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EXPERIMENTAL STUDY OF THE EFFECT OF ADDING FAN PALM FIBERS ON CONCRETE DURABILITY EXPOSED TO SEVERE ENVIRONMENTS

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Abstract

Adding Fiber to Concrete became a common practice to improve its durability, but for environmental purposes, it is preferable to use natural fibers instead of synthetic ones. In addition, using fibers prepared from tree waste that improves many concrete physical and mechanical properties is environmentally effective and costly preferable. Natural fibers extracted from Fan Palm trees that were cured chemically when used in concrete lead to improvements in concrete physical and mechanical properties. On the other hand, one of the major challenges that faces the commercial use of natural fibers in concrete is its durability. For that reason, an experimental program was conducted to study the durability of natural fibers by measuring the volume stability of the concrete when exposed to different severe environment conditions. The investigation recorded the length change of concrete bars with 1% fiber volume fraction and without fibers when exposed to sea water, solution with 2% $MgSO_4$, 2% Na_2SO_4, and NaOH for a period of 150 days. The study was performed on three grades of concrete 30MPa ,40MPa, and 60MPa to monitor the effect of different concrete grades on the results. From the results, it can be concluded that adding Fan Palm fibers to concrete significantly improves its resistance when exposed to sea water, $MgSO_4$, Na_2SO_4, and NaOH solutions. After 150 days of exposure to harsh environment, the expansion of concrete bars for length change measurements was recorded for the concrete with fibers and compared to that of control mixture (without fibers). The reduction was between 20% and 40% for different Concrete grades and solutions. In Summary, Fan Palm Fibers maintain their durability in concrete when exposed to severe chemical exposures. In addition, adding natural fibers to concrete decreases concrete bar Expansion thus improves its durability.

Keywords:
Concrete; Durability; Natural fibers; Fan Palm; Length change; Chemical exposures

1 INTRODUCTION

In recent days, Concrete durability became a vital property beside its compressive strength for going towards friendly environmentally products. It’s well known the negative effect of the concrete production and manufacturing on the environment especially when studying the CO_2 emissions all over the construction process. For that, many new researchers have been working to decrease this effect by improving concrete durability [Criado 2014] [Torgal 2011]. In particular, volume stability is one of concrete durability concerns expressed by reducing shrinkage & expansion of concrete elements especially when exposed to severe chemical attack or environments. Besides, one of the preferred method to improve this property is when using waste recycled materials as an additive to the concrete mix where it improves also the greenness of the concrete [Dawood 2012] and [Kriker 2007] .

For these reasons, an experimental study was conducted to investigate the effect of adding natural fibers extracted from Fan Palm leaves 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.

Fibers extracted from natural plants are one of the preferred resources environmentally. 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] and [Faruk 2012].

Therefore, in a previous research, an experimental study was performed on Fan Palm fibers to overcome these obstacles [Machaka 2014]. 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] and [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 neutralised 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) [Machaka 2014]; 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].

As a consequence, in this study, 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.

Fig. 64: Fan Palm tree

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), manufactured by a Company for cement production, Chekka, in north Lebanon. The used superplasticizer in the concrete mix was (Type F) Sikament NN (High Range Water Reducing), Sika brand. Sikament NN is a highly effective dual action liquid superplasticizer. 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), manufactured by a Company for cement production, Chekka, in north Lebanon. The used superplasticizer in the concrete mix was (Type F) Sikament NN (High Range Water Reducing), Sika brand. Sikament NN is a highly effective dual action liquid superplasticizer.

Fig. 65 : Treated Fan Palm fibers

Tab.15. 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

The Dosage specified is between 0.83% by weight of cement depending on desired workability and strength. The Silica Fume is brought from SODAMCO Company, Beirut-Lebanon.

Tab.16. 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 %	

2.2 Mix proportions

To study the effect of adding Fan Palm fibers on concrete durability exposed to severe environment, three grades of concrete with three different water to cement ratio were prepared. These three grades are

C30, C40, and C60. The concrete mix design presented in Tab.3. The absolute volume method was used in the design. The aggregate weights are in dry condition.

Palm fibers were added to the mixer with the coarse aggregates. The amount of fibers was calculated based on the volume fraction of concrete noting that the mix proportions for the mixes shown in Tab.3 where for one cubic meter of concrete. The volume fraction used in this study is 1% for the three mixes. Specifically, the weight of fibers added for one cubic meter of concrete for all the concrete mixes equal to 5 Kg of dry fibers.

Tab. 17. Mix proportions

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

3 EXPERIMENTAL PROGRAM

3.1 Durability study

The evaluation of concrete durability was investigated based on the comparison of the length change measurement for the concrete specimens in different severe exposure mediums. This study carried out by measuring the length change in concrete prisms with time for each severe environment using the apparatus of length change measurement shown in Fig. 3. Practices from ASTM C1012 and ASTM C452 were used in this study.

Fig. 66 : Length change measurement apparatus

Five solutions were selected. These solutions are saturated lime water as a control, sea water from the sea shore at saadiet (South of Lebanon), 2% concentration of Magnesium Sulphate ($MgSO_4$), 2% concentration of Sodium Sulphate (Na_2SO_4), and finally solution of Sodium Hydroxide (NaOH) with 1N concentration.

The Comparison of length change measurements results obtained aim to study the effect of adding fiber to get the new composite Palm Natural Fiber Concrete (**PNFC**) compared to control concrete mixes (without fiber) for the different exposure environments, to study the effect of different Concrete grades with and without fiber for every exposure, and finally to study the effect of different exposure environment on the volume stability of concrete with and without fibers.

3.2 Specimen preparation and curing conditions

Concrete prisms 75*75*300 mm with steel studs at both ends were used in the investigation. For each concrete grade, ten concrete prisms were casted as control concrete while other ten were casted using 1% by volume of Palm Natural fiber with 3 cm fiber length. Sixty concrete bars were casted in total. All the concrete specimens were subjected to the five different solutions after 24 hours of casting. The ten specimens from each mix were divided in five containers of five different solutions, two in each one as shown in Fig. 4.

Fig. 67 Containers for durability tests

The five solutions were prepared according to the specified concentrations taking into consideration that the liquid solution volume must not be less or equal to four or five times the concrete specimens' volume in the container. In addition, the solutions were replaced after each test measurement at 7, 14, 30, 45, 60, 75, 90, 120, and 150 days.

3.3 Test methods

Using the length change measurement apparatus to read the length change for the concrete prisms in millimeters, the initial length for each prism was taken after removing the specimen from the molds after (24 hours of casting) and this reading was used as a starting record for the measured samples. The readings for length change measurements were recorded at 7 days, then at 14, 30, 45, 60, 75, 90, 120, and 150 days. The measurement was taken within 5 minutes from removing the specimen from the five solutions even that the specimen was covered by a towel submerged in the same solution to maintain the environment of exposure during the readings. The length change was measured using a dial gage with an accuracy of 0.002 mm as shown in Fig. 3. The final result used in the study was the average of two readings recorded for the two prisms of each concrete grade and solution. After that, the strains were calculated for comparison and plotted in the graphs as microstrains with time of exposure.

4 RESULTS AND DISCUSSION

The effect of adding Fan Palm natural fiber on the volume change of concrete was investigated by measuring the concrete expansion as length change measurement. The results of the length change measurement for concrete prism cured in saturated Lime water as a control are compared to the other four solutions. The length change due to concrete expansion was calculated in microstain, for the three different grades. Readings are recorded at several dates and the relation between length change in microstrain and time is plotted for each grade and exposure. To summarize, in this report the comparison was made at the final date of reading which is 150 days.

4.1 Typical length change figure

Fig. 5 shows a typical figure plotted for all solutions and grades. Results for concrete prism immersed in saturated lime water (Control solution) is plotted and presented as shown in Fig. 5 for concrete grade 40MPa for prisms with and without fiber.

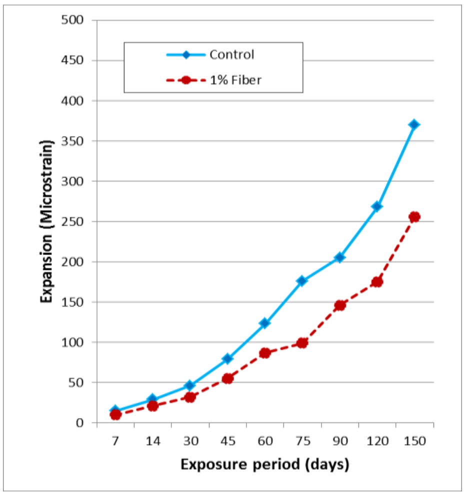

Fig. 5 Effect of adding fibers on the expansion of concrete prisms *(Grade 40MPa) immersed in* saturated lime *water*

The figure show that the length change after 150 days reach a value of 370 microstrain, where the length change recorded for concrete with1% Fan Palm fiber in the same solution and date was 256 days. From these results, we conclude that adding fiber to concrete decrease the length change measurements up to 17% at 150 days. The investigation was made to the sixty concrete prisms at the specified dates until 150 days and the results were recorded to plot figure for every grade and solution. From the obtained result, the percentages of reduction in length change were calculated and presented in the following results for every grade individually.

4.2 Length change of PNFC for grade 30MPa

The length change results presented in Tab. 4 shows that adding 1% volume fraction of fibers to concrete grade 30MPa decreases significantly the expansion of concrete prism in micro-strain and result in more durable composite. Fig. 6 shows the Percentage of length reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 30MPa and immersed in various solutions. These reductions are 7, 12, 17, 18, 42 percent for Sodium Hydroxide (NaOH) with 1N concentration, 2% concentration of Sodium Sulphate (Na_2SO_4), saturated lime water, 2% concentration of Magnesium Sulphate ($MgSO_4$), sea water, respectively. Tab. 4 and Fig. 6 shows that the most severe environment was when concrete subjected to sea water attack due to the presence of different salts (chloride, Sodium, Sulfate, Magnesium). The expansion of concrete prisms in micro-strain for grade 30MPa after 150 days, with and without fiber are 719 and 1238 respectively. The highest performance of Palm fiber concrete was found in sea water environment compared to 2% Magnesium Sulphate, saturated lime water, 2% Sodium Sulphate, and Sodium Hydroxide, with 1N concentration respectively.

Tab.18 Length change of concrete prism in microstrain for grade 30MPa at 150 days with and without fiber.

Exposure Condition	Control Concrete (without fiber)	Concrete with 1% fibers
Water Cured	476	393
Sea Water	1238	719
Na_2SO_4	571	502
NaOH	621	576
$MgSO_4$	1069	880

The least performance of palm fiber concrete was in sodium solutions and this due to the concentration in the alkali solution that attack the fibers itself noting that the volume expansion was smaller than that of magnesium sulfate and sea water.

4.3 Length change of PNFC for grade 40MPa

The results presented in Tab. 5 shows that adding 1% volume fraction of fibers to concrete grade 40MPa decreases significantly the expansion of concrete prism in microstrain up to 150 days. At first, it was noted that the results of length change smaller than that of 30MPa by about 20% and this due to the increase in the concrete strength. As for previous results, Fig. 7 shows the percentage of length reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 40MPa and immersed in various solutions. These reductions are 7, 2, 31, 8, 32 percent for Sodium Hydroxide (NaOH) with 1N concentration, 2% concentration of Sodium Sulphate (Na_2SO_4), saturated lime water, 2% concentration of Magnesium Sulphate ($MgSO_4$), sea water respectively.

Tab.19 Length change of concrete prism in microstrain For grade 40MPa at 150 days with and without fiber.

Exposure Condition	Control Concrete (without fiber)	Concrete with 1% fibers
Water Cured	370	256
Sea Water	1041	706
Na_2SO_4	745	727
NaOH	630	588
$MgSO_4$	808	743

Tab. 5 shows that the most severe environment was when concrete subjected to sea water attack which was the same results for concrete grade 30Mpa. The expansion of concrete prisms in microstrain for grade 40MPa after 150 days, with and without fiber are 706 and 1041 respectively. The highest performance of Palm fiber concrete was in sea water environment compared to saturated lime water, 2% Magnesium Sulphate, Sodium Hydroxide, with 1N concentration, and 2% Sodium Sulphate respectively.

The smaller effect was in sodium solution, we note that for sodium hydroxide, the reduction was approximately negligible. Concerning the concrete grade effect, for Control solution for example, the reduction was greater than that of grade 30, it was about 31% and this due to the increase in concrete strength that result in higher bond between fibers and cement matrix.

4.4 Length change of PNFC for grade 60MPa

As the behavior of concrete grade 30 Mpa and concrete grade 40 Mpa, the results presented in Tab. 6 shows that adding 1% volume fraction of fibers to concrete grade 60MPa also decreases significantly the expansion of concrete prism in microstrain up to 150 days.

Tab.20 Length change measurements in micro-strain For concrete grade 60MPa at 150 days.

Exposure Condition	Control Concrete (without fiber)	Concrete with 1% fibers
Water Cured	268	216
Sea Water	987	603
Na_2SO_4	643	638
NaOH	435	395
$MgSO_4$	786	546

Fig. 8 shows the percentage of length reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 60MPa and immersed in various solutions. These reductions are 9, 1, 19, 31, 39 percent for Sodium Hydroxide (NaOH) with 1N concentration, 2% concentration of Sodium Sulphate (Na_2SO_4), saturated lime water, 2% concentration of Magnesium Sulphate ($MgSO_4$), sea water, respectively. Table 6 also shows that the most severe environment was when concrete subjected to sea water attack which was the same results for concrete grad 30Mpa and 40Mpa. The length change of concrete prisms in microstrain for grade 60MPa after 150 days, with and without fiber are 603 and 987 respectively. The highest performance of Palm fiber concrete was in sea water environment compared to 2% Magnesium Sulphate, saturated lime water, Sodium Hydroxide, with 1N concentration, and 2% Sodium Sulphate respectively.

Fig. 8 also shows that the effect of using Palm fiber in concrete subjected to 2% Sodium Sulphate was insignificant (1%) . On the other hand, the performance of Palm fiber in concrete was moderate in the sodium hydroxide solution where the percentage of length reduction of concrete prism was about 9%. The superior effect of using Palm fiber in concrete was found in the case of sea water attack with *percentage of length change reduction of concrete prism* equal to 39%.

5 CONCLUSION

From the present study on the effect of adding natural Fan Palm Fiber to concrete on the length change measurement when exposed to severe environment, we conclude the following conclusions:

1. Adding Fan Palm Fibers to concrete improve its performance significantly in the length change when exposed to Sea water and Magnesium sulfate (The reduction was between 18% and 42%).
2. the reduction in the length change measurements when exposed to sodium solutions such as Sodium Sulfate and Sodium Hydroxide was insignificant compared to water cured concrete.
3. Adding Fan Palm Natural Fibers to concrete of different grades improves the performance of the water cured concrete, that represent normal condition of exposure, in resisting length change and thus increases its durability.

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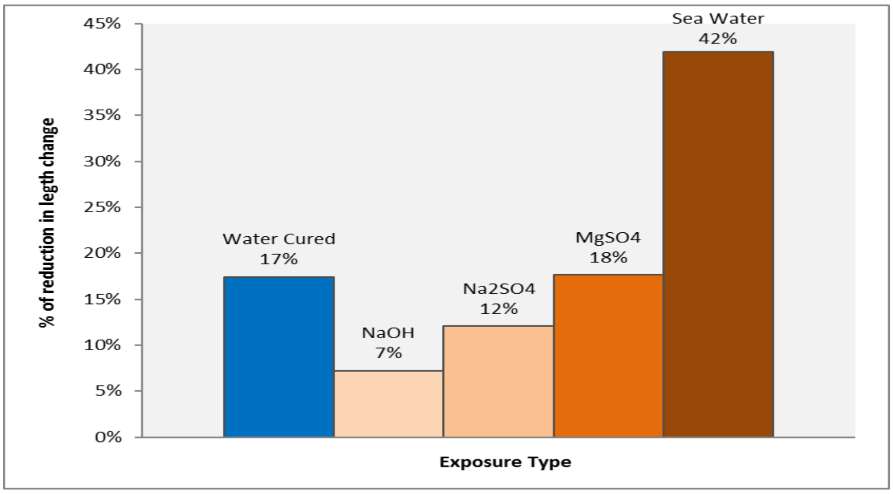

Fig. 6 Percentage of length change reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 30MPa, immersed in various solutions.

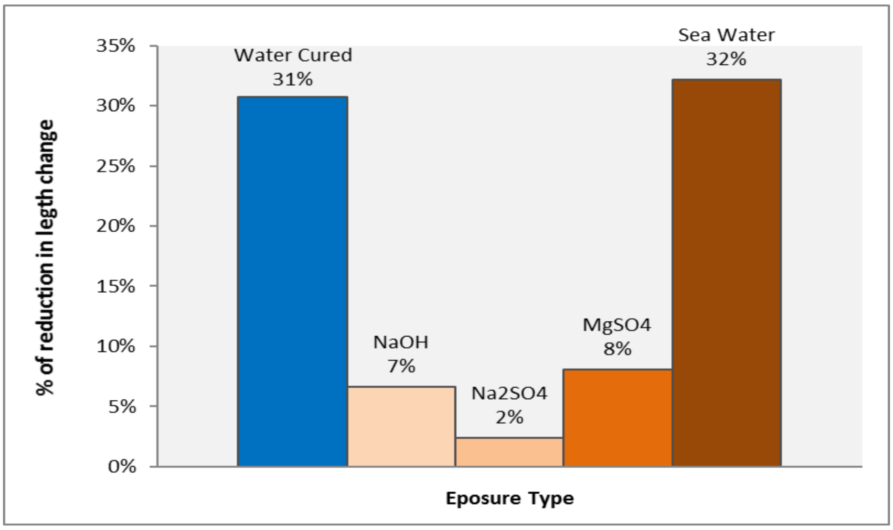

Fig. 7 Percentage of length change reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 40MPa, immersed in various solutions

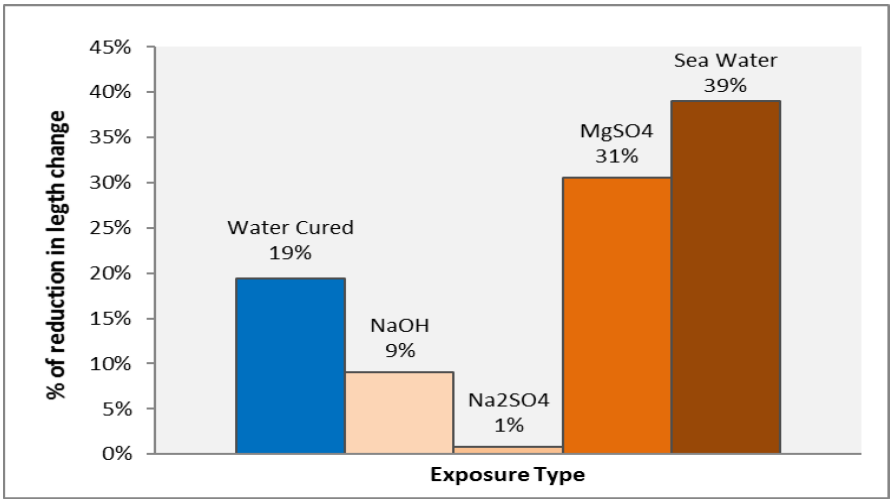

Fig. 8 Percentage of length change reduction of concrete prism with 1% fiber compared to concrete without fiber for Grade 60MPa, immersed in various solutions.