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Using local materials (palm fronds) to improve the properties of concrete

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ABSTRACT

The Concrete is one of the most widely used construction materials. However, improving its mechanical properties, particularly its tensile strength and resistance to cracking, remains a significant challenge in civil engineering. This study aims to investigate the effects of incorporating natural palm frond fibers, 1 cm in length, on the properties of fresh and hardened concrete.

The experimental program was divided into two phases. The first phase involved preliminary tests on the constituent materials, including cement, fine aggregate, coarse aggregate, and water, to verify their compliance with the relevant standard specifications. The second phase involved preparing and testing five concrete mixtures: a control mixture without fibers and four mixtures containing palm frond fibers at proportions of 0.5%, 1%, 1.5%, and 2% by weight of cement.

The experimental tests included the slump test to evaluate the workability of fresh concrete, compressive and tensile strength tests at curing ages of 7, 14, and 28 days, and a flexural strength test at 28 days. The results were used to evaluate the effects of different fiber contents on concrete performance and compare the fiber-reinforced mixtures with the control mixture. The study aims to assess the

potential of palm frond fibers as a natural additive for improving the mechanical properties of concrete while promoting the sustainable utilization of agricultural waste

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Keywords: palm fronds, compressive strength, tensile strength, coarse aggregate, fine aggregate, Failure, design

1. Introduction

Concrete is one of the most widely used construction materials due to its high compressive strength, the widespread availability of its constituent materials, and its ease of placement and molding. However, its relatively low tensile strength and susceptibility to cracking remain significant challenges that may affect its performance and durability. Consequently, numerous studies have investigated the use of supplementary materials to improve concrete properties. Among these approaches, the incorporation of environmentally friendly natural fibers has attracted attention because such fibers may help control crack development and improve certain mechanical properties. In Libya, where hot and dry climatic conditions prevail across many regions, investigating locally available materials for concrete production is of particular interest. Palm fronds, which constitute a readily available form of agricultural waste, represent a potential source of natural fibers for use in concrete. Utilizing these residues may contribute to the efficient use of local resources and promote more sustainable waste management practices. In this context, the present study investigates the use of palm frond fibers, 1 cm in length, as an additive in concrete and evaluates the effects of different fiber contents on the properties of fresh and hardened concrete. The main problem addressed in this study is the relatively low tensile strength of concrete and its susceptibility to cracking, which necessitates investigating alternative materials that may improve concrete performance while remaining economically and environmentally viable. Although natural plant fibers offer potential benefits, their effects depend on factors such as fiber type, length, and proportion. Therefore, systematic experimental investigation is required to determine the influence of palm frond fibers at different contents on concrete properties. Accordingly, this study aims to evaluate the effects of incorporating palm frond fibers at proportions of 0.5%, 1%, 1.5%, and 2% by weight of cement, focusing on workability, compressive strength, tensile strength, and flexural strength, and comparing the results with those of a reference mixture containing no fibers. Several previous studies have investigated the use of palm

residues and other natural fibers in concrete. Oguzhan Yavuz Bayraktara et al. (2022) [1] investigated the feasibility of using palm leaves in concrete production as a replacement for CEN standard sand at proportions of 0%, 5%, 10%, 20%, 30%, and 40%; the study also examined a 10% replacement level involving cement, although the precise procedure requires verification from the original publication. Haifaa Al-Aboudi and Zainab Hassan (2022) [2] reported that a concrete mixture containing 1% vegetable fibers achieved higher compressive strength than both plain concrete and a mixture containing 5% vegetable fibers. Rana Lakys, Mohammad Yassin, and Zein-Eddine Merouani (2022) [3] found that incorporating palm tree fronds (PTF) at a concentration of 1% by weight resulted in reductions in mechanical properties that could be considered acceptable compared with the reductions observed at higher PTF concentrations. Nursiah Chairunnisa, Ratni Nurwidayati, and Gusti Muhammad Madani (2021) [4] found that adding 0.12% alkali-treated banana fibers improved the mechanical strength of concrete, indicating their potential application in self-compacting concrete. Mohammad Yassin et al. (2020) [5] investigated the use of palm tree frond materials as a partial replacement for fine aggregate at proportions below 1%, and their findings suggested that PTF powder could potentially improve the thermal and mechanical properties of concrete more effectively than PTF fibers. Loughi Tariq and Bin Musa Boubaker (2019) [6] reported that concrete containing 1% fibers exhibited a 6.11% improvement in flexural strength compared with the control mixture, whereas a mixture containing 2% fibers showed a 51% reduction relative to the control mixture. Siti Osmi et al. (2022) [7] reported that increasing the proportion of the material identified as PLAF improved the compressive strength, flexural strength, and splitting tensile strength of concrete, with the highest mechanical performance reported at a content of 0.3%; however, the precise meaning of PLAF should be confirmed from the original publication. Kayibanda Patrick, Richard Ocharo Onchiri, and Geoffrey N. (2019) [8] found that incorporating pineapple leaf fibers (PALF) increased concrete water absorption as the fiber content increased, although the fibers were also reported to improve the strength of normal-strength concrete. Similarly, R. Abhirami and D. S. Vijayan (2020) [9] reported that adding PALF at a content of 0.1% increased compressive strength by up to 30.62% and improved the mechanical properties of fiber-reinforced concrete compared with conventional concrete. Collectively, these studies indicate that natural fibers may influence concrete performance, although their effectiveness depends on the fiber type and content. Therefore, the present study focuses specifically on palm frond fibers measuring 1 cm in length and evaluates four addition proportions to identify the content that provides the most favorable overall

performance under the investigated experimental conditions.

1.1Plant fibers

They are fibrous biological structures consisting of cellulose, hemicellulose, and lignin. In a relatively small percentage Non-nitrogen extracts, crude protein materials, fats and minerals. The proportions of these components depend on A large limit on the species, age and members of the plant, as this type of local material is used with different places The original, in improving the mechanical properties of concrete, especially its resistance to tensile and deformation.

Plant fibers also have a low thermal conductivity that can be used for thermal insulation.

1.2Palm fronds

A palm branch or palm fronds are the branched leaves of a palm tree, which are feathery in shape, rough in texture, and have sharp tips, or what is also called palm leaf or wicker.

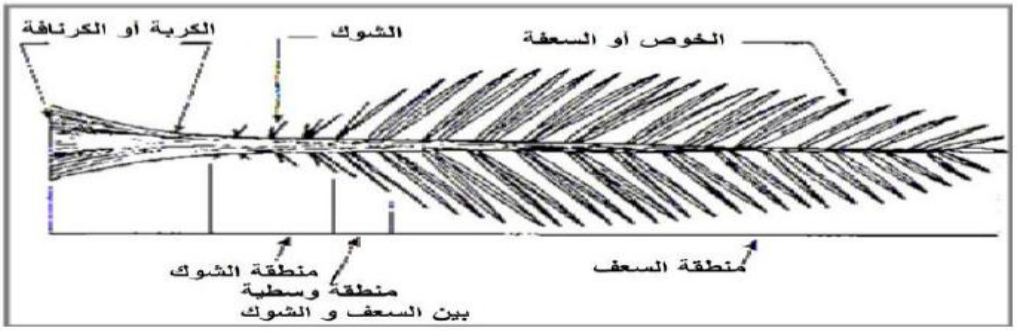


Figure 1 :Palm fronds components

The number of palm trees in Libya is estimated at about 9 million palm trees, according to the statistics of the Ministry of Agriculture for the year (2010).

Based on what we mentioned, each leaf contains, on average, about 180 palm fronds, and each frond weighs 5 grams. Within a year, he left behind about 15 newspapers.

Accordingly, the amount of palm fronds leftovers can be estimated at about 121.5 thousand tons annually Through this approximate estimation of date palm waste, we selected the fronds of the date palm leaf as an additive to the concrete.



Figure2 : Leaf and palm fronds used.

1.3 Physical properties of palm frond

Strengthening mechanisms have triggered interest among researchers to enhance the mechanical properties such as compression, tensile, flexural, or impact strength, and wear behavior that signify the high achievement of good materials. There is a strong indication that the fiber-matrix properties are important in improving mechanical properties that determine the capability of material under extreme loading as well as in critical conditions.

Palm fronds have many physical properties **[12]**, the most important of which are shown in Table 1.

Table 1: physical properties of palm frond

Density (g/cm3)	1-1.2
Tensile strength (MPa)	97-196
Young's modulus (MPa)	2.5-5.4
Deformity (%)	2-4.5

1.4 Chemical properties of palm frond

A chemical property is a characteristic or behavior of a substance that could be discovered when it undergoes a chemical alternate or response. Chemical homes are visible either during or following a response, considering the fact that the association of atoms inside a pattern ought to be disrupted for the property to be investigated. That is one-of-a-kind from a bodily property, which is a attribute which may be determined and measured without changing the chemical identity of a specimen. Within the average fibers we've got the cellulose, hemicellulose, lignin are the principal chemical properties**[11]**,, Table 2 shows the most important chemical properties of palm fronds.

Table 2: chemical properties of palm frond.

Cellulose (%)	43.05
Hemicellulos (%)	31.34
Cellulose lignin (%)	25.6

1.4.1 Cellulose

It is a polysaccharide compound made of several linked glucose units. It is a distinct structural component of the cell walls in plants, and also in some oomycetes and algae. It is the most abundant organic polymer found on Earth. Cellulose is mostly obtained from cotton and wood pulp for commercial purposes. Cotton fiber has approximately 90% cellulose content, while wood has around 40-50%.

1.4.2 Hemicellulose

They are polysaccharides that are closely related to cellulose. Hemicellulose is made of several units of glucose, xylose, mannose, rhamnose, galactose and arabinose. It has short and branched sugar units when compared to cellulose that has unbranched linear units.

1.4.3 Lignin

It is an organic polymer found in most plant tissues. It is vital in the development of cell walls, especially in bark and wood. Lignin provides rigidity and also prevents rotting. It is a cross-linked polymer that fills the gap between cellulose, pectin and hemicellulose in the cell walls. Also, it is found in vascular and supporting tissues. It plays a crucial role in conducting nutrients and water in stems. This lignin is present in most vascular plants.

2 Material and proportion

In this study, the same materials were used throughout the testing and specimen casting periods. All materials were obtained from the same sources, maintained consistent characteristics, and complied with the relevant British Standards (BS).

2.1**Coarse Aggregates**

In this study, coarse aggregate from the city of sirte were used, specifically the Al-shawish quarry. The results of the primary sieve analysis were as follows:

Table 3 : Sieve analysis of coarse aggregate

Sieve opening (mm)	*Weight retained (g)*	*Retained (g)*	*Cumulative retained (%)*	*Passing (%)*	*BSI specification*
20	*0*	*0*	*0%*	*100%*	*95-100*
14	*1079.5*	*1079.5*	*53.98%*	*46.02%*	*40-70*
10	*840.6*	*1920.1*	*96.03%*	*3.97%*	*30-60*
5	*75.4*	*1995.5*	*99.79%*	*0.21%*	*0-10*
Pan	*4*	*1999.5*	*100%*	*0%*	*0*

Through the results in table (3), we notice that there is a shortage in the aggregate passing through the sieve 10. Therefore, the experiment was repeated by adding the required size, which is the aggregate with a size of 10 mm, by (30%) of the total weight of the aggregate. The results were as shown in the following table (4).

Table 4: sieve analysis of coarse aggregate

Sieve opening (mm)	*Weight retained (g)*	*Retained (g)*	*Cumulative retained (%)*	*Passing (%)*	*BSI specification*
20	*0*	*0*	*0%*	*100%*	*95-100*
14	*1140.4*	*1140.4*	*38.02%*	*61.99%*	*40-70*
10	*898.3*	*2038.7*	*67.95%*	*32.05%*	*30-60*
5	*737.7*	*2776.4*	*92.54%*	*7.46%*	*0-10*
Pan	*223*	*2999.4*	*100%*	*0%*	*0*

The second time two sizes of coarse aggregates, 15 mm and 10 mm, were used in the mixture, and the gradation was well within British specifications.

"BS 882 1992 Aggregates For Concrete " As for the rest of the results of the characteristics of the coarse aggregate used in this project as measured in the laboratory, they were as follows:

Table 5: properties of coarse aggregate

Properties of coarse aggregate	*SIZE(10)*	*SIZE(15)*
Specific Gravity	*2.68*	*2.64*
Absorption	*1.98%*	*1.96%*
Moisture content	*1.2%*	*1.064%*
Abrasion	*18%*	*19.4%*
Unit weight (in loose condition)	*1118.8kg/m³*	*1101.4kg/m³*
Unit weight (in compacted condition)	*1190.9kg/m³*	*1157kg/m³*

2.2 Fine aggregate

In this study, the sand of the city of sirte was used, specifically the sand of the sawawa region, and the gradation was good within the required specifications according to the British code, "BS 882 1992 Aggregates for Concrete" as shown in Table (6) The specific weight of fine aggregate, moisture content, and absorption ratio were also tested, Table (7) shows the properties of fine aggregate.

Table 6: Sieve analysis of fine aggregate

Sieve opening (mm)	*Weight retained (g)*	*Retained (g)*	*Cumulative retained (%)*	*Passing (%)*	*BS specification*
4.75	*0*	*0*	*0%*	*100%*	*85-100*
2.36	*0*	*0*	*0%*	*100%*	*85-100*
1.18	*2.2*	*2.2*	*0.44%*	*99.56%*	*75-100*
600µm	*147*	*149.2*	*29.89%*	*70.11%*	*60-79*
300µm	*208*	*357.2*	*71.58%*	*28.42%*	*12-40*
150µm	*78*	*435.2*	*87.21%*	*12.79%*	*0-15*
75µm	*60*	*495.2*	*99.23%*	*0.77%*	*0-15*
pan	*38*	*499*	*100%*	*0%*	*0*

Table 7: Properties of fine aggregate

Specific Gravity	*2.78*
Absorption	*1.31 %*
Moisture content	*2%*
Unit weight (in loose condition)	*1600 Kg/$\boldsymbol{m^3}$*
Unit weight (in compacted condition)	*1620 Kg/$\boldsymbol{m^3}$*

2.3 Cement

An ordinary Portland cement (OPC) cement of (42.5N) conforming to the Libyan standard specifications No.340/2009 was used to obtain a mixture that conforms to the code specifications.

2.4 Palm fronds

Throughout history, palm fronds have been widely used, whether green or dry, in many fields, including traditional industries, agriculture ,and nutrition….etc.

The palm fronds can be obtained from the palm tree. The fronds are found in the upper part of the tree, palm fronds are considered a natural material and are abundant in our country. It has good properties when used in concrete mix the compressive and tensile strength. In this study, the frond fibers were cut to a length of (1cm), The fronds were also washed and soaked in water for 24 hours, then dried

well before using them in the mixture for an operational increase in the mixture in different proportions (0.5%,1%, 1.5%, 2 %) of the weight of the cement.

It is preferable to use sodium hydroxide to treat palm fronds, as it cleans the surface of the fibers and increases the roughness of the fibers through chemical modification to increase the bond between them and the concrete mixture, However, we did not obtain this compound, so tests were conducted by washing the fronds and using them



Figure 3. The shape and length of the palm fronds

3 Mix design

In this study. The concrete mix is designed according to the American Code ACI, The ACI Standard 211.1 is a "Recommended Practice for Selecting Proportions for Concrete".

3.1 Mix proportions

For the control mix design, we used materials in table (8).

Table 8: mix design of material for 0.04m³ concrete by ACI method

Stage Item	*Value*
Coarse aggregate type	*Crushed*
Fine aggregate type	*Uncrushed*
Maximum aggregate size	*20 mm*
characteristic strength	*30 N/mm2*
Target mean compressive strength	*38 N/mm2*
Water/ cement ratio	*0.47*
Water content	*8.02kg*
Cement content	*17.08kg*
Total weight of aggregate	*39.68kg*

At each testing age, 10 cubic specimens, 9 cylindrical specimens, and 3 beam specimens were used to evaluate the mechanical properties of the concrete, as shown in the figure(4).



Figure 4. specimens after Casting

4 RESULTS AND DISCUSSION

4.1 Slump results

The slump of all tested concrete mixtures was maintained within the design limits within the range (2-8cm).

To avoid a high rate of absorption in the palm fronds mixture, the palm fronds are immersed in water for 24 hours to avoid reducing the mixture water due to the fronds absorbing water and to obtain the same level of slump in all mixtures and to increase the performance in concrete mixture in all proportions added to the fronds, palm fronds length was (1cm) in all mixtures. The following tables (8) show the percentage of palm fronds for each mixture and the results of the slump tests.

Table 9: percentage , length of palm fronds concrete mix and results of slump.

Mix symbol	*Percent of palm fronds % (cm)*	*Length of palm fronds (cm)*	*Slump (cm)*
Mix A	***0***	***1***	***7***
Mix B	***0.5***	***1***	***7.5***
Mix C	***1***	***1***	***8***
Mix D	***1.5***	***1***	***8***
Mix E	***2***	***1***	***8***

From Table (9) we notice that the slump values were close, where the maximum value of slump was 8 cm for the (C, D, and E) mixture, while the slump was for the control mixture (A) 7 cm, and this indicates that the palm fronds improved the workability of the concrete.

4.*2 Density of concrete*

concrete is poured into cylinder molds measuring (300×150mm) with nine cylinder ,the density of concrete was calculated for samples in the form of cylinder to clarify the effect of adding palm fronds on the density of concrete. The result shown in table (10).

Table 10 : the density of concrete

Mix symbol	*Weight(Kg)*	*Density (g/cm3)*		
	(kg)	*7 days*	*14 day*	*28day*
Mix A	*12.50*	*2.36*	*2.37*	*2.36*
Mix B	*12.56*	*2.36*	*2.36*	*2.36*
Mix C	*12.44*	*2.35*	*2.34*	*2.35*
Mix D	*12.38*	*2.33*	*2.34*	*2.34*
Mix E	*12.46*	*2.33*	*2.34*	*2.34*

We note that the density of the capacitive concrete was slightly less than the density of the control mixture, where the maximum density value was 2.37 g/cm³ and the lowest value was 2.33 g/cm³

4.3 Compressive strength

The compressive strength of (100 x100 x100) mm cube samples were measured, and the resistance was measured after 7, 14 and 28 day.

The compressive strength test result of the control concrete (without palm fronds), and when adding the palm fronds, in different proportion at (0.5, 1, 1.5 and 2%), are showing in figure (5).

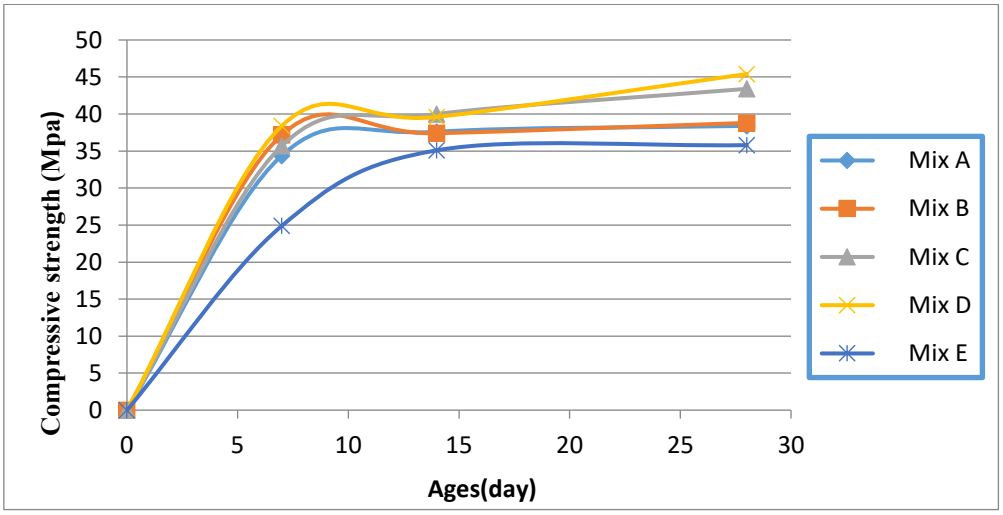


Figure (5): compressive strength of mixes at (7, 14, 28 day)

From the results in figure (5), we note that the compressive strength was improving for the mixtures (C, D) compared to the control mixture.And as for the mixture E,

we notice that the compressive strength value decreased significantly compared to the control mixture (A).

4.4 Splitting tensile strength

The result of splitting tensile strength test for control concrete mix (without fronds palm), and adding the palm fronds for concrete mix) A, B, C, D, E) at 7, 14, and 28day as shown figure (5).

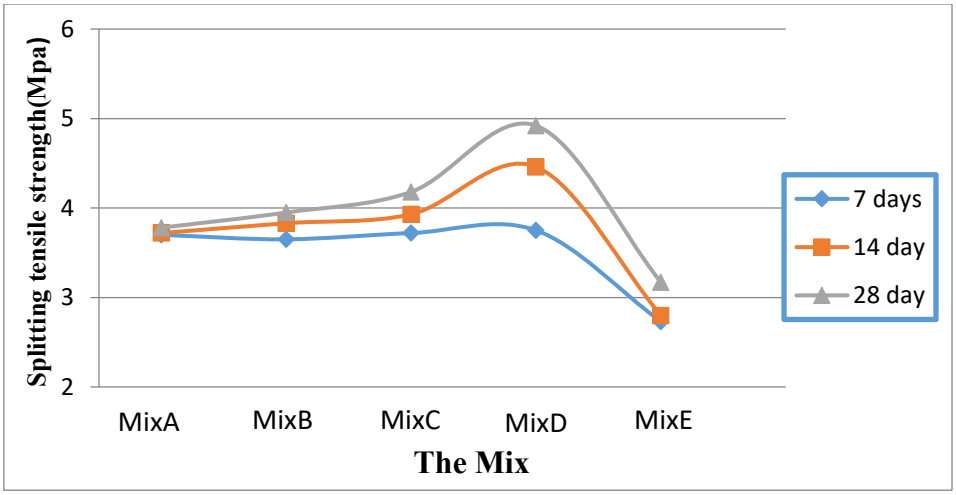


Figure 6: Splitting tensile strength of mixes at (7, 14, 28 day)

From the results in figure(6). we note that the Splitting tensile strength was improving for the mixtures (B , C , D). As for the mixture E, we notice that the Splitting tensile strength value decreased significantly compared to the control mixture (A).

4.5 Flexural strength

The result of Flexural strength test for control concrete mix (without palm fronds), and adding the palm fronds concrete mix (A,B,C,D,E) at 28 day as shown in figure (7).

Flexural strength at the age of 28 day mixed with different properties of palm fronds. An increase in flexural strength was observed when adding palm fronds ratios of 0.5, 1, and 1.5% compared with the control mixture, decrease in flexural strength was when the ratio was increased by 2%, and the best strength was at the ratio of 1.5%.

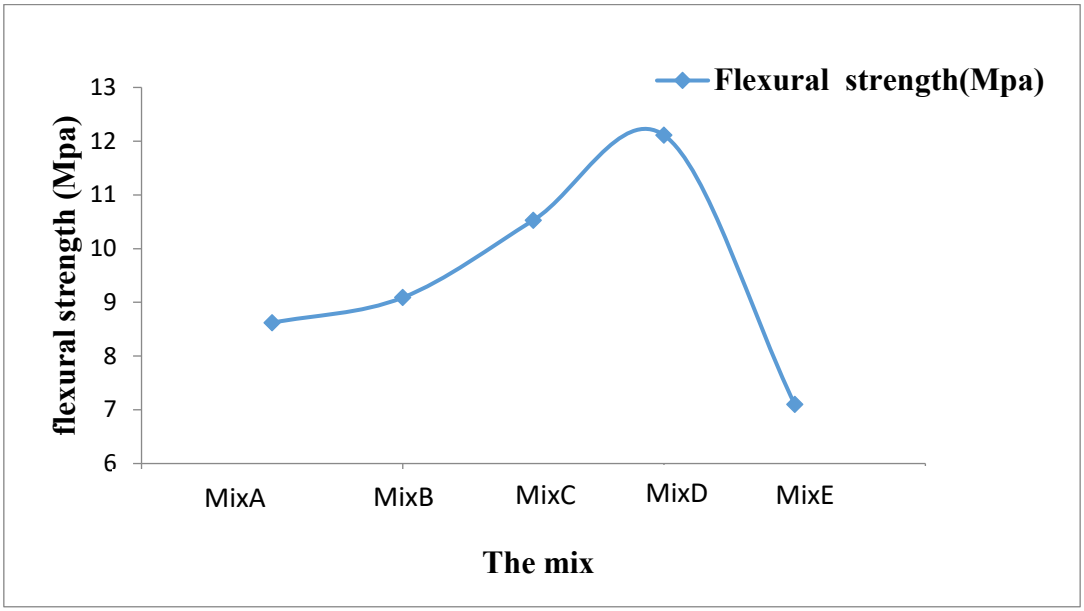


Figure (7): Flexural strength of mixes at (28 day)

4.6 Failure of concrete specimens

4.6.1 Compression failure

The form of failure in the cubes of the control mixture or when adding the fronds was among the expected forms of collapse and as shown in the figure (8).



Figure 8: failure in cubes with or without Palm fronds.

4 .6.2 Splitting tension failure

The shape of the failure in the tensile test of the cylinders is different from the pressure test. When the tension is applied to the cylinders, the failure is by splitting the cylinder in half. Figure (9) shows the forms of collapse for the tensile test.



Figure 9: failure in cylinder with or without Palm fronds.

4.6.3 5 Flexural failure

This failure mode occurs when the loads on the beam exceed its flexural capacity, Figure (10) shows the forms of collapse for the flexural test.



Figure 10: failure in beam with or without Palm fronds

5 Conclusion:

Based on the tests that were conducted on the palm concrete, whether it was fresh or solid, the following results were reached:

1. The effect of palm fronds on the properties of fresh and hardened concrete was clear.
2. Variation of the amount of palm fronds affects the mechanical properties of the concrete composite
3. As a result of using palm fronds of small lengths, workability was significantly improved, especially in the MIX C, MIX D, MIX E
4. The addition of palm fronds to an increase in compressive strength at 7 days was 11.63%, at 14 days the increase was 6.33% and at 28 day it was 18.23% when adding (1.5%).
5. As for the mixture (E) with the addition of 2% palm fronds, the result was a decrease in compressive strength by a large percentage of up to 6.77% after 28 day.
6. The effect of adding palm fronds to concrete was clear on Splitting tensile strength, as the strength increased after 7 days by 1.3% when adding (1.5%) of palm fronds, but after 14 day it increased by 19.9% and after 28 day it increased by 30.16%.

7. As for the mixture (E) with the addition of 2% palm fronds, the result was a decrease in splitting tensile strength by a large percentage of up to 19.24% after 28 day. The reduction in splitting tensile strength of mixture (E), containing 2% palm fronds, may be attributed to the increased void content within the concrete matrix and the high water absorption capacity of the fibers, which may reduce workability and weaken the bond between the fibers and the cementations matrix.
8. The effect of adding palm fronds to concrete was clear on flexural strength, as the strength increased after 28 day by 40.5% when adding (1.5%) of palm fronds.
9. As for the mixture (E) with the addition of 2% palm fronds, the result was a decrease in flexural strength by a large percentage of up to 17.63% after 28 day.

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