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ORIGINAL PAPER

Effect of fibers surface treatments on the mechanical and thermal properties of composites reinforced by eco-friendly fibers

H. Guesmi[1,2] · A. Adili[3,4] · L. Dehmani[1]

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Abstract

This paper deals with the enhancement of thermal insulation of building construction materials by the incorporation of treated natural fibers (posidonia oceanica and esparto grass). The surface treatment of the natural fibers aimed at the improvement of the adhesion between fibers and construction material matrices. Untreated and treated posidonia oceanica and esparto grass fibers have been characterized through Fourier Transform Infrared spectroscopy, X-ray diffraction, and scanning electron microscopy. The obtained results indicated a clear change in the surface morphology, enhancement in the crystallinity, and modification in the chemical structure of the treated posidonia oceanica and esparto grass fibers in comparison with untreated fibers. Experimental investigations have been carried out to examine the effect of the incorporation of treated posidonia oceanica and esparto grass fibers on the interfacial adhesion with matrices, the compressive strength of cement and gypsum composite samples compared to those with untreated fibers and their thermal properties. Results indicated, on the one hand, an improvement of the interfacial adhesion and compressive strength of matrices filled with treated fibers compared to those filled with untreated fibers. On the other hand, results have shown a clear reduction in thermal diffusivity, thermal conductivity, and bulk density of composites with the addition of treated fibers compared to those of composites without fibers. Finally, the treated posidonia oceanica and esparto grass utilized can replace conventional synthetic fibers and will be an interesting alternative that would solve simultaneously environmental and energy concerns.

Keywords Building materials · Compressive strength · Energy efficiency · Esparto grass · Interfacial adhesion · Posidonia oceanica · Thermal insulation

Introduction

The rapid increase in the world's population, industrial development and standard of living has led to a continuous rise in energy consumption, raising concerns about the depletion of energy resources, the difficulties of supply and serious environmental effects such as climate change and global warming. An additional key concern is that fossil fuels, on which the global world still relies for more than 80% of its energy demands, will peter out over 50 years at present usage levels (B.P. Statistical Review 2021; Holechek et al. 2022).

The construction sector is one of the main contributors to environmental degradation through resource depletion and waste creation. In addition, a significant quantity of greenhouse gas emissions and acidifying gases come from the construction industry. Cement is one of the most widely used construction materials and its production is increasing worldwide. Cement production requires the consumption of

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✉ H. Guesmi
hela.guesmi@fst.utm.tn

[1] Laboratoire de Maîtrise de L'Energie Eolienne et de Valorisation Energétique des Déchets, Centre de Recherches et des Technologies de L'Energie, Technopole de Borj-Cédria, B.P. 95, 2050 Hammam-Lif, Ben Arous, Tunisia

[2] Faculté des Sciences de Tunis, Université de Tunis El Manar, Campus Universitaire Farhat Hached, B.P. 94, Rommana, 1068 Tunis, Tunisia

[3] Laboratoire des Procédés Thermiques, Centre de Recherches et des Technologies de L'Energie, Technopole de Borj-Cédria, B.P. 95, 2050 Hammam-Lif, Ben Arous, Tunisia

[4] Institut Supérieur des Sciences et Technologies de l'Environnement, Université de Carthage, B.P. 1003, 2050 Hammam-Lif, Ben Arous, Tunisia

large amounts of fossil resources, raw materials, and leads to the production of a considerable quantity of solid waste and carbon dioxide emissions.

In this context, the construction sector offers opportunities for considerable reductions in energy requirements and carbon dioxide emissions while improving energy efficiency by using new eco-friendly raw materials, alone or mixed with other materials. The addition of brick dust (Bayraktar et al. 2019a), silica fume and marble dust (Bayraktar et al. 2019b) to Portland cement is an important solution for eliminating waste and reducing costs and risks of accidents in buildings subjected to high temperatures.

Furthermore, the reinforcement of construction materials (cement, gypsum, mortar, etc.) with waste or natural fibers extracted from plants, stems, leaves, has many benefits such as their low weight, availability, biodegradability, cost-effectiveness, non-toxicity, low thermal conductivity, and low emission of CO_2. Therefore, these materials can also lead to energy savings and a decrease in environmental pollution. Among the natural admixtures, there are bamboo (Ren et al. 2014), pineapple leaves (Sena Neto et al. 2015), jute (Rokbi et al. 2019), hemp (Santoni et al. 2019), wood dust (Kumar et al. 2019), coir (Taban et al. 2020), oil palm fibers (Momoh and Osofero 2020).

The inclusion of natural fibers in a cement or gypsum matrix affects its thermal conductivity, mechanical strength, and density. Thermal conductivity and density decrease with increasing fiber fraction (Benmansour et al. 2014; Akinyemi and Dai 2020; Charai et al. 2021; Karimah et al. 2021). Numerous studies have shown that the incorporation of raw natural fibers without any treatment enhances the thermal conductivity but decreases the mechanical properties. Lertwattanaruk and Suntijitto (2015) studied the mechanical and thermal performances of including oil palm and coconut coir fibers in the cement-based materials, as well as, Fiore et al. (2020) studied the effect of the incorporation of sheep wool fibers. Their results showed that the addition of these fibers into the mix proportion reduced the thermal conductivity and the mechanical strength of the cement composite. Horma et al. (2022) indicated that the use of spent tea decreases the thermal conductivity by 67% and the compressive strength by 97% of cement-based mortar. Moreover, Bamaga (2022) showed that the compressive strength of mortar decreases significantly with length and percentage of fiber, which reduces by 83.91% for 3% by weight of date palm fiber of 50 mm in length.

This research aims to improve, on the one hand, the thermal properties of cement and gypsum by mixing each of them with Posidonia Oceanica (PO) and Esparto Grass (EG) fibers; on the other hand, the interfacial adhesion between fibers and matrices, which is of the highest interest for the mechanical properties of composite materials.

Natural fibers are known as hydrophilic materials and their surface is covered by an envelope containing hemicellulose, lignin, and non-cellulosic materials (waxes, pectins, sugars) (Koohestani et al. 2019). These covering materials possess some disadvantages when used in composites such as high moisture absorption and poor compatibility between matrix and fibers (Zhou et al. 2016). Therefore, to increase the compatibility of the matrix with the natural fibers, it is required to remove the covering materials (Chaiwong et al. 2019). There are three main methods of removal: physical, biological and chemical. The physical method (plasma, corona…) modifies the structural and surface properties of the fiber and thus influences the interfacial bonding with the matrices. The biological method uses biological agents such as enzymes and bacteria to modify the surface properties of the fibers. The chemical method uses chemical agents to decrease the hydrophilic nature of the fibers and thus enhances the compatibility between the fibers and the matrix. This method is effective, inexpensive and does not require advanced equipment like biological and physical methods (Neto et al. 2019; Oushabi 2019).

The treatment process used in this work-involves sodium chloride (NaCl), hot water, sodium hydroxide (NaOH) and acetic acid treatments to remove the surface layer of lignin, impurities, waxes and hemicellulose from the fiber surface and increase its crystallinity. The effectiveness of these treatments in removing the covering materials from the surface of PO and EG natural fibers is verified by scanning electron microscopy micrographs, x-ray diffraction, and Fourier transform infrared spectroscopy analyses.

Although several studies were effected on natural fiber-based composites, there are no precedent works reported on the determination of thermal and mechanical properties of gypsum and cement-based materials with treated EG (TEG) and treated PO (TPO) fibers. This study shows the benefit of EG and PO fiber dewaxing for the enhancement of the interfacial cohesion with cement and gypsum composites leading to the improvement of the thermal and mechanical properties of composites. The entire research work was performed at the Research and Technology Center of Energy of Borj-Cedria (Tunisia), during year 2020–2021.

Fig. 1 **a** EG stems, **b** untreated EG fibers, **c** treated EG fibers, **d** PO balls, **e** untreated PO fibers, **f** treated PO fibers

Materials and methods

Preparation of samples

Fibers extraction and treatments

In this paper, two types of natural fibers have been used, EG and PO (Fig. 1). The PO balls are considered as a waste and might be an essential supply of fibers and the EG is a perennial plant and is considered as one of the most interesting non-wood plants for the production of fibers. Therefore, the valorization of these fibers in the construction field to yield bio-insulation materials may decrease energy consumption and organic waste.

EG stems were collected from the Kasserine region of Tunisia and the PO balls from Hammam chatt (Tunisia).

These materials were washed with running water to eliminate impurities, then, dried at ambient temperature for 48 h and crushed to extract fibers of about 5 mm of length.

In this study, four types of treatments were performed on the fibers:

- Treatment with sodium chloride: sodium chloride treatment was carried out by soaking the extracted fibers in a 3.5% NaCl solution at 60 °C for 24 h, followed by rinsing with water until the pH of the water reached 7.
- Treatment with hot water: the PO and EG fibers were submerged in boiling water for 4 h. Afterward, they were removed and washed with distilled water, and then dried at room temperature for 24 h.
- Treatment with sodium hydroxide: the fibers were treated with 5% NaOH solution at 30 °C during 4 h, and then rinsed many times with distilled water until all sodium hydroxide is removed.
- Treatment with acetic acid: the fibers were immersed in a distilled water solution with 2% of acetic acid to neutralize the pH, and then washed several times with distilled water.

Finally, the PO and EG fibers were dried under normal conditions for 24 h and then in an oven at 100 °C for 6 h to remove the trapped moisture.

Composites manufacturing

The construction raw materials used in this work were Portland cement CEM II/A-L 32.5 N and gypsum. To investigate the composites' specimens' thermal and mechanical properties, different percentages of PO and EG fibers (0, 2, 5, 7, and 10% by weight) were mixed with construction raw materials. The water cement and water gypsum ratios were 0.45 and 0.55, respectively.

The constituents were introduced into a mixer and mixed at slow speed and then a volume of water was added progressively with no stopping the mixing. Once the mixture turned homogeneous, it was versed into molds. The samples were demolded after 24 h and preserved at ambient temperature during 28 days.

Characterization

Fourier transform infrared (FT-IR) spectroscopy

Infrared spectra of untreated and treated PO and EG fibers were examined using a VERTEX 80v vacuum FT-IR spectrometer. The spectra were recorded in a potassium bromide (KBr) matrix in the wavenumber range from 4000 to 500 cm^{-1} in transmission mode. Samples in the form of discs were obtained by compressing a homogenized mixture of finely ground fibers and KBr using a hydraulic press at 5 MPa pressure.

X-ray diffraction (XRD)

XRD analysis of raw and treated fibers were carried out at room temperature by using a Bruker D8 Advance diffractometer with monochromatic copper Kα radiation ($\lambda = 1.5418$ Å). All specimens were scanned in the range of 2-theta between 10° and 80°. The voltage was set at 40 kV with a current of 40 mA.

Scanning electron microscopy (SEM)

The surface morphology of raw and treated fibers and composites were observed using a Thermo Scientific Quattro Environmental Scanning Electron Microscope.

Compressive strength test

The compressive strength of the elaborated cylindrical samples (height: 6 cm, diameter: 3 cm) was performed with a speed of 2 mm min^{-1} using a Universal Testing Machine (Lloyd Instruments) equipped with a 50 kN load cell. Three samples were tested for each composite formulation and the results given were the average values.

Thermal tests

The thermal characteristics were measured with a Hot-Disk apparatus. The Hot-Disk technique gives thermal conductivity, specific heat capacity, and thermal diffusivity of saturated and dry specimens. This method is well known as a Transient Plane Source technique (TPS). The transiently heated plane sensor process is the base of the

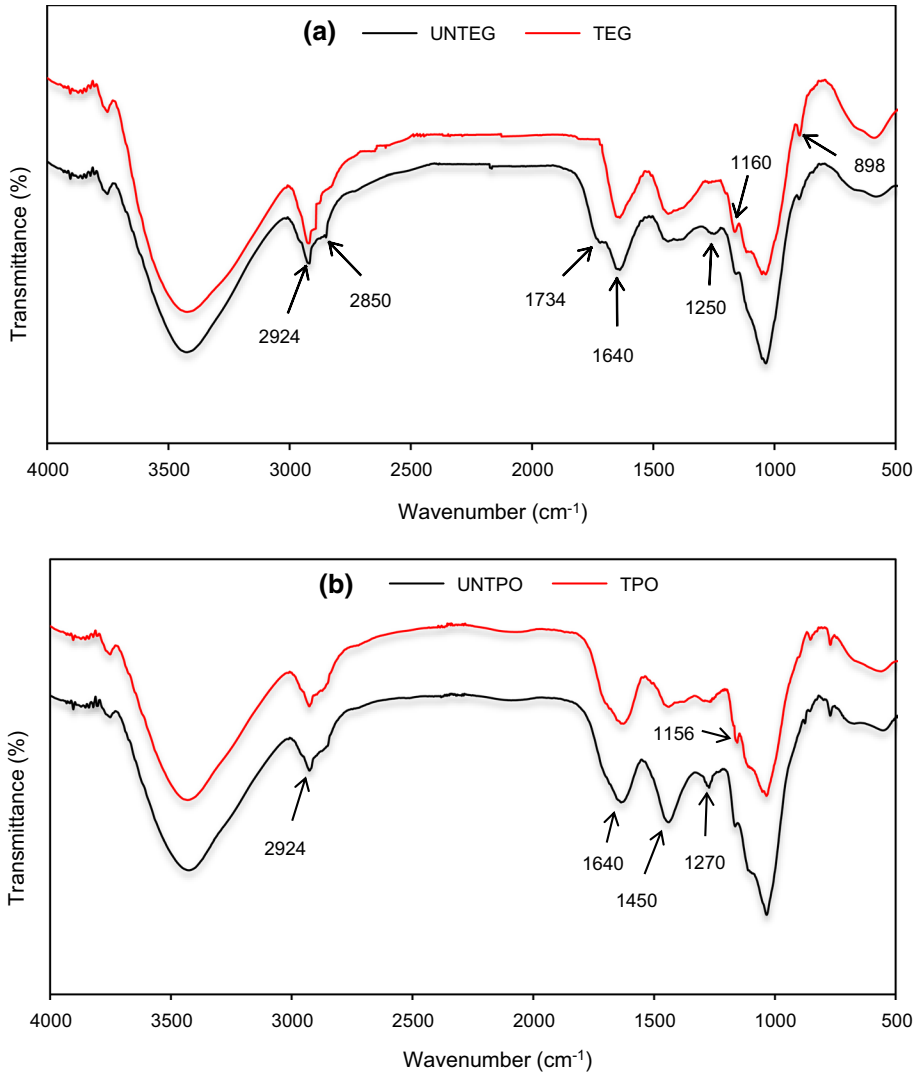

Fig. 2 FT-IR spectra; **a** UNTEG and TEG, **b** UNTPO and TPO

TPS system. The hot-disk sensor is composed by a metallic motif in the form of a dual spiral of nickel; this spiral is wrapped by two thin foils of insulating material (Kapton). Over the measurement, the hot-disk sensor is fixed between two identical pieces of the specimen. The running electrical stream leads to an increase in the temperature of the sensor, and at the same time indicating the temperature resistance increase as a function of time. Therefore, the Hot-Disk sensor deals as a dynamic temperature sensor and as a heat source (Colinart et al. 2021; Vitiello et al. 2021).

In this investigation, the experiments were realized by a Hot-Disk TPS 500S. The specimens (4 × 4 × 1 cm) were measured using a probe 5465 (reference) with a radius of 3.189 mm. A heating power of 80 mW was applied with a measurement time of 20 s. The Hot-Disk TPS 500S specifies the accuracy of the thermal conductivity measurements as ± 2%, though the accuracy of the thermal diffusivity measurements as ± 5%. The results were obtained from the average of three repeated analyses for each sample.

Results and discussion

FT- IR spectra

The FT-IR spectra of the untreated and the treated fibers (Fig. 2) present a broad band at 3600-—3300 cm^{-1} assigned to the O–H stretching vibration of the hydroxyl groups (Reddy et al. 2014). Bands at 2924 and 2850 cm^{-1} were ascribed to the C-H stretching of CH and CH_2 in

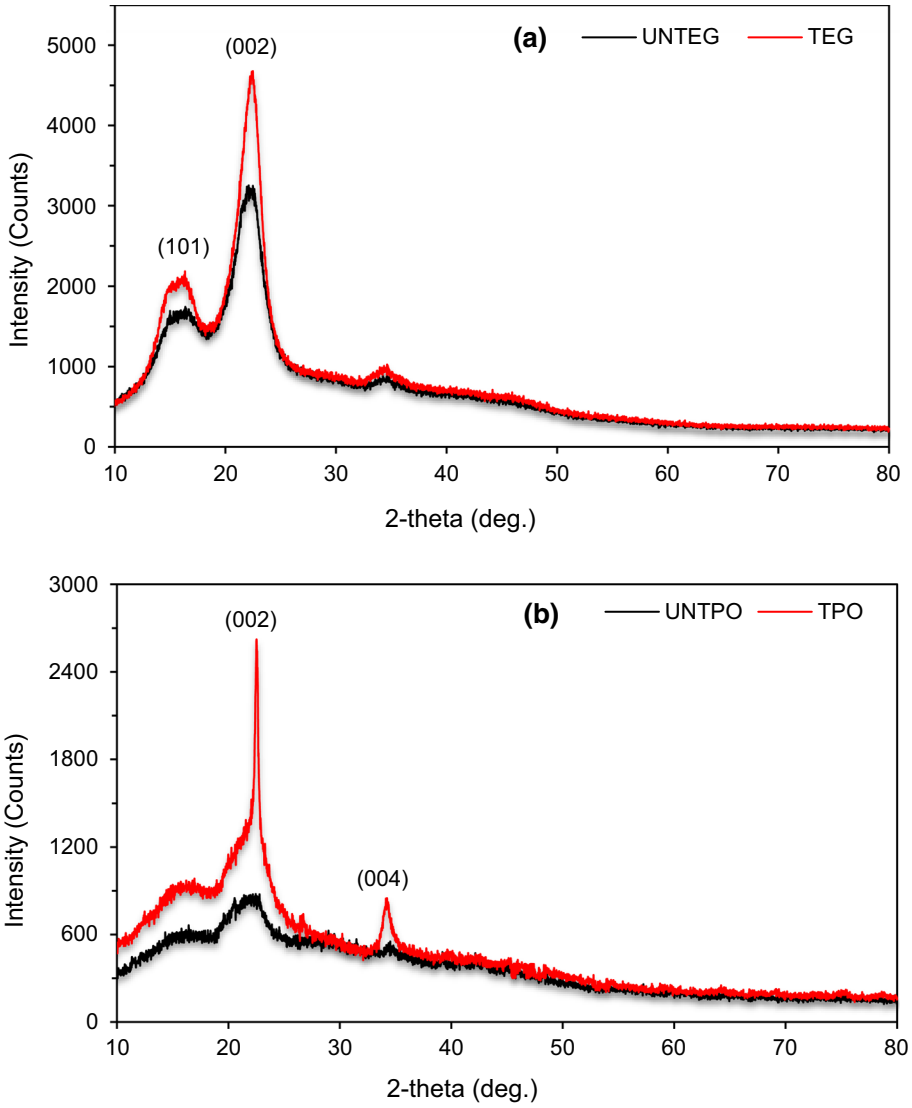

Fig. 3 XRD; **a** UNTEG and TEG, **b** UNTPO and TPO

hemicellulose and cellulose (Reddy et al. 2014). Spectra of untreated EG (UNTEG) fibers exhibit a band at 1734 cm^{-1} attributed to the ester groups in hemicelluloses and in aromatic constituents of lignin (Reddy et al. 2014). The absorption band at 1640 cm^{-1} is ascribed to the O–H bending of absorbed water. The band around 1450 cm^{-1} for untreated PO (UNTPO) is attributed to the C-H deformation in methoxyl, methylene, and methyl groups of lignin (Uma Maheswari et al. 2012). The bands at 1250 cm^{-1} for UNTEG and 1270 cm^{-1} for UNTPO are ascribed to the C–O stretching of acetyl groups in the hemicelluloses. The bands localized at 1160 cm^{-1} for TEG and 1156 cm^{-1} for TPO are linked to the C-O stretching and C-H deformation vibrations of the cellulose pyranose ring skeletal. In the weak wavenumber range, the band at 898 cm^{-1} for TEG is assigned to the β-glycosidic bonds among the cellulose sugar units (Uma Maheswari et al. 2012).

After treatments, it can be noted, on the one hand that the peaks indicating hemicellulose and lignin at 1734, 1450, 1250 and 1270 cm^{-1} in the spectra of untreated fibers are not present in the spectra of TEG and TPO fibers. On the other hand, the intensity of the peaks indicating cellulose at 1160, 1156 and 898 cm^{-1} increases slightly in the spectra of treated fibers. These results confirm that the treatments processes remove most of the lignin and hemicellulose covering materials.

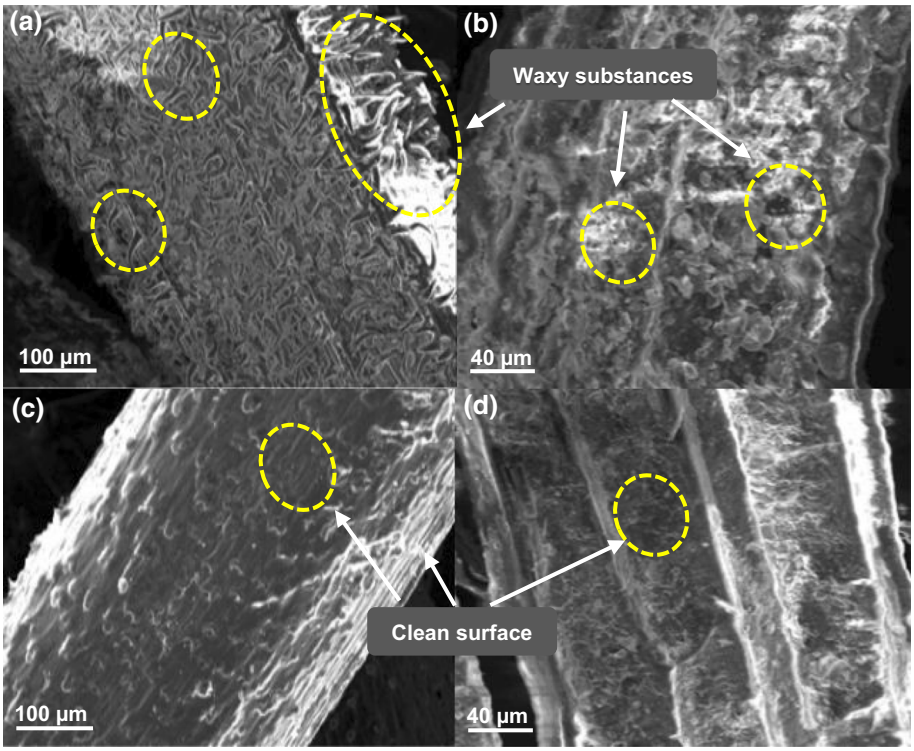

Fig. 4 SEM micrographs of fibers; **a** UNTEG, **b** UNTPO, **c** TEG, **d** TPO

X-ray diffraction

The EG and PO fibers used were examined using the XRD technique. Figure 3 presents the XRD intensity of untreated and treated fibers as a function of the diffraction angle.

The XRD curves of untreated and treated PO and EG fibers show different peaks at the same diffraction angles with different intensities. It is observed from the figure that crystalline peaks related to cellulose I were located around $2\theta = 16.6°$, 22.7°, and 34.6°correspond respectively to the planes (101), (002), and (004) (Nam et al. 2016).

It can also be observed that the peak intensities of the EG and PO fibers increased significantly after the treatments. This increase can be attributed to the fact that the treatments eliminated a part of the amorphous components covering the untreated fibers. These results are in accordance with the FT-IR analysis.

Morphology

The morphological changes that arise for EG and PO fibers after different treatment processes are shown in Fig. 4. The difference in their surface morphology before and after the treatments is clearly illustrated in these micrographs. It can be seen that there are impurities on the outside of the surface of the untreated fibers (Fig. 4a, b). These impurities make the surface rough and irregular. Therefore, the roughness of the surface of the fiber leads to a lower interfacial adhesion of the matrix with the fibers. Figure 4c, d shows that the treatments clean the surface of the fibers by removal of a large quantity of lignin, hemicelluloses, and waxy substances. Consequently, the treatment ameliorates the surface morphology. The PO fibers' surface is smoother and more regular than the EG fibers' surface, which can be attributed to the lesser quantity of impurities in PO fibers.

Figure 5 presents SEM micrographs of cementitious and gypsum samples filled with untreated and treated PO and EG fibers. In all treated fibers, a good adhesion among the matrix and the fibers can be observed from Fig. 5a–d. It can also be noticed that the TPO and TEG fibers are well dispersed in the gypsum and cement matrix. Moreover, a bad adhesion can be observed between the untreated fibers and the pastes (Fig. 5e–h), which is due to the existence of impurities leading to the formation of air voids decreasing the mechanical interlocking between fibers and matrices and facilitating the propagation of cracks in the specimens. Consequently, it

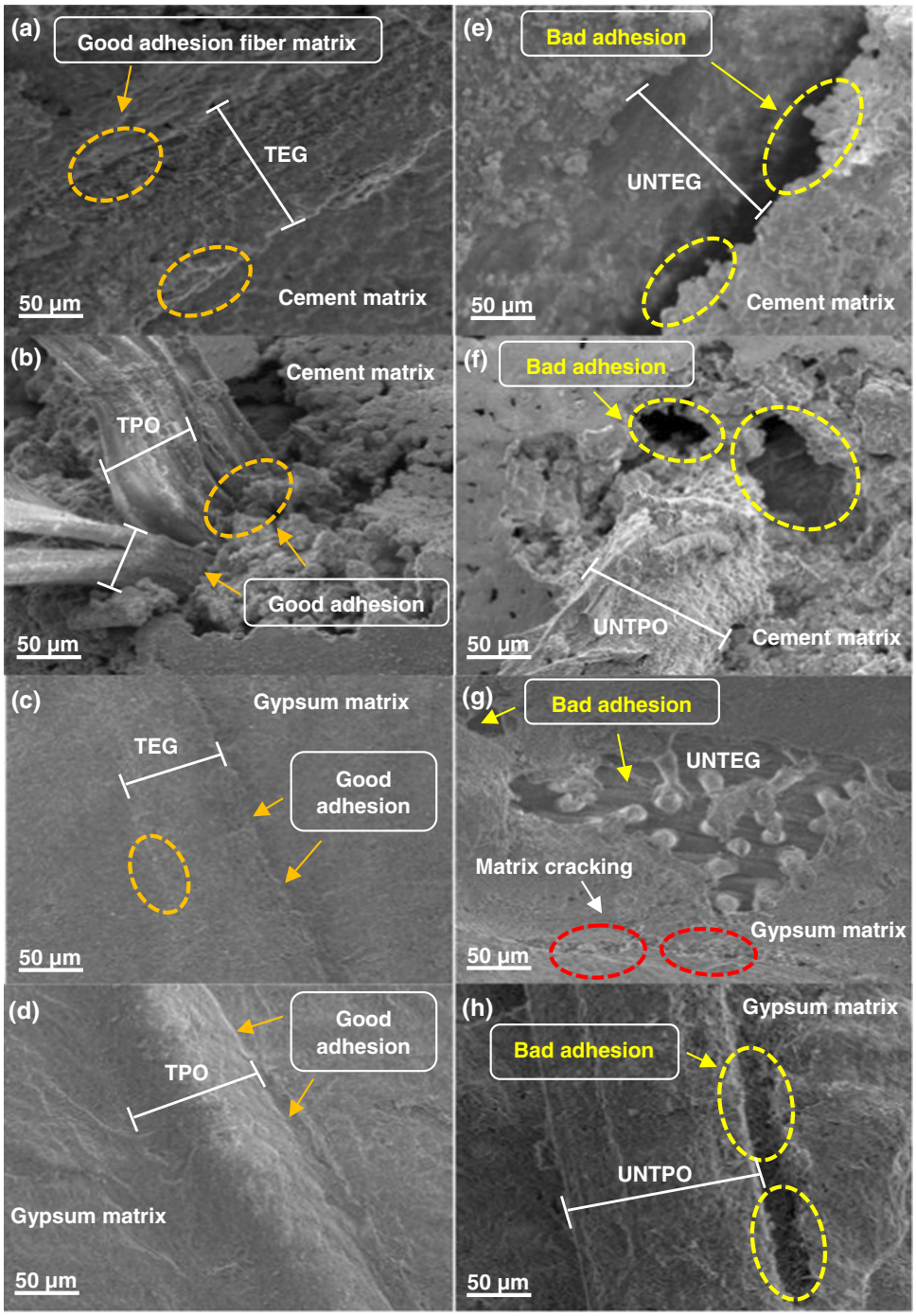

Fig. 5 SEM micrographs of composites; **a** Cement/TEG, **b** Cement/TPO, **c** Gypsum/TEG, **d** Gypsum/TPO, **e** Cement/UNTEG, **f** Cement/UNTPO, **g** Gypsum/UNTEG, **h** Gypsum/UNTPO

is clear that the treatments enhance the interfacial adhesion between fibers and matrices.

Chemical analysis of cement and gypsum

Table 1 shows the chemical composition of cement and gypsum examined by x-ray fluorescence (XRF). As stated by the XRF analysis, the main constituents of cement are calcium oxide CaO (56.94%) and silicon dioxide SiO_2

Table 1 Chemical composition of gypsum and cement

Composition (wt%)	Cement	Gypsum
Na_2O	0.095	0.014
MgO	1.304	1.457
Al_2O_3	3.468	0.154
SiO_2	17.932	0.861
P_2O_5	0.167	0.013
SO_3	2.639	47.215
K_2O	0.403	0.049
CaO	56.938	35.216
TiO_2	0.186	0.015
Cr_2O_3	0.008	0.000
Fe_2O_3	4.139	0.081
ZnO	0.010	0.000
SrO	0.089	0.342
Mn_2O_3	0.120	0.003

(17.93%). In the instance of gypsum, they are principally the sulphur trioxide SO_3 (47.22%) and CaO (35.22%).

Compressive strength

The impact of the treated and untreated EG and PO fibers content on the compressive strength of cement and gypsum composites is illustrated in Fig. 6 and the percentage of variation of the compressive strength of the elaborated composites compared to matrices without fibers is shown in Table 2. In comparison with pure matrices (cement and gypsum), it can be observed that the compressive strength is enhanced by the addition of TEG into gypsum composites and TPO into cement and gypsum composites until a maximum of 5% mass of fiber content, then the compressive strength reduces when the fiber content raises, although, composites filled with treated fibers show higher compressive strength than composites filled with untreated fibers. Moreover, composites made with PO fibers present better mechanical strength compared to composites with EG fibers. The insertion of 2% of TPO into cement improves its compressive strength by up to 23.56% which is the best improvement observed (Table 2).

In conclusion, the enhancement of the compressive strength of composites including treated fibers can be ascribed to the improvement of the interfacial cohesion between fibers and matrices by the treatments.

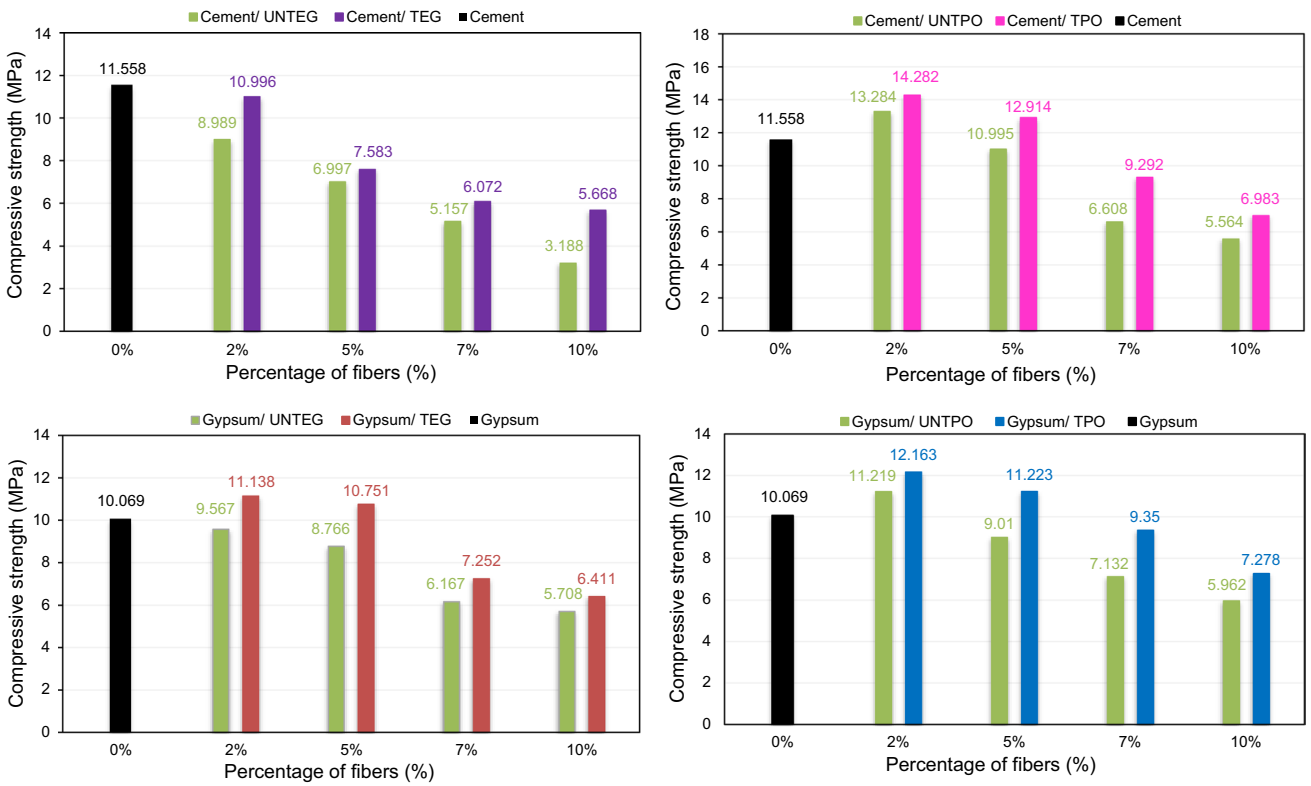

Fig. 6 Compressive strength of composites

Table 2 Percentage of variation of compressive strength of elaborated composites compared to pure matrices [reduction (−) and increase (+)]

Composites	Percentage of fibers (%)	Percentage of variation of compressive strength (%)	
		Untreated fibers	Treated fibers
Cement/EG	2	− 22.22	− 4.86
	5	− 39.46	− 34.39
	7	− 55.38	− 47.46
	10	− 72.41	− 50.96
Cement/PO	2	+ 14.93	+ 23.56
	5	− 4.87	+ 11.73
	7	− 42.82	− 10.60
	10	− 51.86	− 39.58
Gypsum/EG	2	− 4.98	+ 10.61
	5	− 12.94	+ 6.77
	7	− 38.75	− 27.97
	10	− 43.31	− 36.32
Gypsum/PO	2	+ 11.42	+ 20.79
	5	− 10.51	+ 11.46
	7	− 29.16	− 7.14
	10	− 40.78	− 27.72

Thermal conductivity and thermal diffusivity of composites

The thermal properties (thermal conductivity and diffusivity) measurements of the elaborated composites were performed using the transient plane source (TPS) method. The thermal diffusivity of a material determines the rapidity with which the material responds to a change in temperature. Thermal conductivity is the most important thermal property of insulation materials because it directly affects the heat transmission resistance that the insulating material must offer. Figures 7 and 8 display the variation of the thermal conductivity and the thermal diffusivity of the diverse materials as a function of TEG (or TPO) fibers content. The addition of TEG (or TPO) into the gypsum or cement matrix reduces the thermal conductivity and diffusivity of the composites. The more the amounts of the TEG (or TPO) fibers increases the more the thermal conductivity and the thermal diffusivity of the composite decreases. In fact, for a percentage of the additional fibers ranging from 0 to 10% of the cement mass, the thermal conductivities and thermal diffusivities decrease, respectively, of about 56% and 37.63% in the case of TEG fibers, and of about 47% and 32.37% in the case of TPO fibers. It can also be seen that the thermal conductivities of the gypsum-based samples of TEG and TPO decrease respectively of about 27.83% and 19.64% by increasing the percentage of fibers from 0 to 10%. The diminution of the thermal conductivity of the composites is linked to the lower thermal conductivity of the TEG and TPO fibers comparing to that of cement and gypsum on the one hand and to the air voids content in the paste on the other hand.

For 2, 5, 7, and 10% mass percentages of fibers, the incorporation of TPO and TEG fibers into the mixture improves more the thermal properties of cement than gypsum. Furthermore, the thermal performance of Cement/TEG composites is lightly better compared to the other elaborated composite materials. The obtained results are in accordance with many investigations (Braiek et al. 2017; El Wardi et al. 2019; Asadi et al. 2021), which showed a decrease of the thermal diffusivity and thermal conductivity of the composites by using diverse types of natural fibers.

Thermal performance

The experimental study of the thermal properties of these eco-friendly composite materials (cement or gypsum/TPO or TEG fiber composites) was carried out for their use in construction. The comparison of two walls, one including the composite with fibers and the other including the composite without fibers, possessing the same thickness "e" and subject to the same temperature gradient "ΔT" yields the following relations for the heat flux "$\emptyset$":

For an area of 1 m^2;

$$\emptyset = \frac{\Delta T}{R} \tag{1}$$

and the thermal resistance "R" for a homogeneous wall is

$$R = \frac{e}{\lambda} \tag{2}$$

where λ is the thermal conductivity,

The heat flux can be given by

$$\emptyset = \frac{\Delta T \cdot \lambda}{e} \tag{3}$$

For an area of 1 m^2 and a similar thickness, the ratio of the two heat fluxes passing through the two walls can be deduced by:

$$\frac{\emptyset_{\text{Composite with fibers}}}{\emptyset_{\text{Composite without fibers}}} = \frac{\lambda_{\text{Composite with fibers}}}{\lambda_{\text{Composite without fibers}}} \tag{4}$$

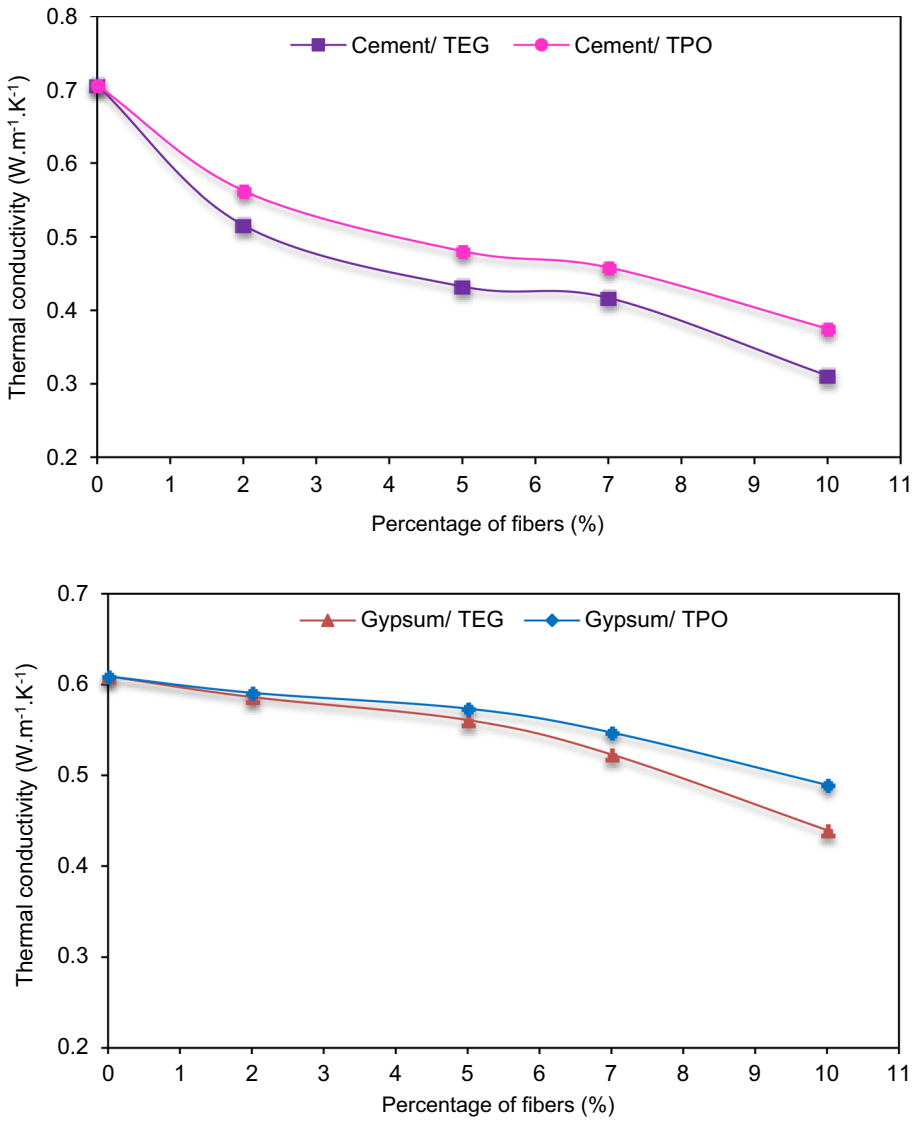

Fig. 7 Evolution of the thermal conductivity as a function of fibers content

Thus, energy savings can be calculated using the following relation (Braiek et al. 2017):

$$\text{Energy saving} = 100 \times \left(1 - \frac{\emptyset_{\text{Composite with fibers}}}{\emptyset_{\text{Composite without fibers}}}\right) \quad (5)$$

The variation of the energy saving of composites as a function of the fiber content is represented in Fig. 9 and shows that the Cement/TEG composite has a better thermal performance in comparison with the other elaborated composites, which presents a reduction of energy consumption of about 56% for a specimen containing 10% of TEG fibers. Besides, it can be noted that the Cement/TEG composite in this study has a better thermal performance compared to the cement mortar/coconut coir composite studied by Lertwattanaruk and Suntijitto (Lertwattanaruk and Suntijitto 2015) and to the concrete reinforced with wood aggregates (Taoukil et al. 2011), which exhibit an energy consumption decreasing, respectively, of about 44% for a 10% of mass percentage of coconut coir fibers, and about 35% for a 10% of mass percentage of wood aggregates.

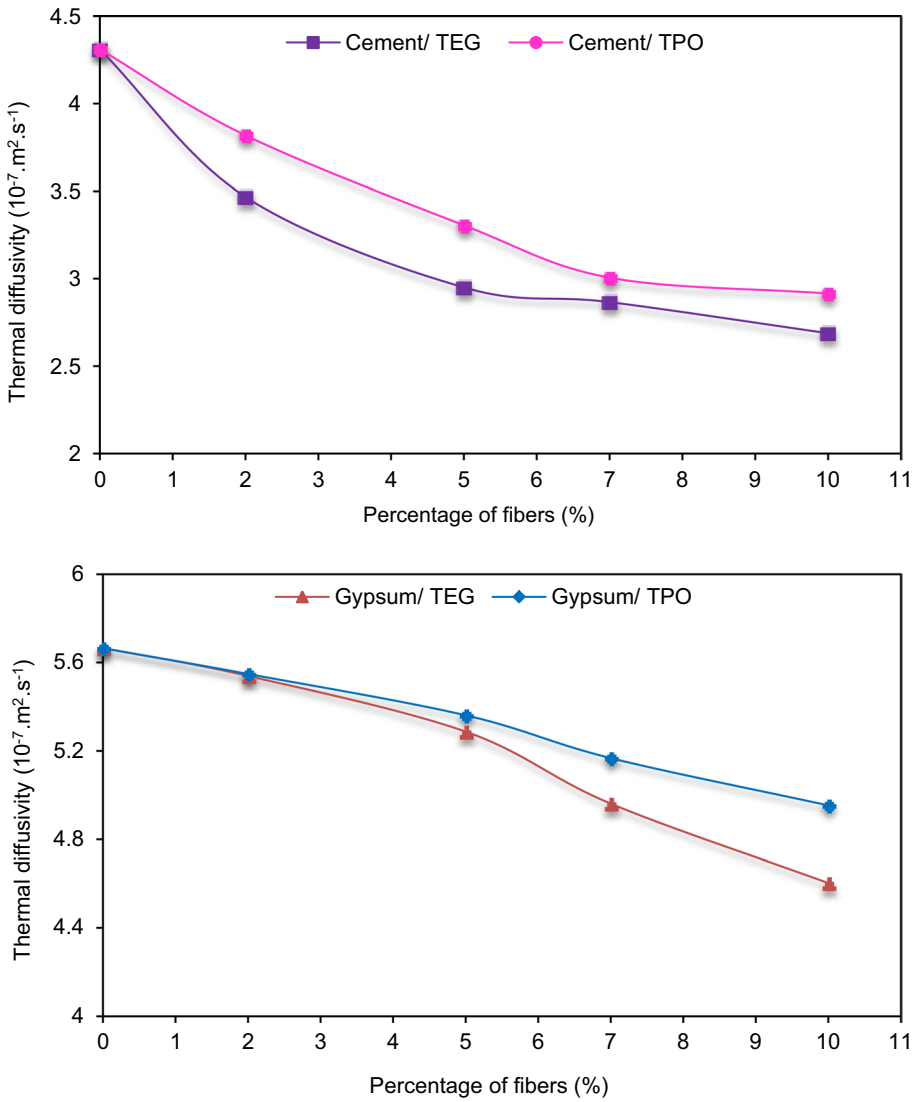

Fig. 8 Evolution of the thermal diffusivity as a function of fibers content

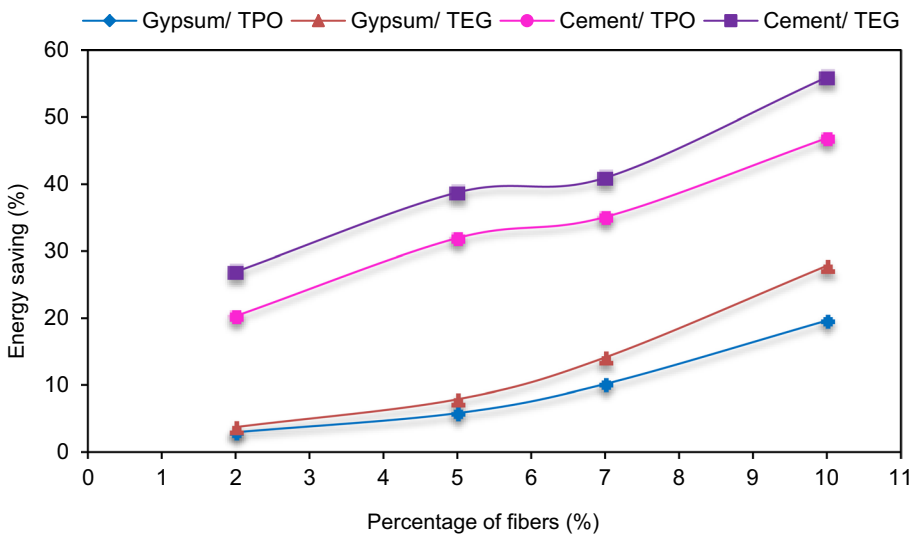

Fig. 9 Energy saving of composites

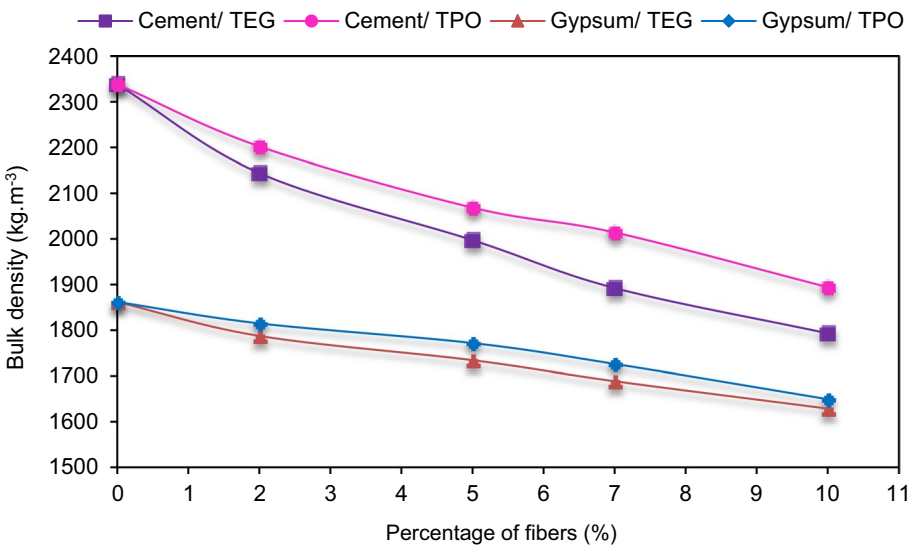

Fig. 10 Variation of bulk density as a function of fibers content

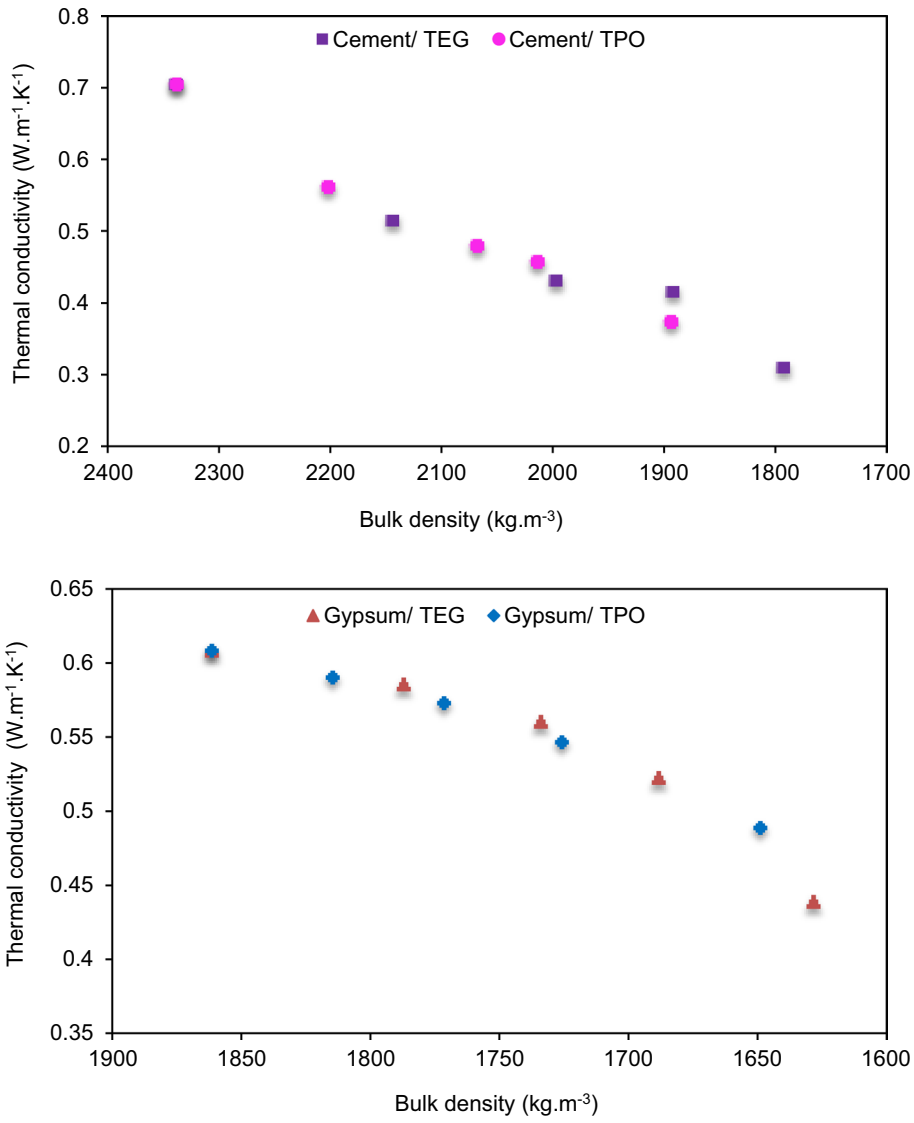

Fig. 11 Evolution of the thermal conductivity of the composites as a function of bulk density

Influence of fibers content on the density of composite materials

The evolution of bulk density as a function of fibers percentages is shown in Fig. 10, it can be seen that the insertion of TPO or TEG fibers considerably reduces the bulk density of the elaborated materials, particularly in the case of Cement/TEG composites. For a fibers content of 10%, this decrease is about 23.33% for the Cement/TEG composites, 19% for the Cement/TPO specimen, 12.52% for the Gypsum/TEG sample, and 11.41% for the Gypsum/TPO composite. This reduction can be attributed to the air voids formation by the fibers throughout the mixing on the one hand and to the lower density of the TEG and TPO fibers comparing to that of the cement and gypsum pastes on the other hand.

Figure 11 shows a notable influence of bulk density on thermal conductivity. The thermal conductivity reduces when the bulk density reduces. This diminution is related to the lower conductivity of the TEG and TPO fibers comparing to that of the cement and gypsum pastes and to the porosity content in the specimen. Therefore, the inclusion of fibers leads to increase the pores in the matrix yielding to lighter samples and lesser thermal conductivity. This comportment is consistent with previous works (Koru 2016; Boumhaout et al. 2017; Hung Anh and Pásztory 2021), which manifests that the thermal conductivity varies depending on density.

Conclusion

Buildings contribute significantly to primary energy consumption worldwide and are evenly significant sources of carbon dioxide emissions. In this context, improving the thermal insulation and energy efficiency of building envelopes with ecological composite materials leads to lessening the energy requirements and giving a sustainable environment.

The use of natural fibers as reinforcement in building materials is interesting due to their many environmental and energy benefits. However, natural fibers must be treated before being mixed with construction materials to remove certain chemical compounds that lead to decreased mechanical strength and affect the durability and quality of composite products over the long term. The goal of this paper is to show that the treated esparto grass and posidonia oceanica naturel fibers can be utilized in different proportions in gypsum and cement construction materials for applications in the residential and construction industry.

This study showed the benefits of TEG and TPO fibers for the enhancement of the thermal insulation of cement and gypsum construction materials and the effectiveness of the treatments used for the improvement of the interfacial adhesion between fibers and matrices.

In a first step, the impact of the treatments on the removal of lignin, hemicellulose and non-cellulosic components from the surface of PO and EG fibers was studied for a better adhesion between the fiber and the building materials.

In a second step, the new eco-friendly composite materials were elaborated by mixing various masses of untreated and treated EG and PO fibers with the cementitious and gypsum raw materials and the thermal and mechanical properties of these composites were then evaluated.

In summary, the subsequent conclusions were pulled out:

- The FTIR results of the PO and EG fibers showed that the most-part of lignin, hemicelluloses, and waxes was removed from the fiber surfaces after treatment. The x-ray diffraction characterization of these fibers revealed that the treatment by NaOH, NaCl, acetic acid and hot water increased the global crystallinity, which was ascribed to the elimination of a large proportion of amorphous constituents.
- The SEM images revealed that the treatment process modifies the morphology of EG and PO fibers and that the impurities were eliminated, which increased the interfacial interaction and adhesion between matrices and fibers, and consequently, the mechanical strength of the composites.
- The percentage of EG and PO fibers used as cement or gypsum replacement has a significant effect on the mechanical properties of composites. For low fiber content (2 and 5%), the compressive strength value of the composites filled with TEG increased compared to pure gypsum. In the case of TPO, the compressive strength raised in comparison with both pure matrices (cement and gypsum). For higher fiber content (7 and 10%), the mechanical properties of all samples reduced, however, the composites based on treated fibers showed a higher compressive strength value compared to composites based on untreated fibers.
- The thermal properties of composites are controlled by the percentage of fiber used. As results, increasing the content of TEG and TPO fibers decreased the thermal conductivity and diffusivity of cement and gypsum-based materials. In addition, the use of TEG fibers allowed a better thermal performance of the cementitious matrix

compared to TPO fiber. The insertion of 10% of TEG into cement makes the composite lighter by decreasing its bulk density by around 23.33%, reducing its thermal diffusivity by 37.63%, and by improving its thermal performance by up to 56%. However, the use of TPO allowed a better mechanical performance of the cementitious matrix than TEG. The addition of 2% of TPO into the cement matrix increases its mechanical performance by up to 23.56%.

- The lightening of cement or gypsum by TEG or TPO results in a considerable increase in thermal insulating capacity. Therefore, bulk density is the main factor that significantly affects the thermal conductivity coefficient.

Finally, integrating cement or gypsum with TEG or TPO gives rise to green composites technology, which has low CO_2 and CO emissions directly or indirectly in the environment, and can be employed as bio-sourced material for building energy consumption decreasing and replace conventional synthetic fibers.

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Declarations

Conflict of interest The authors declare that there are no conflicts of interest.

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