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Comparative Study of Gypsum Composite Materials Reinforced with Date Palm and Polyester Fibres

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ABSTRACT

Gypsum is a polyvalent building material, whose composition gives it interesting properties for the construction industry, but its major disadvantage is its fragility. We proposed to study the feasibility of obtaining gypsum-based composite materials using plant fibres derived from date palm waste (DPF: date palm fibres), in order to exploit a local resource, and using synthetic polyester fibres (PF: polyester fibres) for comparison. We have developed gypsum-based composites with three types of reinforcement with mass percentages of the order of (0.5% DPF), (0.5% PF) and (0.25% DPF+0.25% PF). It was found that the addition of (0.5% DPF) can increase the flexural strength by up to 29.25% and that mixing gypsum with (0.25% DPF+0.25% PF) can slightly reduce its thermal conductivity by around 13.09% and increase its flexural strength by around 45.07%. However, a decrease in the transverse compressive strength of gypsum reinforced with date palm fibres was observed for the two mixtures of (0.25% DPF+0.5% PF) and (0.5% DPF) of approximately 12.56% and 24.32% respectively. These poor results of compression are due to the poor adhesion between the date palm fibres and the gypsum matrix, as well as to the porous structure of the date palm fibres observed under the microscope. Gypsum composites incorporated by DPF can be used for thermal insulation to reduce energy consumption and as decorative materials to line a wall, create a partition or a false ceiling.

1. INTRODUCTION

The sustainability of construction has become a major issue of our time, and this is what researchers and engineers want to achieve. There are many construction materials used in building and public works, and the range is relatively wide. They include wood, glass, steel, plastics (particularly insulation) and materials derived from the processing of quarry products. These materials have always played a central role in the development of our civilisation, since there is no such thing as a perfect or ideal material, but rather materials with limited properties. Until recently, it was simply a matter of assembling different materials with complementary properties, each of which obeyed a particular specification, known as composite materials.

Gypsum has been used in building and construction for a very long time. It consists mainly of calcium sulphate, which occurs naturally in two forms: gypsum ($CaSO_4$, $2H_2O$) and anhydrite ($CaSO_4$). It is the oldest hydraulic binder used in architecture to make mortar. It is also used to make coatings (interior or exterior) and decorative elements. It has a wide range of uses, and can be applied to many different types of construction. It has a number of advantages, including ease of manufacture, rapid setting, good thermal and acoustic insulation and excellent fire resistance, but despite these benefits, its fragility limits its use [1].

On the other hand, waste treatment is one of the major problems in environmental protection, as its disposal entails considerable additional investment costs for local authorities. To date, research into the reuse of waste materials, whether natural or synthetic (glass, polymers, tyres, slag, etc.) has focused mainly on their incorporation into coatings, mortars and concretes [1-4].

A number of researchers have studied the effect of synthetic and natural fibres on the physical, thermal and mechanical properties of gypsum, these effects varying positively or negatively depending on the length, nature and method of incorporation of the fibres, noting that plant fibres have a porous structure which contributes to the reduction of the thermal conductivity [5]. Recently, Muntongkaw et al. [6] developed a gypsum-based composite to improve physical, thermal and mechanical properties by adding natural Typha Angustifolia fibres (1 and 3% by weight). Gypsum ceiling composites with 1% by weight Typha angustifolia fibres produced optimum conditions with high compressive stress, high nail tensile strength, high thermal shock resistance, low thermal conductivity and light weight. Abir et al. [7] used jute fibre as an additive to the gypsum matrix to assess the impact of jute fibre on the mechanical properties of gypsum gypsumboards with percentages in the range of (2, 4, 6 and 8%). They found an increase in tensile strength up to a percentage of 6%, above this value the resistance decreases due to the weak mechanical bond and the presence of voids in the structure. Iucolano et al. [8] studied the mechanical effect of abaca fibres on the gypsum matrix at percentages of around (1%, 2% and 3%). They observed that gypsum composites incorporating 1% and 2% raw abaca fibres or abaca fibres treated with distilled water have better workability, while a higher fibre content of 3% considerably reduces workability, which is due to the heterogeneous fibre distribution observed in the microstructural analysis. The results show that a fibre content of 2% gives good flexural strength. Dawood and Mezal [9] studied the effect of barchip fibres (synthetic fibres) on the mechanical properties of gypsum. They used percentages of (0, 0.5, 0.75, 1, 1.25 and 1.5%). They found that 1% Barchip fibre increased compressive strength and flexural strength by about 44% and 62%, respectively. Jia et al. [10] reviewed previous studies on gypsum composite materials reinforced with fibres and concluded that several factors can influence the properties of composites: the type, length, distribution and morphology of the fibres, and chemical treatment has a favourable effect on mechanical properties, as it promotes adhesion between the fibres and the matrix.

The date palm is considered to be one of the most widely available sources of natural fibre in Morocco. It has a fibrous structure with four types of fibre: leaf fibres in the peduncle, baste fibres in the stem, wood fibres in the trunk and surface fibres around the trunk [11]. These fibres are obtained from renewable natural resources and do not cause deforestation or compete with food production. The huge quantities of fibrous material in the form of stipe and palm, poor quality dates and seeds are thrown into the environment. This waste holds immense potential as a raw material that can be used in a number of areas, including construction, energy storage, food and biology. Our article focuses on the recycling and recovery of this waste in building materials. Date palm fibres have previously been studied with gypsum matrix by several authors:

Rachedi and Physico-Mechanical [12] studied the physical and mechanical behaviour of fibres of lengths of (20, 60 and 100 mm) on gypsum mortar with diameters varying between (0.2-1mm). They added the fibres randomly with the gypsum powder in percentages between (0% and 2%) with a step size of 0.5%. They found an optimum composition for fibres 20mm long, and a mass percentage equal to 1.5% that meets the various mechanical and physical characteristics (workability, water absorption and density) and requirements necessary for a construction material.

Braiek et al. [13] studied the thermal behaviour of adding percentages of (0% to 20%) of these fibres, which are randomly dispersed with gypsum powder. The results show a remarkable improvement in the thermal properties of composites incorporating fibres compared with gypsum alone, with a reduction of up to 61.50% in terms of thermal conductivity. They attributed this effect to the low thermal conductivity of the fibres and the reduced density of the composites due to the increased level of porosity.

Rachedi and Kriker [14] studied the thermal properties of gypsum composites with palm fibres at percentages ranging from (0.5% to 2%) and for four lengths of (10mm-40mm) randomly dispersed with gypsum powder. They concluded that adding 2% fibre with a length of 40mm gives better thermal results.

Chikhi [15] used petiole fibres with lengths of (3 and 6 mm) with addition percentages of (0, 1.2, 3, 5, 7, 8 and 10%). Gypsum containing date palm fibres at different fibre sizes showed higher porosity than pure gypsum. They found that composites containing fibre percentages of less than 5% with lengths of 6mm had lower porosity. Regarding the mechanical effect, they observed that percentages below 5% do not affect the Young's modulus of composites. The Young's modulus increases progressively until it reaches an optimum, after which it decreases as the fibre load increases. This can be attributed to a number of factors such as incompatibility between the matrix and the fibres, inappropriate manufacturing processes, degradation and fibre orientation.

Al-Rifaie and Al-Niami [16] used sheath fibres from the base of the sheet. The fibres are dispersed in the gypsum matrix with a volume fraction of (0, 2, 4, 6, 8 and 10%). Compressive strength decreases with the addition of fibres due to the reduction in density caused by both the fibre content and the mixing technique. On the other hand, the incorporation of date palm fibre increases the modulus of rupture of gypsum up to 4% fibre.

In general, the addition of date palm fibres in most works generates an increase in porosity due to the poor adhesion with the gypsum matrix and also due to the high content of fibres added in a random non-oriented manner which contributes to the creation of pores due to the entanglement of the fibres. On the other hand, the porous structure of the fibres allows them to absorb water during the preparation of the mixes, which evaporates after hardening, leaving pores within the volume. The presence of a high porosity content directly affects the thermal properties in a positive way, but it also weakens the composite materials mechanically. Based on previous work, we have tried in this study to use a minimum percentage that guarantees a compromise between the thermal and mechanical properties for both types of fibre (palm and polyester), and we have also chosen to incorporate the palm fibres in an oriented manner into the gypsum matrix in order to avoid the entanglement and heterogeneous distribution of the fibres and, consequently, the creation of undesirable pores.

In this context, we propose to study the feasibility of obtaining a composite material, based on gypsum with sufficient mechanical and/or thermal resistance, using on the one hand plant fibres from date palm waste, in order to enhance a local resource and also to develop materials taking into account the impact on the environment, and on the other side to use synthetic polyester fibres to make a comparison between the two types.

The new ideas of this work are based on the use of palm fibres oriented in one direction with lengths of 16cm in the gypsum paste, whereas in other articles, the plant fibres are generally dispersed randomly in the matrix. This work also involves a comparison with synthetic fibres, which are rarely used in scientific research. Palm fibres are used without chemical treatment. We tested three types of fibre incorporation in the gypsum: 0.5% date palm fibre, 0.5% polystyrene fibre and 0.25% of both types of fibre at the same time. The idea of mixing the two types of fibre in the same mix with percentages of 0.25% came from a study carried out by

Dawood and Ramli [17] who prepared concrete with varying percentages of steel, palm and barchip fibres. They found that the best pull-out test value was obtained using concrete reinforced with (1.5% steel fibre+0.25% palm fibre +0.25% Barchip fibre) as the repair material. The microstructure, mechanical and thermal properties of gypsum-based composites developed are studied using Scanning Electron Microscopy SEM, mechanical tests (compressive and flexural tests) and the Hot Disk method.

2. METHODOLOGY

2.1 Materials

2.1.1 Gypsum

The gypsum used as a matrix in this study produced at LAFARAGE [18], from natural gypsum from the Safi region (Morocco). The degree of purity of this product is approximately 91%. It is used for staff finishing work and for the production of decorative elements by moulding and modelling (moulded sculptures, ceilings, rosettes). The thermal conductivity of this gypsum is estimated at 0.0985 $W.m^{-1}. K^{-1}$ [1]. Table 1 illustrates their physical properties [18].

Table 1. Characteristics of gypsum

Characteristics	Value
Fluidity	22cm
Setting time	7mn
End of setting	18mn
Particle size sieve	
Refusal to 400µm	< 1%
Refusal to 100µm	< 13.5%

2.1.2 Fibres

Date palm. The date palm was named Phoenix dactylifera L. it is also called "Nakhla" in Arabic. The part that interests us is the surface fibres of the date palm "Lif" in Arabic, also called " fibrilium ", the latter is the sheath of fibres that surround the stipe between the bases of the palms. The ecological role of these fibres is to strengthen the trunk (stipe), and protect it against external shocks and heat [11].

The fibres are harvested from date palms found in the areas around the city of Agadir in Morocco. They are manually extracted and then cut to a length of 16 cm with variable diameters as indicates in Figure 1. They were then washed with distilled water to remove all traces of impurities and dust.

Figure 1. Date palm fibres (DPF)

Figure 2. Polyester fibres (PF)

Polyester. It is appropriate for a diverse range of applications, from bedding stuffing, industrial applications, construction and interior materials, such as general-purpose industrial materials, car seats and non-woven fabrics, woven. The synthetic fibres used in this experiment are found in the market in the form of yarn mats, they are processed and dispersed manually, as shown in the Figure 2.

2.2 Characterization of materials

X-ray diffraction examination (DRX) is performed at room temperature using a Bruker D8 Advance twin diffractometer equipped with a copper anti-cathode. The diffractogram in Figure 3 shows the presence of a single phase of $CaSO_4$, ½ H_2O hemihydrate, which is represented by the mineral bassanite.

Figure 4 shows the secondary electron microscopy image of gypsum, determined using the JEOL JSM IT-100, coupled to an EDX X-ray emission detector. It is viewed as a microporous solid made up of an assembly of microcrystals. The Table 2 gives the chemical composition of gypsum detected by EDX.

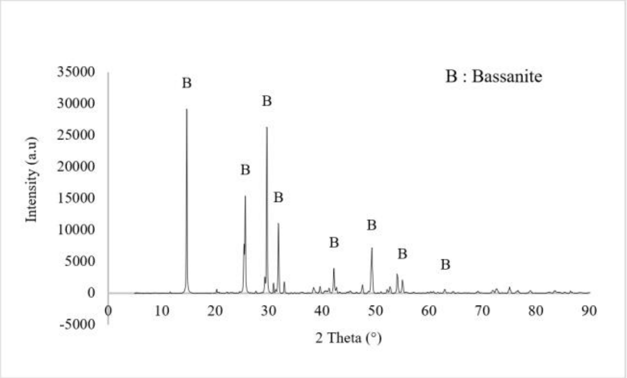


Figure 3. Diffractograms of gypsum

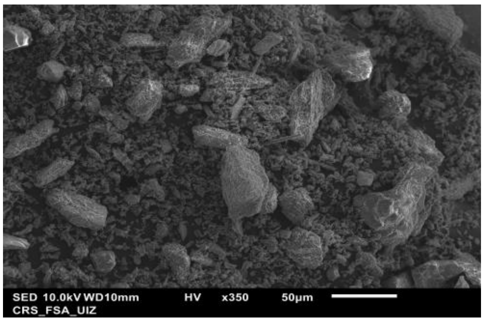


Figure 4. SEM secondary electron images of gypsum

Table 2. Chemical distribution of gypsum

Formula	C	MgO	Al_2O_3	SiO_2	SO_3	K_2O	CaO	FeO
mass%	3.39	5.68	11.17	36.47	16.84	2.33	12.47	11.65

Figure 5 shows the secondary electron microscopy images of the two types of fibres. It can be seen that date palm fibre Figure 5. A) has a completely porous structure, the morphological nature of these fibres is well analysed by [11], whereas polyester fibre Figure 5. B) has a non-porous structure. Table 3 shows the chemical composition of the two types of fibres. The results showed that the weight percentages of the various components vary between the two types of fibre, however Carbone and Oxygen elements are the main components of the fibres, Figure 6 presents peaks of these chemical distribution detected by EDX.

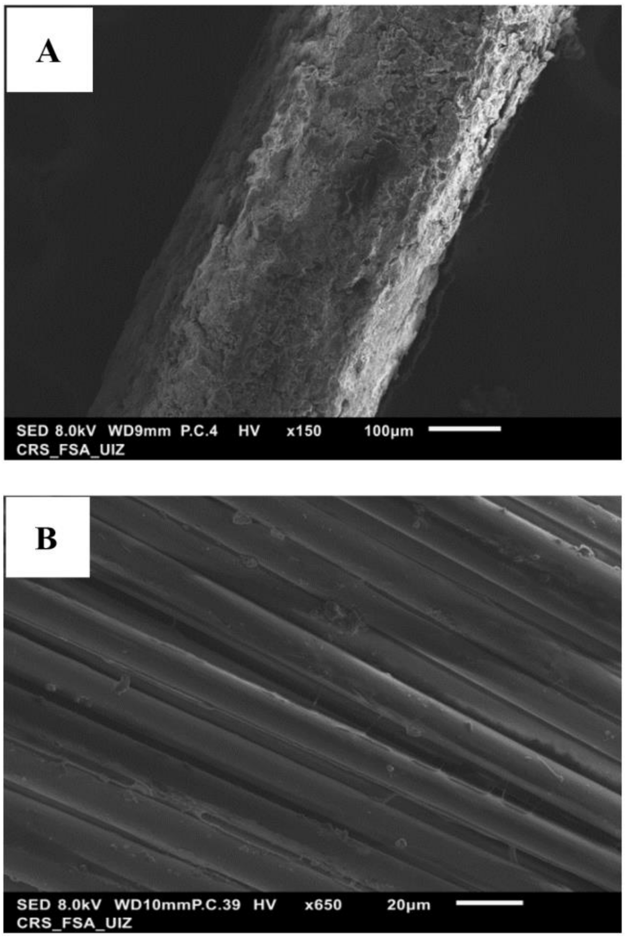
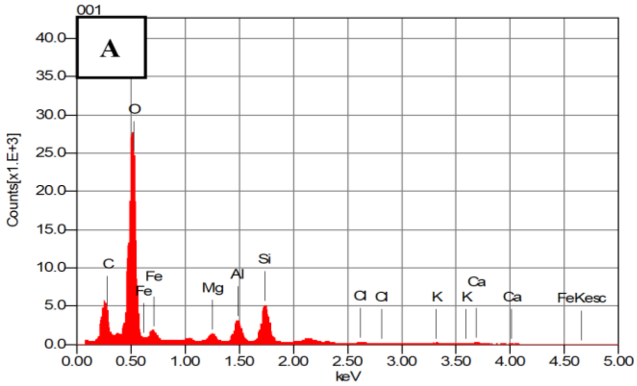


Figure 5. SEM images of fibres: A) date palm (DPF), and B) polyester (PF)



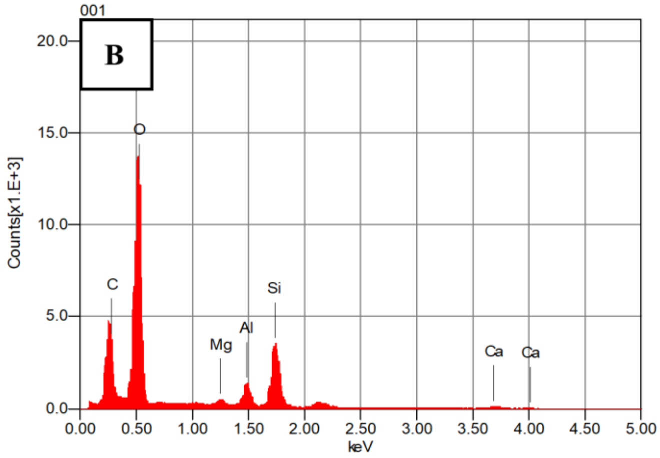


Figure 6. Peaks of the chemical distribution of fibres: A) date palm (DPF), and B) polyester (PF)

Table 3. Chemical distribution of date palm and polyester fibres

	Mass (%)								
Formula	C	O	Mg	Al	Si	Cl	K	Ca	Fe
DPF	10.34	45.46	2.04	6.08	12.07	0.88	1.44	2.10	19.59
PF	19.74	53.23	1.27	5.22	17.27	-	-	3.27	-

2.3 Mix and design

The mixing water used was potable tap water, with a gypsum/water ratio of 1.33. The masses of the date palm and polyester fibres as shown in the Table 4 were measured according to the following formulae of the law of mixtures [15]:

$$m_C = m_m + m_f \tag{1}$$

With

$$\phi_f(\%) = \frac{m_f}{m_f + m_m} \times 00 \tag{2}$$

We will then obtain

$$\mathbf{m}_f = \mathbf{m}_m \left[\varphi_f(\%) / \left(100 - \varphi_f(\%) \right) \right] \tag{3}$$

$\mathbf{m_f}$ and $\mathbf{m_m}$ are respectively the masses of the fibres and the matrix (gypsum with water), φ_f is the mass percentage of fibres.

After establishing the ratio (P/W) and the masses of the various constituents, we proceeded to prepare four types of mixtures, the first being gypsum paste alone, which was considered as a control, the second being gypsum paste with (0.5% DPF), the third being gypsum paste with (0.5% PF) and the last being gypsum with percentages by mass of fibres (0.25% DPF+0.25% PF). We developed three composites for each mixture (Figure 7) in order to obtain multiple analyses. The mass of water was fixed during the experiment for all the blends, and the date palm fibres were immersed in water to absorb the necessary water before the composites were made, since they are hydrophilic in nature.

Table 4. Mass composition of the mixtures

Composition	Mass (g)			
	Gypsum	DPF	PF	Water
Control	250	0	0	187.5
0.5% DPF	250	2.2	0	187.5
0.5% PF	250	0	2.2	187.5
0.25% DPF+0.25% PF	250	1.1	1.1	187.5

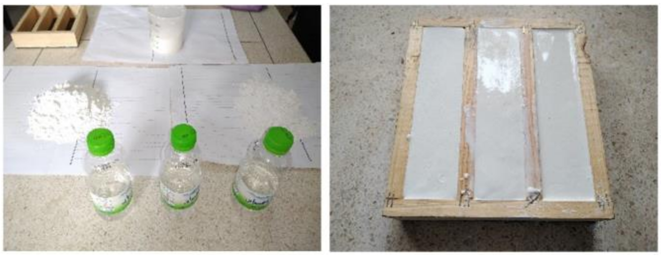


Figure 7. Preparation of three composites for each blend

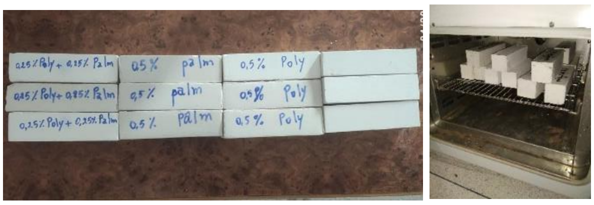


Figure 8. Demoulded specimens

Two methods are used when adding fibres: the first involves mixing the dry PF with the gypsum powder, then pouring in the mixing water to prepare the paste. The second consists in placing a layer of gypsum paste alone in the mould, then placing a layer of DPF on the paste and so on until the mould is filled. The samples were prepared under laboratory conditions (temperature between 21°C and 24°C and relative humidity of 65%) using 4cm*4cm*16cm moulds for the thermal and mechanical tests according to study [19].

The mortar is vibrated with a stem to give the fibres the correct distribution and orientation, and finally the surface of the mortar is shaved and smoothed. The prepared moulds are placed in the laboratory. After 24 hours, all the samples are carefully removed from the moulds to avoid any deterioration. They are then dried in an oven at 50°C for 2 days to remove any interstitial water (Figure 8).

2.4 Tests and methods

2.4.1 Physical test

The physical properties of the samples were determined by measuring the densities of the various specimens from the apparent masses and volumes using an IVYMEN type electronic balance. We made three specimens in different percentage, to obtain multiple analyses of the different test.

2.4.2 Thermal test

The conductivity and other thermal properties were determined according to study [20] using the TPS 1500 hot disc apparatus marketed by Thermo-Concept. The HOT DISK method is a transient technique, based on the use of a disc-shaped probe consisting of a double nickel spiral electrical resistor placed on a plastic support. The probe is then placed between two identical samples to be characterised. Both test materials must have smooth, flat faces and their dimensions must be sufficient to allow the medium to be assumed to be semi-infinite.

Once the specimens have hardened in the oven, they are placed in the desiccator until the day of the thermal test. The thermal properties are measured under ambient laboratory conditions. For testing under ambient temperature, the room temperature sample support consists of a sample and sensor holder made of stainless steel and a cylindrical polished cover made of stainless steel with a height of 150mm and a diameter of 200mm as shown in Figure 3. This cover is designed as a protection against temperature disturbances through air draft to the sample during the transient recording.

2.4.3 Mechanical test

The compressive and flexural strengths were measured using the Controls Automax5 machine equipped with the Microdata Autodriver software, according to standard NF EN 196-1 [19] on 4cm*4cm*16cm prisms for the flexural test and on the 4cm*4cm*8cm prisms for the compressive test. They are carried out after the thermal test.

To determine the bending strength, the 4*4*16 samples are placed on two steel support rollers, spaced (100.0±0.5) mm apart, and the load is applied vertically to the side face, increasing it regularly up to 10kN with a precision equal to ±1.0% of the load recorded at a speed of (50±10)N/s until failure. The flexural strength R_f is calculated according to the following formula in MPa:

$$R_f = \frac{1.5 \times Ff \times l}{b^3} \tag{4}$$

With, (b) is the side of the square section of the prism, in millimetres, (F_f) is the load applied to the middle of the prism at breakage in Newton's et (l) is the distance between the supports, in millimetres.

After the bending test, the specimens are placed on the compression test plate measuring (40.0±0.1)mm wide and (40.0±0.1)mm long, which allows a rate of load increase of (2400±200)N.s^{-1}. The compressive resistance R_c is calculated by the following formula in MPa:

$$R_C = \frac{F_C}{1600} \tag{5}$$

With, (F_c) is the maximum breaking load, in Newton's, (1600) is the area of the trays or auxiliary plates (4cm×4cm), in square millimetres.

3. RESULTS AND DISCUSSION

3.1 Morphology of composites

Figure 9 shows the secondary electron images of the fracture faces of gypsum-based composites. Gypsum composite without additives Figure 9, A) generally consists of entangled needle-or platelet-shaped crystals with micropores. Low adhesion is observed for the gypsum composite reinforced with date palm fibres Figure 9, B) represented by the pores and cavities created between the surface of the fibre and the matrix, which is due to the fact that the palm fibres have a hydrophilic nature, swelling as they absorb water during the preparation of the mixes, this water evaporates after curing leaving cavities in their place. Several researchers have found the same behaviour, which can be improved by chemical treatment of the fibres [8, 13]. However, Figure 9, C) shows good adhesion between the synthetic fibres and the gypsum matrix, as well as an almost homogeneous distribution of the fibres in the matrix, since they do not clump together in the same place.

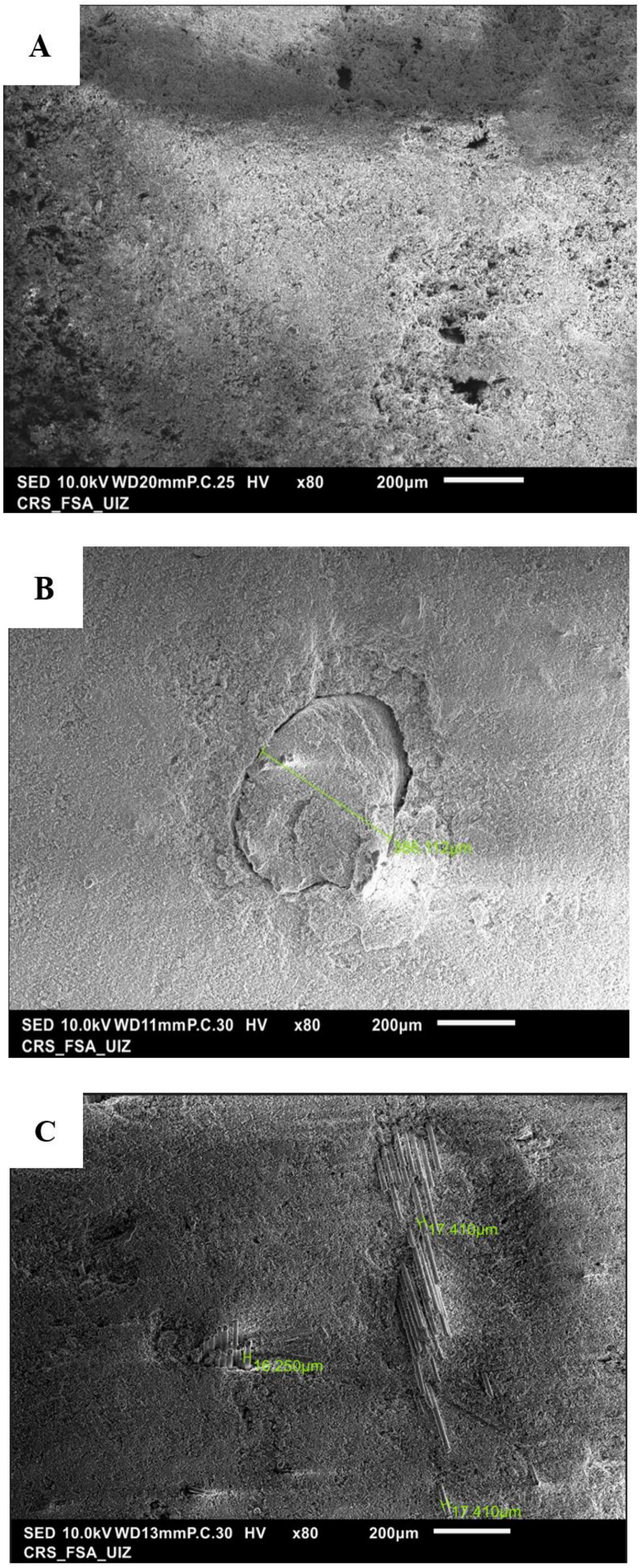


Figure 9. SEM images of the fractures faces *of gypsum-based composites* of: A) Control, B) (0.5% DPF), and C) (0.5% PF)

3.2 Physical properties

As Table 5 shows, the apparent density of composites varies according to the incorporation of fibres. The incertitude of measurements is determined from the following equation:

$$\frac{\Delta X}{X} = \frac{|X_{max} - X_{aver}|}{X_{aver}} \qquad (6)$$

With X the estimated variable, X_{max} the maximum value among the measurements and X_{aver} the average value of the measurements.

We can see that the gypsum composite with (0.25% DPF+0.25% PF) has a lower density than all of the composites, which achieved a reduction rate of 5.34% compared with pure gypsum, followed by gypsum with (0.5% DPF), which achieved a rate of 3.05%. This gives us information about the volume of pores within the composite and shows us that the composite with the two types of fibre with (0.25% DPF+0.25% PF) has more pores even though the polyester fibre structure is non-porous, which may be due to the creation of pores during the preparation of the paste. These results are demonstrated by the presence of pores between the gypsum matrix and the date palm fibres observed by scanning electron microscopy Figure 9, B). Reinforcing gypsum with both types of fibre at the same time can contribute to an increase in the pore rate due to the entanglement and heterogeneous distribution of the fibres in the matrix. Several authors have observed that the density decreases with the incorporation of gypsum by the fibres [10, 12, 21].

Table 5. Apparent density of different percentage of composite

	Apparent Density (Kg.m^{-3})				
	ρ_1	ρ_2	ρ_3	ρ_{aver}	$\Delta\rho/\rho$ (%)
Control	1018.65	1030.32	1021.35	1023.44	0.67
0.5% DPF	992.72	985.79	998.06	992.19	0.59
0.5% PF	1030.15	1058.45	1040.31	1042.97	1.48
0.25% DPF+0.25% PF	960.70	970.44	975.11	968.75	0.66

3.3 Thermal properties

The thermal properties of the composites, measured under normal laboratory conditions by hot disc method (Figure 10). They are given in Table 6. The uncertainties concerning the measurements made are calculated according to Eq. (7).

Figure 11 shows that the thermal conductivity of the gypsum composite with (0.25% DPF+0.25% PF) has a lower value than that of the control sample and the other samples, achieving a reduction rate of 13.09% compared with the reference. However, the thermal conductivity of the gypsum composite with (0.5% DPF) is slightly lower than that of gypsum with (0.5% PF). This suggests that the presence of DPF favours a reduction in thermal conductivity, particularly for the last mix. We can explain the variation in the thermal conductivity of these three composites by the variation in density (Figure 12), since the gypsum composite with (0.25% DPF+0.25% PF) has a low density, which translates into an increase in internal pores and consequently an increase in thermal resistance. There are two main reasons for the increase in pores inside the volumes: the first is that DPF has a porous structure compared with PF (Figure 5) and causes poor adhesion with the gypsum crystals (Figure 9, B)), and the second is that the addition of the two types of fibre disrupts the mineral skeleton of the mortar, creating voids inside the paste and increasing its porosity. Several authors have confirmed that thermal properties improve when fibres are incorporated into gypsum [6, 13, 14]. The variation in thermal conductivity as a function of porosity has been observed by several authors [21-23].

Figure 10. Hot Disc instrument

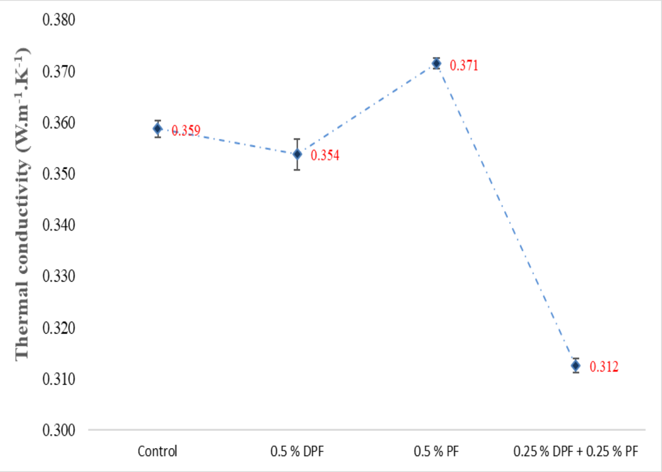


Figure 11. Evolution of the thermal conductivity of composites

Table 6. Thermal properties of gypsum based composites

	Thermal Conductivity (W.m^{-1}. K^{-1})					Thermal Diffusivity (mm^2.s-^{1})		Specific Heat (MJ.m^{-3}. K^{-1})		Thermal Effusivity (W. s$^{1/2}$ .m^{-2}. K^{-1})	
	λ_1	λ_2	λ_3	λ_{aver}	$\Delta\lambda/\lambda$ (%)	A_{aver}	$\Delta\alpha/\alpha$ (%)	$(\rho cp)_{aver}$	$\Delta(\rho cp)/(\rho cp)$ (%)	E_{aver}	$\Delta E/E$ (%)
Control	0.358	0.358	0.360	0.359	0.444	0.378	1.003	0.949	0.803	583.447	0.267
0.5% DPF	0.349	0.357	0.355	0.354	0.853	0.341	0.427	1.038	0.515	605.995	0.684
0.5% PF	0.369	0.372	0.372	0.371	0.273	0.361	1.172	1.030	0.751	618.515	0.506
0.25% DPF+0.25% PF	0.310	0.314	0.314	0.312	0.432	0.445	0.948	0.703	0.374	468.716	0.360

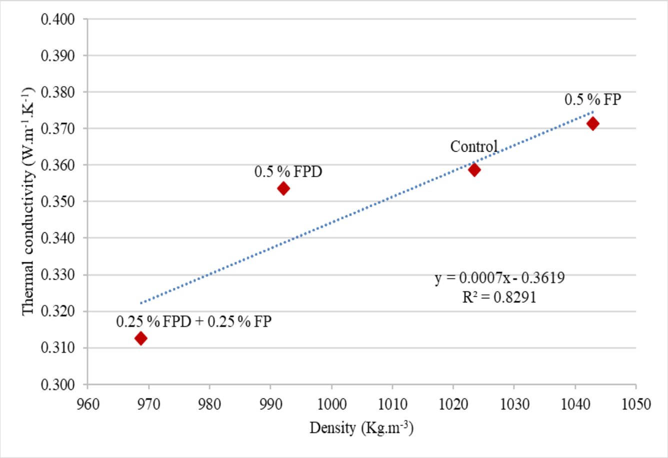


Figure 12. Thermal conductivity versus density

According to the Figure 12 thermal conductivity varies linearly with the density of composites. A correlation is obtained between this two values expressed by the following formula:

$$y = 0.0007x - 0.3619 \tag{7}$$

3.4 Mechanical properties

Table 7 summarises the results of the mechanical tests (Figure 13) on the composites and their errors, calculated from the difference between the maximum and mean values of the measurements obtained for each percentage.

From Figure 14, an increase in flexural strength was observed for the three fibre-reinforced specimens. The highest strength value was recorded for the gypsum composite with 0.5% PF reaching 58.83%, followed by the gypsum composite with (0.25% DPF+0.25% PF) up to 45.07% increase compared to the reference. However, the gypsum reinforced with 0.5% DPF has a value close to that recorded for the control gypsum, which remains fairly modest with an increase of 29.25%. Nevertheless, in Figure 15, the transverse compressive strengths of the two samples of gypsum with 0.5% DPF and gypsum with (0.25% DPF+0.25% PF) are lower than those of unreinforced gypsum, with reductions of 24.32% and 12.56% respectively. In contrast, gypsum with 0.5% PF composite recorded a value comparable to the control. The decrease in compressive strength observed for both composites that contain date palm fibres can be explained by the presence of voids within the volume, which increases its porosity (accompanied by a reduction in densities Figure 16, and can also be explained by the poor distribution of fibres in the composite that contains both types of fibres at the same time as shown in Figure 17, C). However, the improvement in flexural strength for the three fibre-reinforced composites is due to the method of incorporation and orientation of the fibres in the matrix, as indicated by the microstructural analyses Figure 9 of the fracture surfaces and Figure 17, the fibres appear to protrude forward in a direction perpendicular to the applied stress, which makes these composites more resistant in the flexural test. The increase in flexural strength when natural fibres are added, up to a certain percentage, has been observed by several authors [8, 12, 21, 24]. However, Various studies have shown that porosity has a detrimental effect on mechanical properties, especially compressive strength [16, 25, 26].

Table 7. Mechanical results of composites

	Flexural Strength		Compressive Strength	
Composite	R_f (MPa)	Error	R_c (MPa)	Error
Control	2.130	0.120	6.138	0.702
0.5% DPF	2.753	0.347	4.645	0.155
0.5% PF	3.383	0.797	6.023	0.857
0.25% DPF+0.25% PF	3.090	0.110	5.367	0.493

Figure 13. Flexural and compressive test

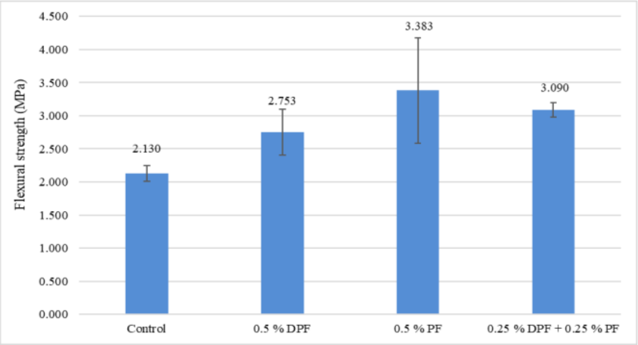


Figure 14. Evolution of flexural strength of composites

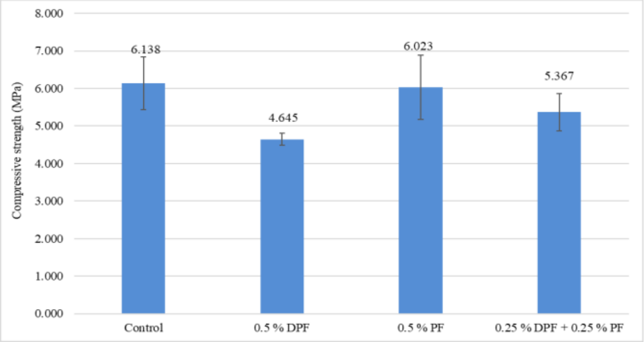


Figure 15. Evolution of compressive strength of composites

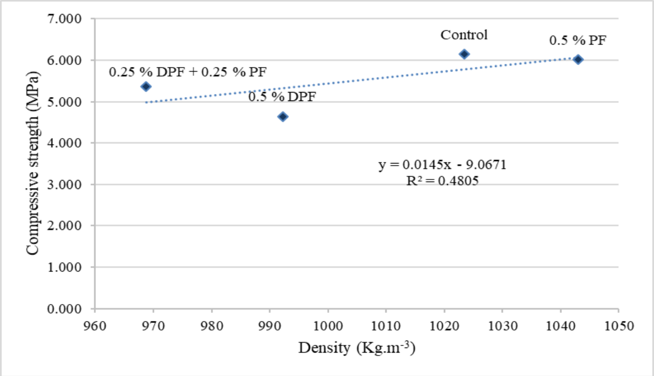


Figure 16. Compressive strength versus density

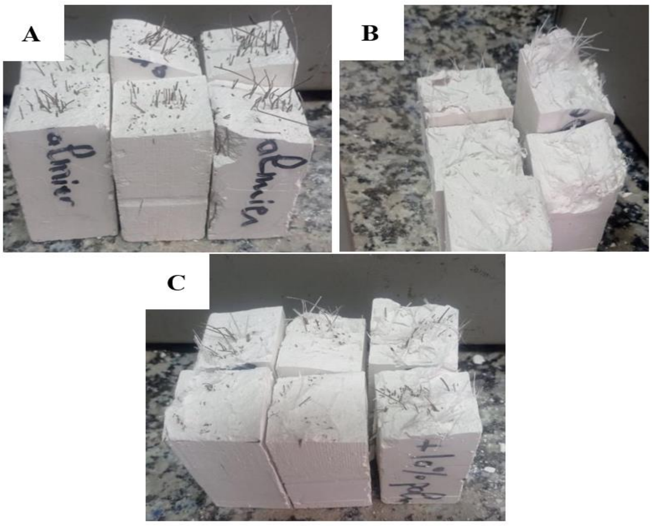


Figure 17. Rupture faces of tested composites: A) 0.5% DPF, B) 0.5% PF, and C) 0.25% DPF+0.25% PF

Figure 16 shows the correlation between the compressive strength and the apparent density of composites, given by the following formula:

$$y = 0.0145x - 9.0671 \tag{8}$$

4. CONCLUSIONS

In this work, we have tried to reinforce gypsum with natural and synthetic elements in order to valorise the region's waste and also to improve the thermal and mechanical properties of the gypsum matrix. Four types of mixtures of gypsum-based composites have been developed: the first is pure gypsum, the second consists of gypsum with (0.5% DPF), the third is incorporated by (0.5% PF) and the last contains both types of fibre (0.25% DPF+0.25% PF). The experiments carried out on the composites developed in this study produced the following results:

- Based on the physical properties and morphology of the two types of fibre, we observed that DPF has a purely porous structure, this porosity helps to reduce thermal conductivity but at the same time weakens the composite.
- According to the microstructure of the composites developed, the gypsum composite reinforced with date palm fibres shows poor adhesion, represented by the pores and cavities created between the surface of the fibre and the matrix. On the other hand, the synthetic fibres show good adhesion to the gypsum matrix.
- Although the percentages added to the gypsum matrix were low, the thermal conductivity values changed slightly, with the lowest value recorded for the mixture containing both FP and FPD, the thermal insulation performance was improved by around 13.09%.
- A negative effect of adding DPF fibres to gypsum was observed on compressive strength, with a 24.32% reduction for the case of 0.5% DPF, and a 12.56% reduction for the case of composite containing 0.25% DPF+0.25% PF, but the composite containing 0.5% PF had a comparable value to the

control. This decrease can be explained by the presence of voids inside the volume.

- An increase in flexural strength values was observed for reinforced gypsum, from an increase of 29.25% for the gypsum composite with 0.5% FPD to an increase of 45.07% for the gypsum composite with (0.25% FPD+0.25% FP). These improvements are due to the orientation of the fibres in a direction perpendicular to the applied force.

Gypsum is generally used in interior decoration, to line a wall, create a partition or a false ceiling. Adding date palm fibres to the gypsum matrix gives good thermal results, so these composites can be used for thermal insulation to reduce energy consumption. The mechanical results obtained in this study can be improved by modifying the percentage of fibres, the method of incorporation into the matrix and the length of the fibres. they can also be improved by chemical or biological treatment of the fibres to improve the efficiency of the fibre/matrix interface.

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NOMENCLATURE

PF	Polyester Fibres
DPF	Date Palm Fibres

Greek symbols

α	thermal diffusivity, m^2. s^{-1}
λ	thermal conductivity, W.m^{-1}. K^{-1}
ρ	density, Kg.m^{-3}
ρcp	specific heat, MJ. m^{-3}. K^{-1}
E	thermal effusivity, W. s$^{1/2}$ .m^{-2}. K^{-1}