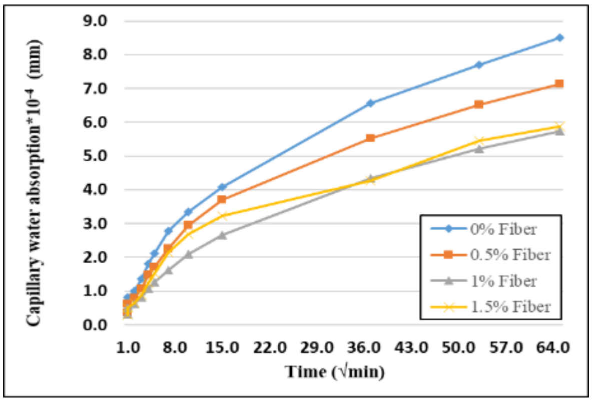

Fig. 54 The effect of fiber volume fraction on the capillary water absorption with time(sqrt) at curing age 91 days (W/C =0.5).

Fig. 10 shows that the capillarity of concrete decrease when adding fibers where after 91 days of curing the capillarity for a 72 hours of water penetration are 8.5, 7.1, 5.7, and 5.9 mm for 0%, 0.5%, 1.0%, and 1.5% of fibers respectively. The results for 1.0% and 1.5% fiber percentages are approximately identical. In addition, adding fibers decreases the percentage of water absorbed by capillarity for 16% when using 0.5% fibers and about 30% when using 1.0% and 1.5% fibers.

On the other hand, from the sorptivity results calculated from the capillary tests. The slope calculated from the reading at 3 and 20 minutes.

Fig. 11 shows the obtained results, from these results we conclude that adding fibers also decrease the sorptivity especially with 1% fiber content where the slope decreases from 0.37 for the control mix to 0.21 when using 1% fibers. In detail, adding 0.5%, 1.0%, and 1.5% decreases the sorptivity value by 16%, 42%, and 26% respectively.

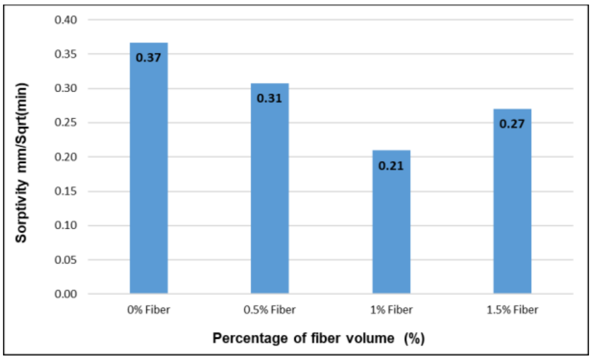

Fig. 55 The effect of fiber volume fraction on the concrete sorptivity at curing age 91 days (W/C =0.5).

5 CONCLUSION

The present study about the effect of adding Fan Palm natural fibers to concrete on the permeability property of the new composite by testing the compressive strength, density, UPV, the total water absorption, capillarity and sorptivity of the concrete showed significant effects on these properties. From the test results it can be concluded that adding natural fibers extracted from Fan Palm leaves to a percentage of 1.5% improve most of the tested properties of the concrete. More precisely, adding 1.5% of fibers increases the compressive strength of the concrete about 20%, decreases density about 4%, and effects slightly the UPV results; in addition, adding 1.5% fibers decreases total water absorption about 50% and the sorptivity about 26%. From these results more, durable concrete composite was obtained that needs more investigation to have this material used commercially related to life time and durability of the natural fibers in the concrete environments.

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