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Preliminary Study on the Effect of Adding Palm Tree Fronds to Concrete

Rana Ezzdine Lakys[1], Mohammad Hany Yassin[1], Zein-Eddine Merouani[1]
[1]The Australian University
PO Box 1411, Safat 13015, Kuwait City, Kuwait
r.lakys@ack.edu.kw; m.yassin@ack.edu.kw; z.merouani@ack.edu.kw

Abstract – Agriculture waste can be used in construction as an alternative to non-environmentally friendly components. Every year, a considerable amount of this waste is thrown without any recycling. In addition to its good tensile properties, natural fibers such as the ones extracted from palm tree fronds (PTF), can be used to enhance the thermal properties of concrete. The consistent increase in the planet temperature, increases the demands for AC usage and electricity consumption. This implies more CO_2 emissions and consequently more temperature rise. In this study, the concept of using this free natural waste in construction has been investigated. This paper is concerned with the use of PTF with concrete as a composite material. The tests that have been carried out on the PTF concrete (PTFC) are focused on the strength and durability of the composite material. Four PTFC mixes where prepared and casted into cylindrical molds for tests at several curing ages. The results indicate some improvement in the thermal resistance of concrete on the cost of its mechanical properties.

***Keywords*:** Palm tree frond concrete (PTFC), Natural fiber, water absorption

1. Introduction

The idea of using natural fibre, such as the palm tree frond (PTF), in constructing shelters has been in application for long time especially in the GCC area. The traditional dwelling, locally called *Arish*, was constructed mainly from the fronds on palm trees and were used during the summer season by locals as a cool living space [1]. Since its invention, concrete has dominated the construction field as the main used material due to its well-known advantages, availability, and efficiency. Studies have focused on the behaviour of concrete reinforced with steel and the mechanism of the composite failure, durability, and other physical and mechanical properties ever since.

The concept of introducing another material to concrete matrix is necessary in most applications in order to compensate for its weak tensile resistance. In many cases, such as in the case of non-structural components, using reinforcing fibres in concrete can provide sufficient tensile resistance and minimize or eliminate the formation of shrinkage cracks. Fibres can be fabricated or found in nature. The manufacture of synthetic fibers is quite expensive and consumes considerable energy. It is in this context that low modulus natural fibres, which are readily available in many parts of the world, could be put to their best advantage, particularly in the production of building components [2].

In addition to its mechanical effects on the performance of concrete [3]–[6], the natural fibres can contribute to the overall thermal resistance of the structure when added to the mix [7] and [8]. This might lead to replacement of the currently used non environmentally friendly insulation material [9] with naturally available material [4]. In this study, fine grinded PTF was added to concrete mix for several weight concentration (0%, 1%, 2% and 4 %) as partial replacement of sand in order to explore the effect of increasing the amount of added fibres on the properties of concrete.

2. PTF treatment and characteristics

The main drawback in using natural fibers, such as PTF, in construction is their high-water absorption leading to lower mechanical properties and poor fiber-matrix adhesion in concrete. This disadvantage might limit the applications of this constituent to some types of structures or purposes. The potential contribution to the tensile strength and thermal resistance shall be compared to the other negative effects of using this material.

Various chemical treatments have been used by many researchers in the past aiming to reduce this negative side effects of applying the natural fiber in concrete mixes. The most common treatment consists on Alkali treatment to clean the fiber surface by removing a certain amount of lignin, wax, and oils while depolymerizing the fibre cell wall [10], [11] improving the interfacial adhesion between the fiber and the cement paste. Furthermore the alkali treatment may promote the ionization of the hydroxyl groups to alkoxides [12] which may enhance the fibre durability in the concrete.

A previous study was performed in [14] to determine the water absorption by examining several Alkali treatments on Fan Palm fibre. The aim was to determine the optimum procedure that will improve the mechanical properties of Fan Palm fibre without causing serious deterioration to the fiber strucutre. The higher tensile strength of the fiber with the optimum roughness was obtained by treating the fibres for a duration of 24 h in a solution of 4% sodium hydroxide. The same treatment was applied for the PTF in this study.

A sieve analysis was conducted in order to determine the fibers size (length) distribution as per the [13]. The results are presented in Fig. 1. It shows that 35 % of fibers range below 0.15 mm while 85 % of fibers range between 0.5 mm and 2 mm.

The water absorption test of the treated PTF was performed for five samples of PTF giving an average value of 188% for the fibers water absorption. This high WA rate was considered in the mix design by adding extra water in mix. This extra water had also affected the overall strength of concrete as can be seen in the results part.

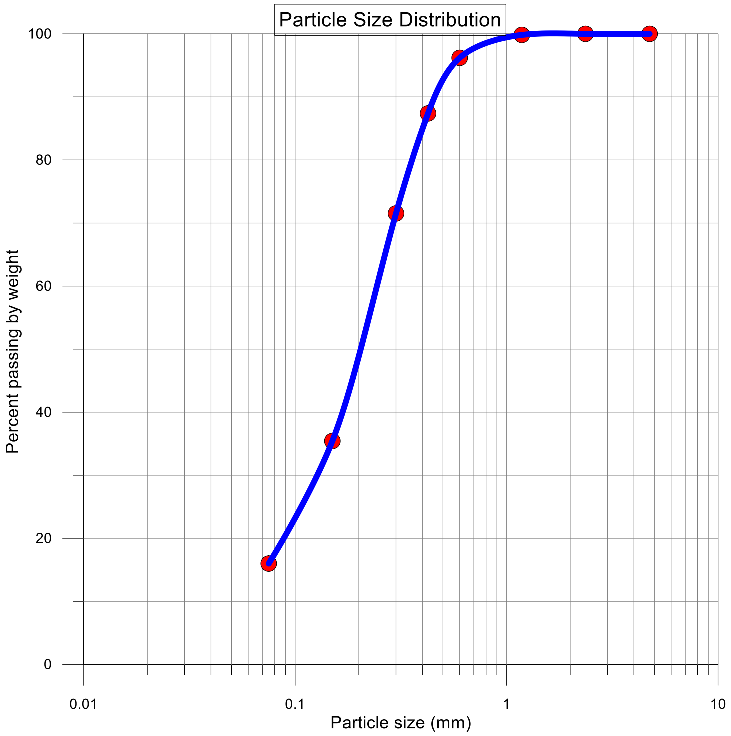

Fig. 1: Particle size distribution for the grinded fibers

3. Concrete mixing and specimen preparation

3.1. Mix Design

The concrete mix in this study was designed for grade 25 MPa as per the guidelines in [14]. Four mixtures were prepared and labelled based on the PTF percentage content. The used mix proportions for the four families are shown in Table 1. The mixes considered water correction to account for the water absorbed by the fibers.

3.2. Concrete mixing

Mixing procedure was performed according to [15]. The main concern regarding the mixing phase was related to the reduction of the water-cement ratio due to high water absorption of the fibres. In fact, the actual water-cement ratio is lower in comparison to its nominal value because of water transfer from fresh cement paste to fibres at early stage (during dormant period). The reduction of water-cement ratio in fresh concrete may lead to negative consequences such as loss of the mixture workability.

In order to minimize the water-cement reduction, the solution adopted in this study was by dosing additional water corresponding to water absorption of the fibres into the dry mixture (coarse aggregates + sand + fibers) before introducing the cement. The dry mixture is mixed with the additional water for several minutes (3 to 5 minutes) to allow enough time for the fibres to absorb water and eliminate any excessive water that may result in a higher w/c than was assumed and consequently reducing the concrete strength and durability.

The temperature for all different families was varying between 28℃ and 29 ℃, which indicates a good quality concrete as per [16] in which a maximum limit between 26.7°C and 35°C is specified. Moreover, the workability of the mixes were checked by mean of slump test as can be seen in the next section.

3.3. Specimen preparation and testing plan

Cylindrical specimens having diameter of 150 mm and length of 300 mm were prepared according 0. A total of 144 specimens were fabricated and moist cured, 36 specimens for each family. Originally, the experimental plan consisted of performing each of the tests (water absorption, compression test, and split tensile test) on six samples from each family at 7 days and 28 days. Due to COVID-19 pandemic and the lab shutdown, the experimental plan was not fully achieved with a delay period of 5 months for the testing at 28.

Table 1: Concrete Mix Design per 1 m^3

Family	**Cement [kg]**	**Water [ℓ]**	**Aggregate (12.5 mm) [kg]**	**Aggregate (9.5mm) [kg]**	**Sand [kg]**	**PTF [kg]**	**Admixture [ℓ]**
CM	280	195	453.5	453.5	710	0.0	3
P1					687.2	22.8	
P2					664.5	45.5	
P4					618.9	91.1	

CM: Control mix family, **P1: Concrete with 1 % PTF**, **P2: Concrete with 2 % PTF**, **P4: Concrete with 4 % PTF**

4. Results

Given the large number of tested samples obtained from different mixes, it was considered necessary to proceed to data mining in order to remove any outlier that may affect the representativity of the results. During the evaluation of samples' measurements, human, mixing or testing machines related errors may occur that could lead to wrong conclusions. Therefore, these data points are called outliers and should be eliminated based on an objective criterion. This can be achieved by using statistically sound test for the detection of outliers. In this study, the Dixon's Q-test chosen due to its simplicity and because it can be applicable when the sample size is less or equal to 25 (sample size in this study is equal to 6) [17]. Any data point flagged as outlier according to Dixon test is rejected and eliminated from the analysis of results presented in the following paragraphs.

4.1 Slump test

The slump test was performed on fresh concrete to assess the effect of added fibers on the workability of the concrete. The results are presented in

Table 2 and Fig. 2. The high workability might be contributed to the water correction that was considered in the mix design.

Table 2: Slump test results

Family	S [mm]	Index
P1	130	High workability
P2	150	High workability
P4	180	High workability

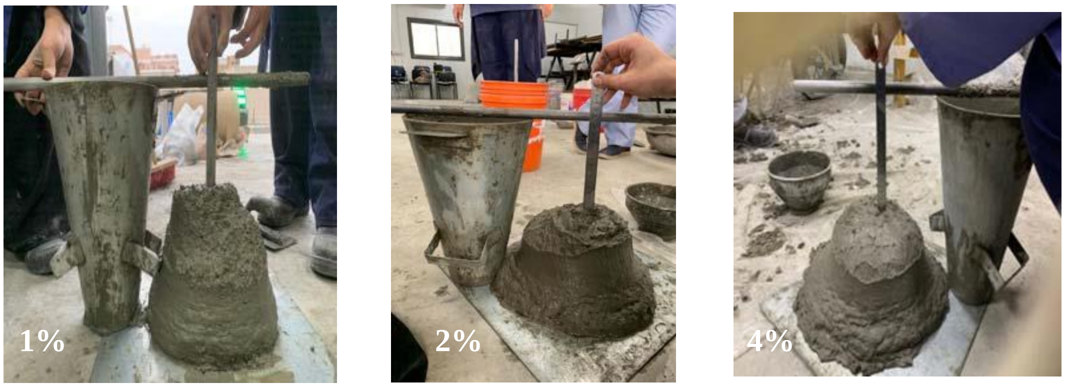

Fig. 2: Slump test for 1%, 2% and 4% PTFC

4.2 Saturated density

Table 3 shows the saturated density of samples for the 4 families CM, P1, P2 and P4. The latter shows large values of the standard deviation compared with the other mixes. The densities of 1% and 2% PTF samples were very close. It decreases for 4% PTF mix. However, the trend of decreasing density with increasing PTF content was expected. This trend is quantified in with the polynomial model shown in the figure. The predicted density for CM from the model is 2318.4 kg/m3 while the experimental average density is 2272 kg/m^3. This model can be used to predict the variation of the density with any added percentage of PTF.

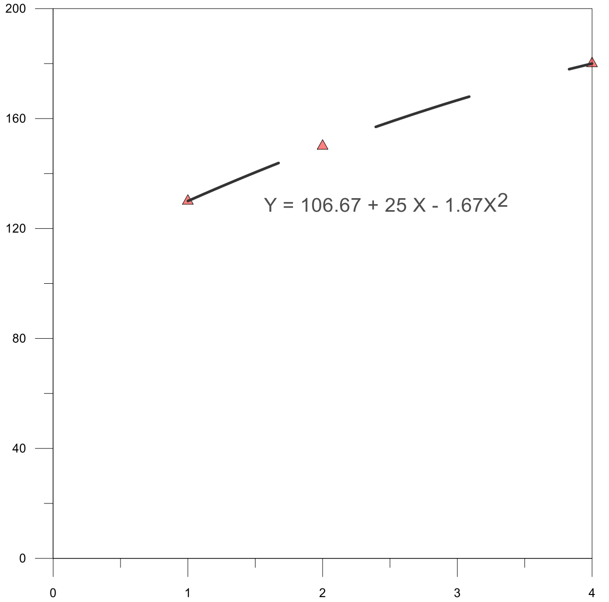

Fig. 3 : Slump of fresh concrete versus PTF%

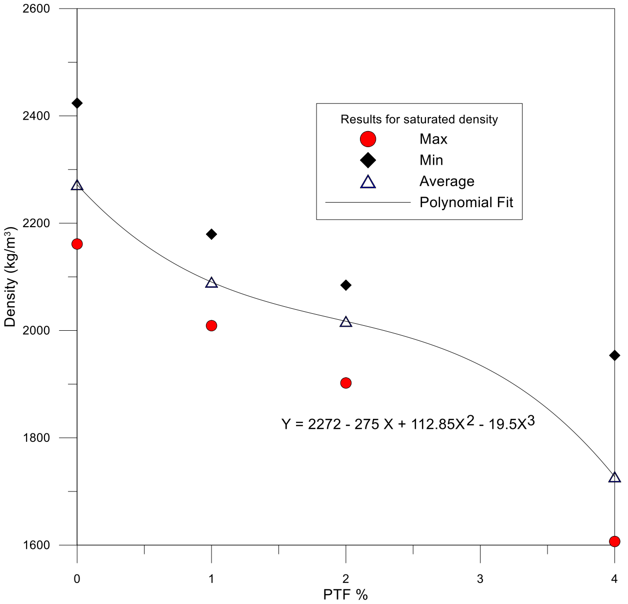

Fig. 4: Saturated density versus PTF%

Table 3: Saturated density results

Family	PTF (%)	Min (kg/m^3)	Max (kg/m^3)	Average (kg/m^3)
CM	0%	2161	2424	2272
P1	1%	2009	2180	2090
P2	2%	1902	2085	2017
P4	4%	1607	1954	1727

4.3 Water absorption results

A previous study [8] demonstrates that date palm fibres show an enormous capacity for water absorption reaching up to 3 times its dry weight. According to this study, the absorption of natural fibres are greatly affected by the fibres size and their chemical composition, particularly their cellulose content.

Table 4 and Fig. 5 both show the results obtained for the water absorption for all the families at 7 days and at 5 months. Unfortunately, the results for the CM are not available at 5 months due to shutdown reasons. The results indicate that the addition of PTF fibres in the concrete causes an important increase of the water absorption at 7 days. Similar result was reported by [8] and it was related to the hygroscopic nature of the fibres. However, the obtained results in this study show that the water absorption of the PTF concrete decrease with curing age. The polynomial models representing this variation are obtained with very high correlation factors and can be used to predict the water absorption of PTF concrete according to the added PTF percentage.

Table 4: Results of water absorption for all families at day 7 and 5 months

Family	PTF (%)	Results at 7 days			Results at 5 months		
		Min (%)	Max (%)	Av. (%)	Min (%)	Max (%)	Av. (%)
CM	0%	6.3	6.7	6.5	N/A	N/A	N/A
P1	1%	9.7	10.7	10.2	7.7	8.1	7.9
P2	2%	10.4	13.7	12.2	8.5	9.8	8.9
P4	4%	10.9	12.7	11.6	8.1	12.1	9.8

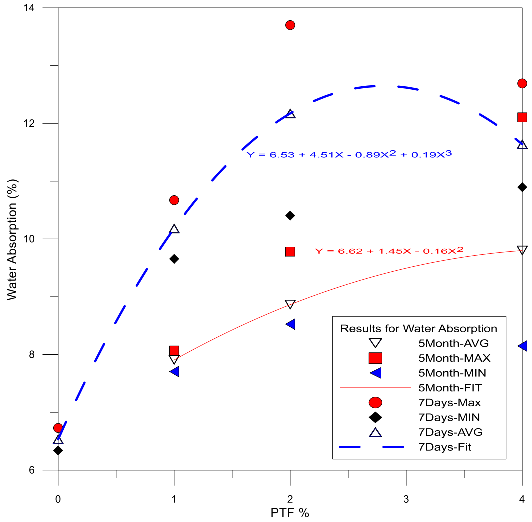

Fig. 5 : Water absorption at 7 and 180 days versus PTF%

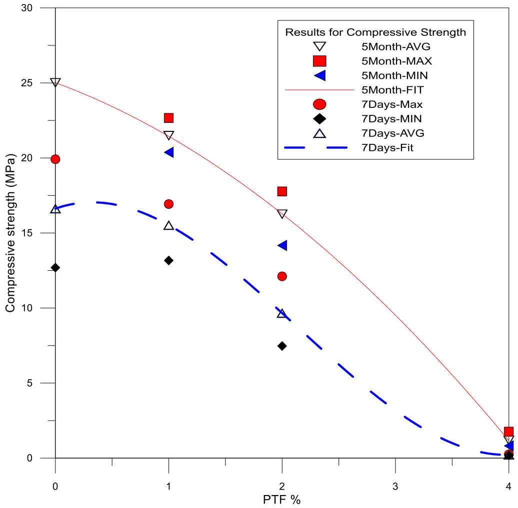

Fig. 6: Compressive strength at 7 and 180 days versus PTF%

4.4 Compressive strength results

Compressive strength is one of the most important mechanical properties of building materials and therefore knowing how it varies when adding PTF is a crucial step in this study. Fig. 6 and Table 5 show the compressive strength of all mixes after 7 and 180 days (5 months). The results indicate a reduction of the compressive strength varying from 6.6 % at 7 days and 14 % at 180 days when adding 1% PTF to 98.6 % at 7 days and 95 % at 180 days when adding 4 % PTF. These results show that PTF concentration higher than 1 % can be detrimental for the compressive strength of the concrete.

4.5 Split tensile strength results

The split tensile strength of concrete affect greatly the extent and size of cracking in structures. Previous study [6] shows that adding natural fibres such as PTF may improve significantly the split tensile strength of concrete at grade 30 MPa. However, this improvement was slighter for higher grades such as 40 and 60 MPa. The results of the split tensile test in this study are shown in Table 6 and Fig. 8. Unfortunately, the results of the split tensile test are not available for the 3% PTF concrete. Samples with 4% PTF were extremely weak at 7 days, and they remained weak after many months. In this case, also it shows a slight reduction in the split tensile strength with 1% PTF at the age of 7 days and 180 days.

Table 5: Results of the compression test at 7 days and 180 days

Family	**PTF (%)**	**Compressive strength at 7 days (MPa)**			**Compressive strength at 180 days (MPa)**		
		Min	Max	Av.	Min	Max	Av.
CM	0%	12.7	19.9	16.6	23.7	26.4	25
P1	1%	13.2	16.9	15.5	20.4	22.7	21.5
P2	2%	7.5	12.1	9.7	14.2	17.8	16.2
P4	4%	0.19	0.25	0.22	0.81	1.77	1.17

Fig. 7 Split tensile apparatus

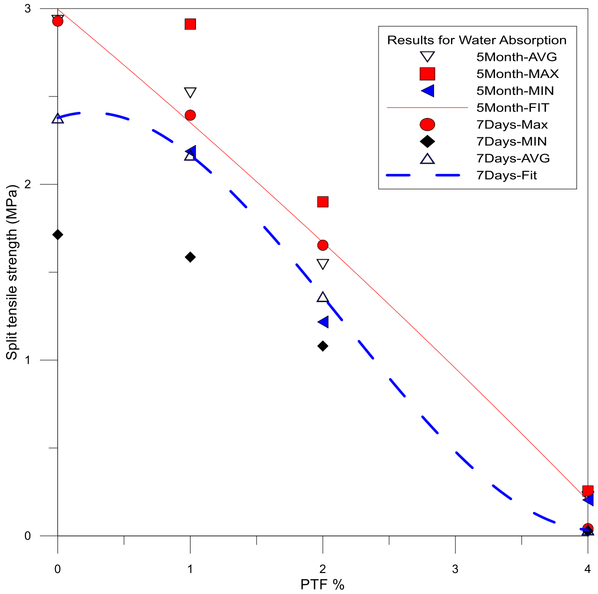

Fig. 8 Split tensile strength at 7 and 180 days

Table 6: Results of the split tensile test at 7 days and 180 days

Family	**PTF (%)**	**Split tensile strength (MPa) at 7 days**			**Split tensile strength (MPa) at 180 days**		
		Min	Max	Av.	Min	Max	Av.
CM	0%	1.7	2.9	2.4	2.5	3.4	2.9
P1	1%	1.6	2.4	2.2	2.2	2.9	2.5
P2	2%	1.1	1.7	1.4	1.2	1.9	1.5
P4	4%	0.03	0.04	0.03	0.20	0.26	0.22

5. Conclusion

The preliminary tests that have been carried during the current study on PTF concrete showed a number of results that helped the research team to deal with a number of issues to be investigated in the future. The experimental investigations indicate that increasing the PTF content in the concrete allows lightening the concrete but results in reducing its mechanical properties.

However, the results obtained when adding only 1% of PTF of weight concentration are interesting as they show a reduction in the mechanical properties that may be considered acceptable when compared to the results obtained for higher PTF concentration.

This indicates that at low concentration, 1 % or less of weight concentration, the PTF concrete may be used as structural and thermal insulators. More investigation will be conducted by the research team in order to identify the optimum ratio of PTF that will allow obtaining a new bio-composite with good thermal and mechanical properties that can be used as a new construction material for energy efficiency in buildings.

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