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Experimental Study on the Addition of Date palm Fibers as a Reinforcement in Gypsum Mortar

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Abstract— **Libya is considered one of the major Arab countries in the cultivation of palm trees, as it holds the fifth place in the Arab world in the number of palm trees with about 8 million of them planted on estimated area of 70 thousand hectares. The present paper aims to characterize date-palm fiber-reinforced gypsum mortar, where different percentages of palm fibers were added by substituting with various percentages of gypsum weight. Untreated date palm fibers have been used after extraction process from date tree as (leaf, root, sheath, trunk…). Physical properties of fibers have been measured as volumetric density, coefficient of absorption and water content. Natural date palm fibers have been used without treatment. For mortar cured up to 28 days, its composition which report W/G = 0.6. The present work consists of studying the effect of gypsum mortar reinforcing with different types of date palm fibers, with different lengths (0.53-19 cm) and different percentages (0-6%) on compression behavior in the hardened state. Cubic specimens' compressive strength was (7x7x7 cm), are removed after 24 hours and then conserved in dry air at 28 days for mechanical testing. The mechanical property of composites such as compressive strength of natural fiber composite was reported and compare with the data for control mix. It has been seen form compression test that palm composite has never been higher compressive strength than the control mix**.

Index Terms*:* **natural date palm fibers, gypsum mortar, physical and mechanical properties of fibers, compression test.**

I. INTRODUCTION

The natural fibers have always played a central role in civilization development since they possess optimal properties. Many scientific researches have shown the advantages of using natural fibers in composite materials. As specific fibers that are selected and introduced into building materials can improve their properties and reduce the total cost of construction or add them as a partial substitute for one of the components of concrete and thus can also support the use of sustainable materials. Natural fibers have many interesting properties as reinforcement by the composit**e**. Such as being low density, which gives relatively light composites with high specific characteristics.

Natural fibers also offer significant cost advantages and associated processing advantages, compared to synthetic fibers. The amounts of cellulose and hemicelluloses in date palm are lower in other natural fibers. As a result, the date palm has a significant amount of lignin compared to other natural fibers [1]. Usually a plant fiber is physically characterized by its diameter, density, water content and percentage of water absorption. It is characterized mechanically by its rupture tensile strength and by the modulus of elasticity [2]. Mahdi et al., 2015, [3] approved that the date palm leaf fiber (DPLF) showed high hydrophilic behavior and reached saturation (98.4%) within 24 hours. Natural Fibers have biodegradable characteristics; the alkali environment of the cement matrix leads to durability problems in the fibers. This will eventually cause reduction in fiber strength and toughness if these fibers were not treated to resist the effect of alkali attack. Moreover, weak bond interface between natural fibers and cement matrix reduces the influence of fibers to improve the performance of the new composite [4].

Today, of researches development, it is possible to obtain extremely resistant materials from a fiber and a fragile elastic matrix. Gypsum has a behavior defined as brittle elastic, that is to say that its failure occurs for relatively small deformations, and it also causes fairly extensive cracks. Gypsum is also hygroscopic, meaning it is susceptible to absorbing moisture, which is accompanied by expansion. Conversely, any departure of water induces a removal of the gypsum mass. Either phenomenon occurs depending on the relative humidity and temperature of the atmosphere, which vary greatly over the course of a year. These repetitive cycles of swelling and shrinkage induce very strong internal stresses in a partition, which causes spontaneous cracking. It is on this characteristic that the bibliographic collection on gypsum is most lacking, probably because the problems relating to setting are more sensitive on a cement; the setting time scales are in fact disproportionate, the setting time of the plaster being measured in tens of minutes, that of the cement in days. In order to improve the natural fiber-gypsum composite

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durability, chemical treatments with sodium hypochlorite and resin coating were carried out to decrease surface tension and improve adhesion with the matrix. Gallala et al., 2020, [5] concluded that the biocomposite showed satisfactory physical, thermal, and mechanical performances, which qualify it as a thermal insulation building material. By incorporating plant fibers into it, a modification of this behavior is generally observed [6]. Gallala et al., 2019 [7] thoroughly discusses date palm fibers, including fiber resources, the properties and treatments required to develop palm fiber-supported gypsum concrete. Gypsum concrete supported by date palm fibers was prepared with variable proportions of palm fibers with a ratio of W / G constant of 0.65, and then he made standard molds for testing. As the results, for the physical properties, increasing the percentage of fiber from 7 to 20% in gypsum concrete, it increased water absorption. This behavior is attributed to the fiber's porosity and its aqueous character which is mainly due to the presence of hemicelluloses.

In the construction sector the uses of natural fibers-gypsum composites are very limited; however they possess attractive properties compared to synthetic fibers-based cement composites. The valorization of this natural fiber and gypsum matrix in the development of the construction sector has several objectives: economic, technical and environmental. Furthermore, many gypsum manufactures are installed because the produced gypsum is mainly used for decorative purposes, although it has interesting thermal properties [8]. Previous studies show the need to interpret and expand the results of gypsum compounds and highlight areas that have not yet been developed and covered, because the commercial production of date palm compounds is still in its infancy, and more efforts should be made to improve formulations and processing standards.

In this paper, The performance of gypsum mortar reinforced with varying percentages and types of untreated date palm fibers is investigated to evaluate their feasibility for structural applications. Natural untreated date palm fiber properties are determined by the physical, mechanical properties. However, the effectiveness of palm fibers in improving gypsum concrete resistance will be tested, in order to obtain environmentally friendly concrete and have no harm to humans, environment. This work concludes that is efficiency of using untreated natural fibers reinforced gypsum composite in dry climate and the palm fibers can be used for the manufacture of reinforced mortars, but it requires controlling their preparation.

II. MATERIALS

A. Gypsum

The water-gypsum ratio (W/G) in the mixing process can vary from 0.6 to 0.8 or higher [9]. The gypsum ($CaSO_4$, $2H_2O$) used in this work is produced by Egypte (Egyptian gypsum code, EGS3C491C015). It is mixed with water, using a water-gypsum plaster of 0.6 by mass. It has been found that this gypsum mortar has a density of 1.2 g/cm^3 and corresponding to a maximum compressive strength of 11 MPa.

B. Date palm fibers

The tree stem in the date palm is surrounded by the mesh made from single fiber. Labib, 2019 [10] explained that the fiber is used for the creation of different diameters from the natural crossed fibers woven mat. Based on the traditional practices, the annual removal of the mat from the trees takes place for the removal of the ropes. The date palm contains a fibrous structure, containing four types of fibers as classified in [11]: 1-wood trunk fibers; 2- leaf fibers in the legs; 3- the leg fibers are at the level of the leg; 4.the superficial fibers around the trunk or at the kernaf. However, fibrous materials between the kernaf and the trunk so called leaf.

Using of leaf fiber with concrete has a significant improvement in compressive strength. The best fiber content was 0.8% and 1% of treated and untreated leaf fiber respectively [12]. A fruitful date palm known as Al Bekrari was brought from the eastern coast of Libya, in order to perform all laboratory tests on it. The preparation was made by first cutting the date palm tree with an electric saw into small pieces to facilitate the extraction of the fibers from it, see Figure. 1. Then the fibers were separated manually as indicated in Figure. 2 or by using sieve analysis to make sure it is free from any impurities and the fibers are assured to be loosen and prepared to be cut into required length for experimental study.

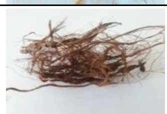
C. Type of fibers

Different types of date palm fibers could be obtained after extraction process as shown in Table 1. Since such fibers should have approximately the same geometrics for the use in the experimental program, it is reasonable to generalize the similar physical properties to the same type of fibers. All fibers have been dried at 50°C for 2 days (stability of weight with time). Moreover, diameter's (D) 0.15 mm and length's (L) 11.4 cm of leaf root; D = 1mm, L = 1.3 cm of trunk fibers; D = 0.36 mm, L = 19 cm of leaf. Physical properties have been studied using water content and coefficient of absorption test. Their values have varied between (25-122%) and (43-348%) respectively, see Table 2. Apparent dry density (1.5-1.9 g/cm^3) and apparent wet density is 2g/cm^3 of trunk leaf, for other fibers detailed in [11]. In addition, mechanical property has effected by tensile test according to ASTM D 3822-07 using SM100 Universal material testing machine capacity 100 kN (10 ton). The general properties of fibers are represented as the high tensile strength in the bundles made of long fiber. The difference in cross section and type of the fiber plays a major role on the deformation of the samples. Maximum tensile strength of 3 cm length samples was 3.54 MPa as shown in Table 3, more detailed in [11].

Figure 1. Palm date tree after cutting with an electric saw.

Figure 2. Palm date tree before (left) and after (right) crumbling.

Table 1. Dimensions of different types of date palm fibers.

Type of leafs	Form of fibers	Diameter	Length
		cm	cm
Date palm root		0.15	11.4
Date palm tree trunk		1	1.3
Leaf		0.36	19
Root hydrated		-----*	6.3
Leaf mixed with trunk		-----*	8.6
Fibers remaining on a sieve 0.6mm		0.6mm	0.53
Fibers remaining on a sieve 1mm		1mm	0.72
Fibers remaining on a sieve 2.36 mm		2.36mm	1.21

* (----): unmeasured data due to geometry of fibers.

Table 2. Absorption coefficient and water content of different types of palm fibers [11].

Type of fibers	Root leaf	Trunk leaf	Sheath leaf	Leaf	Leaf mixed with trunk	0.3 mm	0.6 mm	1 mm	2.36 mm
W (%)	25	30	18	39	40	35	21	28	122
C (%)	143	209	132	137	195	178	348	152	43

Table 3. Mechanical properties of natural date palm fibers [11].

Type of fibers	D	L	F	ε	A	σ	E
	cm	cm	N	mm/mm	mm²	MPa	MPa
Fibers of root	0.6	3	100	0.066	28.27	3.54	54.00

D. Water

In this research, ordinary tap water was used for all the mixes to prepare fresh gypsum mortar.

III. SPECIMENS PREPARATION

A. Control mix

The control mix grade 15 was used in this study. A mortar has been prepared as indicated in Table 4. The dimension of reference matrix (control mix, Ref G) is 7x7x7 cm. The mixing process is effectued out by introducing the dry gypsum first in electrically mixer at a slow speed for a two minutes, then adding the mixing water and being at a higher speed for one minute, then pouring the mixture into the mold and test specimens are removed after 24 hours and then conserved in dry air for 28 days at T = 30- 35 °C for mechanical testing.

B. Date palm fibers reinforced mortar

Date palm fiber was added in the gypsum mortar by the subtraction of gypsum weight of (0 – 6) % as indicated in Table 5.

- *Calculation of fiber and matrix mass in composites*

According to [14] we can apply the following equations:

$$\rho_c = \rho_f + \rho_m \quad (1)$$

$$\varphi_f(\%) = \frac{m_f}{m_f + m_m} \quad (2)$$

$$m_f = m_m \, [\varphi_f \, (1 - \varphi_f) \quad (3)$$

Where:

ρ_c, , ρ_f and ρ_m : are respectivly composite density, fibers density and mortar density.

m_f and m_m : are respectivly the weight of fiber and matrix (water with gypsum).

φ_f : is the used mass fracion.

The mixing process is carried out by mixing the dry gypsum first with choosing short fiber at low speed during two minutes in electric mixer. Mixing water is added with increasing the speed for one minute. But when long fibers are choosen they are mixed with dry gypsum first with low speed for two minutes then mixing water is added with increasing the speed for one minute, but the long fiber was added manually for 30 sec. As a result, using the electric mixer lead to the long fiber wrapped around the paddle, and mortar is deposited in the mixing bowl after adding water. The effect of fiber length on the consistency of mortar is one of the important parameters because long fibers lead to obtain heterogeneous composite with difficulties of molding with decreasing the consistency than short fibers. It is important to note that when the long fibers are introduced into mortar as, so, it is difficult to obtain homogeneous samples as well as these fibers require large molds, and vice versa.

- *Curing test specimens*

After casting, the samples were left for 24h, then it is removed out from mold and cured in dry air for 28 days; temperature was between 30-35°C. Cubes specimens (7x7x7 cm) were used. The dimension of the mold depends on % of fibers and their length that has been introduced. For this reason, we selected the diameter of fibers which coincide with dimension of mold. So Figure. 3 is shown an example of two samples after casting. Homogenization specimens surface depending on the percentage and diameter of fibers, see Figure. 4.

Table 4. Composition of gypsum mortar (g)

W (g)	G (g)	W/G
600	1000	0.6

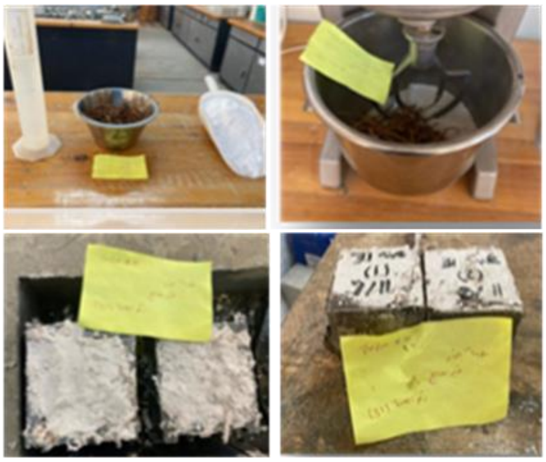


Figure 3. Preparation specimens of gypsum reinforced by date palm fibers.

Figure 4. Specimens of gypsum reinforced by date palm fibers after 24h.

Table 5.Types and percentage of fibers used for compressive strength testing specimens.

Types of fibers	%. of fibres	No. of specimens	size of specimens (cm)
Control mix	0	4	7x7x7
Leaf mixed with trunk	0.3	2	7x7x7
Sleath kernaf	0.8	2	7x7x7
Root	0.4- 2.5	4	7x7x7
Wet root	2	2	7x7x7
Trunk	1.5-6	3	7x7x7
Leaf mixed with trunk fibers	0.3	2	7x7x7
Fibers remaining on sieve 0.6 mm	1	5	7x7x7
Fibers remaining on sieve 1mm	2.7- 3.5	3	7x7x7
Fibers remaining on sieve 2.36 mm	2.7	1	7x7x7

IV. THE EXPERIMENTAL RESULTS AND DISCUSSION

A. *Physical properties*

- *Apparent volumetric weight*

Mean apparent volumetric dry weight at 28 days is 1.2 g/cm^3 of control mix. Figure. 5 shows the results of the gypsum mortar reinforced by leaf of root with different percent ages (0.4-2.5%), their volumetric weight is between 1.1- 1.34 g/cm^3, all values are mentioned in Table 6.

- *Effect the percentage of fibers on apparent volumetric weight*

Figure. 6 shows increasing the percentage of fibers do not improve the results of apparent volumetric dry weight, except for the introduction of the leaf mixed with trunk fiber, the volumetric weight increased by a small amount, the result of mixing two types of fibers.

- *Effect type of fibers on apparent volumetric weight*

No major influence of fiber types on apparent volumetric dry weight, we concluded that values approach to 1.2 g/cm^3.

Thus even the percentage and type of fibers the gypsum mortar reinforced with date palm fibers usually has

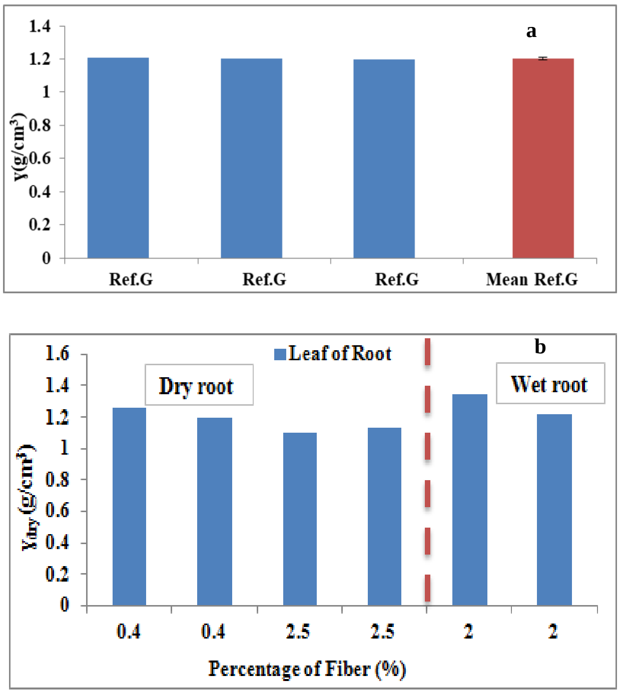


Figure 6. Volumetric density of ref (a), root fibers (b).

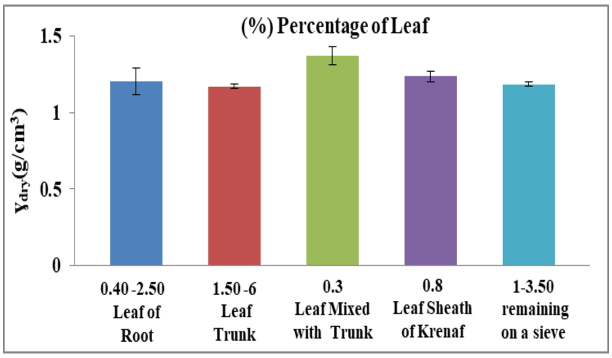


Figure 7. Influence the percentage of fibers on volumetric density.

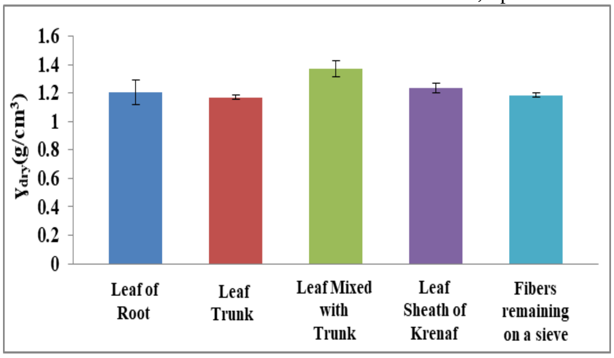


Figure 8. Volumetric densities of different fibers type.

lightweight comparative to cement mortar of 2.1 g/cm[3], Figure. 7. From table 6, so we can be conclude that the volumetric density is affected by the type of fiber more than its proportion in the gypsum mortar. In addition, the structure of fibers and their diameters have been playing an important role than their quantities.

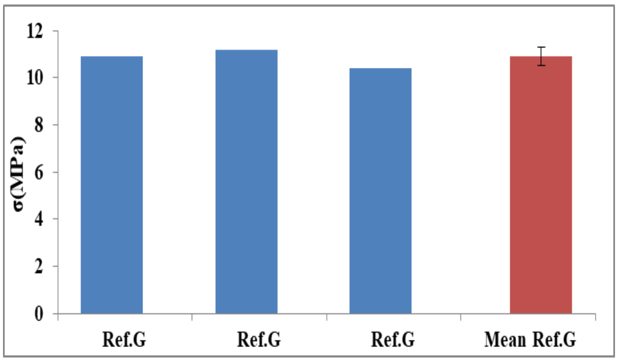


Figure 9. Maximum compressive strength of control mix (Ref G).

B. Mechanical properties

Mechanical testing of hardened mortar samples after 28 days of curing was performed using cubic samples as explained in Table 3; they were subjected to compressive loading based on ASTM C109/C109M where the maximum load and stress at failure were recorded. Note that the high strength values in some cases due to structure of fibers, the difficulty in controlling the dimensions and quantity of the fibers during casting process.

- *Control mix*

The mean maximum strength of control mix at 28 days is equal to 11 MPa as shown in Figure. 8 and Table 6.

- *Effect the percentage of fibers on maximum compression load*

Figure. 9 shows the maximum applied load on cubical specimens contain the remaining fibers on different sieves. Average values is equal to 25 kN for remaining fibers on sieves of 1mm then is equal to 54 kN of control mix (Ref G). And with increasing the diameter of sieve the maximum compression load attain 30 kN but remaining lower than control mix values. It is clear that the resistance of reference, control mix (0% fibers) diminished with added the palm date fibers (22- 30 kN) with different percentages and varied diameter. For leaf of root their strength is no significant compared to preceding figure and varied the percentage of fibers from does not have major influence on maximum compression load compare to Ref G as shown in Fig. 10. It observed that the specimen with 2% given a resistance equal to 131 kN due to internal strength of root fiber or large diameter of fiber in this mold was higher. Mean values of all used fibers and varied percentage of fibers compared to control mix is shown in Fig. 11. Consequently, introduced the date palm fibers reduced maximum compression load compared to control mix. And found a valued higher than control mix due to the reason explained above taking account the coefficient of variability.

- *Effect the percentage of fibers on maximum compressive strength*

Compressive strength test results indicate that as diameter of fiber increases the maximum compressive strength decreasing with the percentage of fibers, see Figure. 12. It is clear that the maximum compressive strength is approached for all kinds of fibers with the diverse percentages of fibers but lower the control mix (Ref G) value as shown in Figure. 13, 14.

However, the water absorption of the developed composite increased with the increase in date palm fibers content. As explained in Table 2, the coefficient of absorption and water content very high for some types of date palm fibers this leads to increasing fin porosity especially at interface level. Moreover, the effects of fiber size, content and porosity on the stiffness of date palm fibers -gypsum composite. The addition of date palm fibers resulted in an increase in the stress–strain and stiffness of date palm fibers gypsum composites and prevented the brittle fracture which can be attributed to the high strength rupture parameter of date palm fibers. Thus, date palm fibers are applicable as a reinforcement for gypsum material in order to develop composite materials for several applications in building constructions [15].

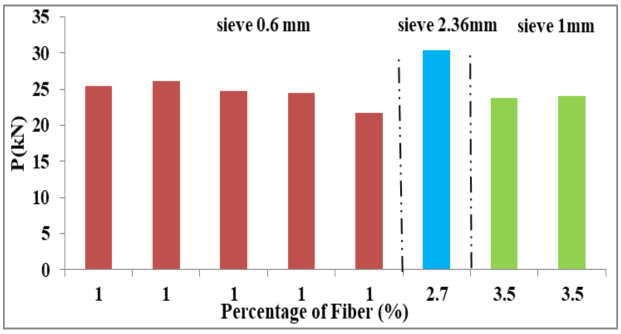


Figure 10. Max. compression load values of remaining fibers on different sieve diameters.

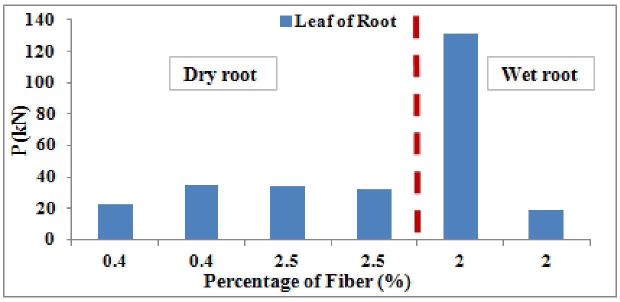


Figure 11. Max. compression load values of fibers of root.

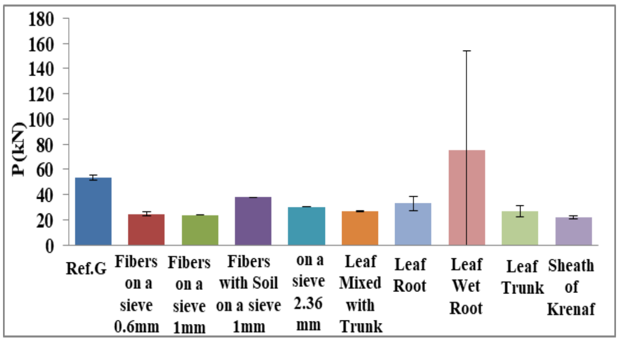


Figure 12. Mean max. compression load values of different fibers.

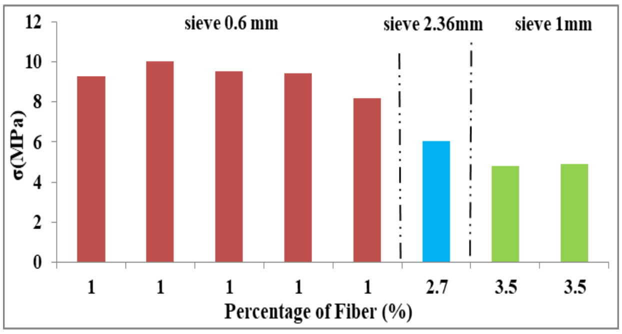


Figure 13. Max. compression resistance of remaining fibers on different sieve diameters.

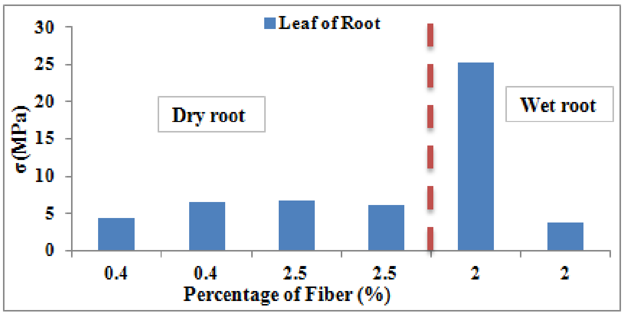


Figure 14. Max. compression resistance of fibers of root.

Table 6. Physical and mechanical properties of untreated date palm fibers- *gypsum* composite

Specimens	**% of fibers**	**γ_{dry} g/cm^3**	**P kN**	**σ MPa**
Control mix (Ref)	0	1.21	53.5	10.9
	0	1.20	54.7	11.2
	0	1.20	50.9	10.4
Fibers remaining on a sieve 0.6 mm	1	1.16	25.5	9.3
	1	1.18	26.1	10.0
	1	1.21	24.8	9.5
	1	1.20	24.5	9.4
	1	1.18	21.7	8.2
Fibers remaining on a sieve 1mm	2.7	1.19	30.4	6.0
	3.5	1.18	23.8	4.8
	3.5	1.20	24.0	4.9
Fibers remaining on a sieve 2.36 mm	2.7	1.20	30.4	6.0
Sleath Kernaf	0.8	1.26	21.1	4.31
	0.8	1.21	23.0	4.49
Root	0.4	1.26	22.2	4.3
	0.4	1.19	34.6	6.6
	2.5	1.1	34.3	6.6
	2.5	1.13	31.8	6.1
Wet root	2	1.34	131.1	25.3
	2	1.22	19.2	3.8
Trunk	1.5	1.15	23.7	4.6
	1.5	1.17	30.2	6.1
	6	1.18	37.8	7.6
Leaf mixed with trunk	0.3	1.41	26.8	5.2
	0.3	1.33	26.5	5.0

Figure. 15 exhibited the mortar reinforced with date palm fibers after compression test. The failure and deformation is brittle and resistance of specimens depends on the quantity of fibers in the specimen.

It can be noted also that the addition of fibres interrputs the mineral skeleton of the gypsum mortar, creating voids inside the matrix and increasing its porosity, by giving it a minimal strength. These observations are in agreement with the results of previous research on different fibres mortar studied.

- *Effect type of fibers on maximum compression load*

An example for the influence of the type of fiber on the maximum compression load exhibited in Figure. 16. Trunk fibers were weak kinds of palm tree as confirmed in [9]. The results shown maximum compression load and compressive strength is lower the control mix (Ref G).

- *Effect type of fibers on maximum compressive strength*

From previous figures, we demonstrated the type of fibers do not have main effect on compression behavior than diameter of fibers. Figure 17 shows that the trunk fibers given approximated one-half the strength of control mix mortar.

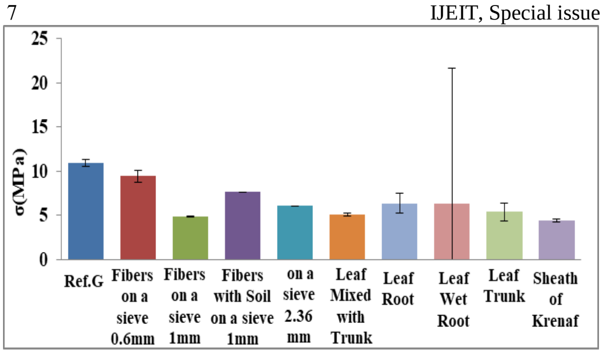


Figure `5. Mean max compression resistance of different fibers.

Figure 16. Specimens of root fibers (left) and remaining fibers on different sieve diameters after failure.

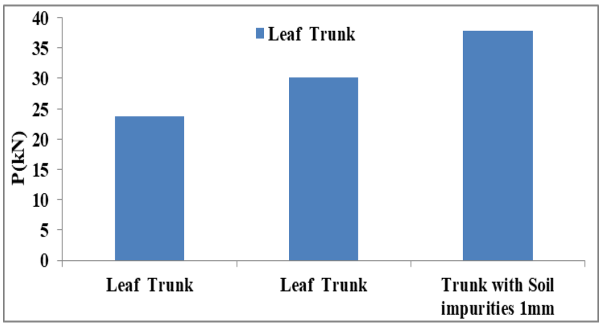


Figure 17. Max. compression load values of trunk fibers.

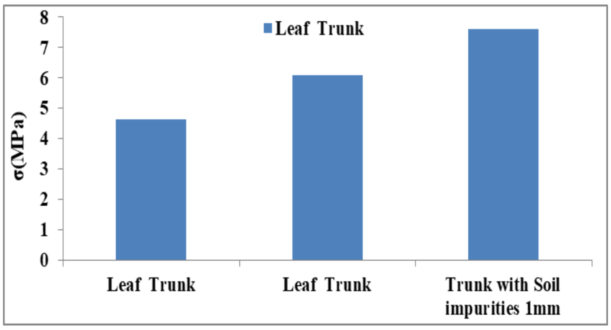


Figure 18. Max. compression resistance of of trunk fibers.

V. CONCLUSION

This study has investigated the effect of date palm fibers on gypsum mortar composite. The properties of these fibres were also studied. Characterization of date palm fibers used as composites reinforcement appeared that efficacy using these fibers with low percentage. The maximum strength of untreated fibers is influenced by the percentage, palm fiber structure. As untreated fibers is depending principally on fibers structure. The maximum strength is influenced by diameter of fibers; from where fine fibers lead to improve the strength than thick fibers take into account coefficient of variation. So, small diameter and untreated fibers lead to obtain more homogenize composite. The larger diameter induces greater the ability of mortar to withstand the applied load and the bonding between the fiber and gypsum depends on the type of fiber. In addition introduced the date palm fibers into gypsum mortar is very weak and has no effectiveness in mortar compared to control mix mortar. This is due to chemical reaction between the fibers and gypsum mortar. Furthermore, an idea to use mixed fibers did not show any efficacy in increasing compressive strength. It is also concluded that the conserved medium has a major role in resisting concrete.

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RECOMMENDATIONS

1. For more support previous results, it is suggested to use microstructure analysis.
2. It is recommended to complete the physical and mechanical test by make chemical test to understand the reaction at interface between fibers and gypsum matrix.
3. It is recommended to varied tests results using different date palm tree kinds and percentages of fibers from 0 to 100% of same sort of fibers.
4. It is recommended in the future to use pretreatment date palm fibers in gypsum matrix and studied their effect on mechanical performance. And investigation on date palm fibers reinforced gypsum concrete under different curing conditions.