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ORIGINAL ARTICLE

Effect of the incorporation of NaOH-treated wood aggregates on thermal and mechanical properties of plaster mortar

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Abstract

Presently, the recycling potential of wood aggregates (WA) is limited. However, their utilization appears to be a viable alternative for building insulation. Recycled wood aggregates in composite materials are usually used in cement as a matrix. The present research focuses on the possibilities of their recycling in the plaster matrix. Wood aggregates/plaster (WAP) composites are prepared with varying WA densities (0; 5; 10; 15; 20 by volume). Four sodium hydroxide (NaOH) solution concentrations (1, 2, 6, and 10%) are used to treat WA at 80 °C for 2 h. Thermal and mechanical properties of newly treated bio-aggregates composites were investigated. Results show that the use of untreated WA makes the composite lightweight and enhances the thermal insulating performances of plaster paste but negatively affects its mechanical strengths. An optimal chemical surface modification of WA improves the flexural and compressive strengths and decreases the water uptake of resulting composites. The adequate treatment process (2% NaOH concentration at 80 °C during 2 h) of wood aggregates was proven when comparing treated and untreated fibers' morphology as well as their crystallinity index. Experimental results confirm the possibility to reuse the wood aggregates in new mortars for insulating and building applications.

Abbreviations

W/P	Water to plaster ratios
NaOH	Solution of sodium hydroxide
PP	Plaster paste
WA	Wood aggregates
WA 0	Untreated wood aggregates
WA 1	Treated wood aggregates with 1% NaOH
WA 2	Treated wood aggregates with 2% NaOH
WA 6	Treated wood aggregates with 6% NaOH
WA 10	Treated wood aggregates with 10% NaOH
WAP 0	Untreated wood aggregates/plaster mortar
WAP 1	Treated wood aggregates/plaster mortar with 1% NaOH
WAP 2	Treated wood aggregates/plaster mortar with 2% NaOH
WAP 6	Treated wood aggregates/plaster mortar with 6% NaOH
WAP 10	Treated wood aggregates/plaster mortar with 10% NaOH

1 Introduction

The international energy context imposes new orientations on the new building or renovation sector. The conventional industries of building materials are very energy consuming. Thus, they are responsible for a high rate of greenhouse gas emissions. Considering the current environmental awareness, the building sector is now faced with increasing interest to use advanced and sustainable materials (Kuqo and Mai 2021). In this context, the present work presents a serious development of a constructive approach based on the use of new, technically efficient and environmentally friendly composite materials.

The wood is used alone or mixed with another type of fiber to develop new composite materials. Many types of composites made with wood have been investigated, such as wood-plastic composites (Zhang et al. 2021a; Ge et al. 2021; Zhang et al. 2021b; Yang et al. 2020 and Bhaskar et al. 2020), wood/polyimide composites (Ren et al. 2021), aluminum-wood composites (Omoniyi et al. 2021), and perlite/

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wood-magnesium composites (Lin et al. 2020) via different fabrication methods, such as extrusion, hand layup, solvent-blending process, compression molding (Jaafar et al. 2019), injection molding and additive manufacturing (3D printing) and for different recent applications (Ravaz Khan et al. 2020). The advantages of wood fiber are its simplicity, ease of preparation and use, and low cost (Berger et al. 2020). The characteristics of treated and untreated wood composites encourage the researchers for further research works and the development of novel wood composites for advanced applications. Wood-based building materials offer interesting hygroscopic characteristics due to their high moisture capacity (Bunkholt et al. 2021). Wood aggregates insulation, on the other hand, may have the same risk of high moisture levels as mineral aggregates insulation. Wood fiber insulation has the benefit of distributing moisture across a larger volume than mineral aggregates insulation.

Thanks to its high hygroscopic, acoustic, mechanical, and thermal properties, many researchers investigate plaster-wood composites. Pedreno-Rejas et al. (2017) evaluated the behavior of a composite material made based on gypsum and wood waste (wood shavings and sawdust) from demolition. Their results show that only the plates perforated with wood waste at 10 wt% and 20 wt% addition were sufficient to reach the minimum values of acoustic conditioning required by Spanish regulations. When the plates with 20% wood shavings are utilized, the largest thermal improvement occurs. Remillieux et al. (2009) predicted numerically the noise transmission of sonic booms inside buildings. Their results show that the plaster–wood composite can be used to minimize the noise impact in residential houses. Kuqo and Mai (2021) assessed the mechanical properties of gypsum plaster composed of Mediterranean seagrass and pinewood fibers. Their results show that the addition of seagrass and wood fibers presents a sustainable and ecological way to improve the major properties of gypsum products. Other researchers experimented with various mixes of recycled wood fiber and rubber powder in ACC (autoclaved aerated concrete) (e.g., He et al. 2019). They conclude that AAC with good thermal insulation performances and relatively high mechanical strengths can be obtained.

Alkaline treatment has two impacts on the fiber: (1) it enhances surface roughness, which improves mechanical interlocking; and (2) it increases the quantity of cellulose exposed on the fiber surface, which increases the number of available reaction sites (Valadez-Gonzalez et al. 1999). As a result, alkaline treatment has a long-term influence on the mechanical behavior of flax fibers, particularly fiber strength and stiffness (Jähn et al. 2002). Alkali treatment increased the tensile characteristics (both strength and modulus) of flax fiber–epoxy composites by up to 30%, according to Van de Weyenberg et al. (2003). This correlated with the elimination of pectin. The mechanical, impact fatigue and dynamic mechanical characteristics of fiber-reinforced composites were also dramatically enhanced by alkaline treatment (Joseph et al. 1996; Sarkar and Ray 2004 and Jacob et al. 2004). Jacob et al. (2004) investigated the impact of many NaOH concentrations (0.5, 1, 2, 4, and 10%) on the tensile strength of sisal fiber-reinforced composites and showed that the 4% NaOH treatment offered the highest tensile strength at room temperature. Mishra et al. (2003) found that a sisal fiber-reinforced polyester composite treated with 5% NaOH had higher tensile strength than a composite treated with 10% NaOH. This is because excess delignification of natural fiber develops at greater alkali concentrations, resulting in a weaker or damaged fiber. After a certain amount of optimal NaOH, the composite's tensile strength dropped significantly.

The aim of the present paper was to valorize cheap and renewable wood waste as a reinforcing material for plaster paste. Different treatments were applied to wood aggregates: 1%, 2%, 6%, 10% of NaOH concentration solution. First, the manufacturing method of composites based on plaster and natural reinforcement (treated and untreated wood aggregates) is presented. Then, physical, thermal, and mechanical characteristics relating to the obtained composites are analyzed. Finally, the microstructure properties and crystallinity characterization of WA are discussed and optimal concentration of NaOH and wood aggregates are highlighted.

2 Methods of characterization

2.1 Materials

To build composites, the mixing rate and the proportions of the components are calculated. The matrix was prepared from the plaster KNAUF with a bulk density of 867 ± 9 kg/m^3. The principal constituent is calcium sulfate hemihydrate. Natural constituents may include limestone, clay, and a small amount of quartz. Additives may include hydrated lime (less than 2.5%), small amounts of polymer water retention agents, binders, dispersants, and setting time modifiers. These characteristics make plaster suitable as a finishing material, rather than a load-bearing material. Plaster is produced by heating gypsum to about 150 °C as follows:

$$2CaSO_2 \cdot 4H_2O + \text{Heat} \rightarrow 2CaSO_4 \cdot H_2O + 3H_2O \quad (1)$$

Plaster paste was characterized to determine thermal conductivity k, thermal capacity Cp, diffusivity D, and effusivity E. These values of plaster paste (PP) are shown in Table 1. Used equipment and the procedure to measure thermal conductivity, thermal diffusivity, thermal capacity and effusivity are described in Mehrez et al. (2022a,b).

Table 1 Thermo-physical properties of plaster paste (PP)

Properties of PP	k ($Wm^{-1} K^{-1}$)	C_P ($J Kg^{-1} K^{-1}$)	D ($\times 10^{-7} m^2 s^{-1}$)	E ($J m^{-2} K^{-1} s^{-0.5}$)
Values	0.25 ± 0.006	826.90 ± 0.154	2.75 ± 0.039	475.87 ± 0.030

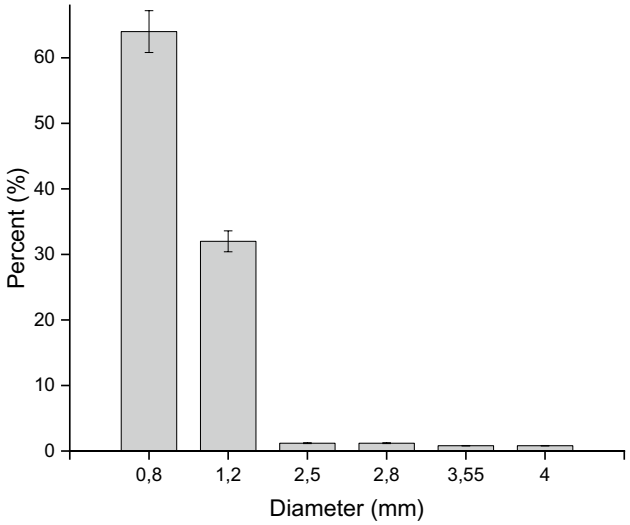

Fig. 1 Sieve analysis grading curve of used wood aggregate

Table 2 Thermo-physical properties of the wood aggregates in raw state (WA 0)

Properties of WA 0	Conductivity ($Wm^{-1} K^{-1}$)	Density (g cm^{-3})	Porosity (%)	Water uptake (%)
Values	0.04 ± 0.0067	0.24	85.04	354.35

Wood aggregates (WA), used as inclusions, were obtained from wood processing sector. The aggregates were then dried in the sun for 1 day and then in a 50 °C oven until dried. Sieve analysis was performed. Figure 1 illustrates the grading curves of wood aggregates used in the fabrication of the samples. The mean aggregates diameter is less than 1.2 mm. The thermo-physical characteristics of wood aggregates in the raw state (WA 0) are shown in Table 2. The used WA has high thermal insulation characteristics. The thermal conductivity (0.04 $Wm^{-1} K^{-1}$) and density (0.24 g cm^{-3}) are extremely low. However, porosity and water uptake are higher.

2.2 Chemical treatment (CT)

The treatment that involves putting the fibers in a dilute solution of sodium hydroxide (NaOH) is called "mercerisation" (Rebelo et al. 2019). In the literature review, different degrees of modification are obtained by varying the concentration of the alkaline solution, the temperature, and the length of treatment. The mercerisation treatment improves the fiber surface adhesive characteristics by removing natural and artificial impurities, thereby producing a rough surface topography (Rebelo et al. 2019). In the present study, fibers were chemically treated in a sodium hydroxide solution (NaOH) by varying the concentration at constant temperature (80 °C) and treatment time (2 h). The treatments consist in immersing the WA in a solution with a mass concentration of 1%, 2%, 6%, and 10% noted WA 1, WA 2, WA 6, and WA 10, respectively (Table 3). This selection was used and chosen from the bibliographical summary of the treatment conditions of the different cellulosic fibers (Valadez-Gonzalez et al. 1999; Jähn et al. 2002; Van de Weyenberg et al. 2003; Joseph et al. 1996; Sarkar and Ray 2004; Jacob et al. 2004; Mishra et al. 2003). Fibers were stirred every 30 min to ensure the efficacy of the treatment.

Table 3 Wood aggregates treatment conditions

Nomenclature	Temperature	Mass concentration	Time	Composites
WA 0	–	Untreated	–	WAP 0
WA 1	80 °C	1% NaOH	2 h	WAP 1
WA 2	80 °C	2% NaOH	2 h	WAP 2
WA 6	80 °C	6% NaOH	2 h	WAP 6
WA 10	80 °C	10% NaOH	2 h	WAP 10

2.3 Composite preparation

Plaster, water, and wood aggregates were used to prepare the composite samples that were analyzed. Tap water with a pH of 7.5 was used to combine the ingredients. Four different volume ratios of wood aggregates were investigated: 5%, 10%, 15%, and 20% in each treatment concentration. For the preparation of the samples, two types of molds were prepared. The thermal and mechanical tests were performed with dimensions of $270 \times 270 \times 30$ mm^3 and $160 \times 40 \times 40$ mm^3, respectively. After 1 h, the composite samples were demounted and then cured in laboratory conditions for 21 days. Next, samples were dried in a regulated oven at 50 °C until constant weight. Regarding the mechanical tests, three replicates were produced for each wood aggregates volume fraction (untreated and treated), resulting in fifteen samples added to three replicates of the reference plaster. Nine composite samples were prepared for thermal

tests (one sample for each wood aggregates volume fraction in both cases treated and untreated).

2.4 Methods

2.4.1 Water uptake

The composite samples were immersed in a water bath at laboratory conditions (25 ± 2 °C), w_d. Before weighing, the samples were wiped off the surface water with a thin cloth, w_t, after t. When the weight of mortars becomes constant (0.1% between two weighing 12 h apart), the water uptake of composites was expressed using Eq. (2).

$$H(\%) = \frac{w_t - w_d}{w_d} \times 100 \tag{2}$$

2.4.2 Density of composite

The apparent density is defined as the ratio of weight by volume. The composite samples were dried in a controlled oven at 70 °C until constant weight. After that, the samples were weighed using an electronic balance with a precision of roughly 10^{-4} g. A caliper with a precision of roughly 0.02 mm was used to measure the dimensions of the samples.

2.4.3 Thermal conductivity

The thermal conductivity of composite samples as a function of volume fractions of untreated and treated wood aggregates was measured using a device called "hot boxes method". This device is mostly used to measure the thermal properties of construction materials with significant size (Mehrez et al. 2022a,b). Boxes are used to measure the thermal conductivity of composite samples in a steady state.

The composite sample is placed between two boxes. The first box is heated (T_h) using a constant electrical source ($q = U^2/R$). The second box is cooled using heat exchanger powered by cryostat (T_c) (Lakrafli et al. 2012). Considering that the lateral faces of the sample are insulated, a unidirectional heat flow was imposed. The principal condition of the hot box method is to adjust the temperature inside the box (T_b) to slightly higher than the outside temperature (T_a) such as the difference ($T_b - T_a$) < 1 °C. Every measurement was repeated five times to estimate the reproducibility of the measurement. Once a permanent regime was established, different temperatures (T_h, T_c, T_a and T_b) were recorded to be used in the thermal conductivity determination using the following equation:

$$k = \frac{e}{S\Delta T}\left(q - \beta \Delta T'\right) \tag{3}$$

$$\text{where} \begin{cases} \Delta T = T_h - T_c \\ \Delta T' = T_b - T_a < 1\,^{\circ}\text{C} \\ \beta = 0.16\,\text{W K}^{-1} \\ q = \frac{U^2}{R}; R = 5000\,\Omega \text{ and } 0 < U < 220\,\text{V} \end{cases}$$

Given that, the calibration of the experimental device used for thermal conductivity measurement was done to determine β coefficient after a series of experimental tests for well-known conductivity materials.

2.4.4 Mechanical characterization methods

The Moroccan standard EN 196-1 was applied to the measurement of flexural and compressive strengths for all tests. The flexural and compressive strengths were measured using a 5 kN capacity LLYOD machine, with speed loading fixed at 10 mm/min and 5 mm/min, respectively.

Three composite samples were tested for different WF mass fractions with dimensions 40 × 40 × 160 mm^3. The load was applied to the segment of the sample. Assuming that tested samples are homogeneous, the flexural strength is expressed as follows:

$$R_f = \frac{3Fl}{2bh^2} \tag{4}$$

where R_f (MPa) is the flexural strength; F (N): the average applied force; b (m): the width of the test sample, h (m): is the thickness of test sample in direction of bending and l (m): support span (0.1).

In the compressive test, the six half prisms of the sample obtained after a rupture in the flexural test were employed. The compressive strength R_c is determined as follows:

$$R_c = \frac{F}{A} \tag{5}$$

where R_c (MPa) is the compressive strength, F (N): load applied to a cross-section and A (mm^2): across a section.

2.4.5 X-ray diffraction

The wood aggregates (treated and untreated fibers) were identified using a Bruker D8 advance diffractometer with CuKα (λ = 1.541 Å). The two fibers were scanned in the 2θ range from 10° to 50° at room temperature, with a step size of 0.020°, using Cu-Kα radiation at 40 kV and 40 mA. The crystallinity index (CrI) of fiber was calculated according to the Segal empirical method (Ben Sghaier et al. 2012; Joonabi et al. 2010) to determine the apparent crystallinity of cellulose:

$$CrI(\%) = \left[\frac{I_{002} - I_{Cr-non}}{I_{002}}\right] \times 100 \tag{6}$$

where I_{002} represents the peak intensity of the crystalline region, whereas $I_{Cr\text{-}non}$ denotes the non-crystalline region (the intensity of diffraction at $2\theta = 18°$).

2.4.6 Microstructure properties

To determine their surface morphology and to make a preliminary identification of the effect of different treatments, treated and untreated wood aggregates were examined under a binocular magnifier ZEISS STEMI 508 with AXIOCAM ERc 5 s camera to determine differences between fibers treatments. Fibers were placed directly on a glass slide and examined under a binocular magnifier at an average magnification of 50 and under polarized light.

3 Results and discussion

3.1 Thermo-physical properties

The thermo-physical properties of untreated wood aggregate/plaster mortars are presented in Table 4. It resumes the obtained experimental results of density and thermal conductivity of proposed composites at different wood aggregate content. It is clearly seen that density, as well as thermal conductivity decreases with wood content, resulting in a lightweight and insulating material. It can also be seen that as the volume fraction of WAs increases, the water uptake increases proportionally. This rise is explained by the specific chemical composition and the porous morphology of the WA. Additionally, when the content of WA increases, the water diffusion process accelerates significantly by the pores created inside the plaster paste.

The thermo-physical properties of untreated and treated WA with 20% volume fraction content are shown in Table 5. When compared to plaster paste, the water uptake rises with the inclusion of fiber (without fibers). The increase in water uptake of the composite can be explained by the increase in the water uptake of WA as well as the composites component adhesion. It is also important to note that the thermal conductivity slightly decreases with the increase in NaOH concentrations. This decrease is about 6%, 13%, 24% and 26% for 1%, 2%, 6% and 10% of NaOH, respectively. This phenomenon can be due to the aggregates porosity as well as the water uptake increases with the NaOH-solution concentration.

Table 4 Thermo-physical properties of untreated wood aggregate/plaster mortars as a function of WA content

WA content (%)	Water uptake (%)	Density (kg/m^3)	Thermal conductivity (W/m K)
0	31.31	1170.82	0.270
5	38.17	1130.56	0.212
10	39.08	1087.23	0.186
15	42.97	1040.47	0.171
20	43.13	993.30	0.141

3.2 Mechanical properties

A preliminary study was conducted to determine the effect of W/P ratio in the plaster paste. The three-point bending tests as well as a compression test for a particular set of W/P ratios (0.5, 0.65, 0.8, 1, and 1.2) were investigated. Figure 2a shows the variation of the mean value of flexural strengths with W/P ratio of plaster paste. By reducing the W/P ratios, the graphs demonstrate an increase in flexural strength. The maximum is attained when W/P is equal to 0.5. Figure 2b depicts the evolution of the compressive strength vs. W/P ratio. Plaster samples had a strength of 9.18 MPa for a W/P ratio of 0.65. When the W/P ratio increased beyond this point, the compressive strength decreases significantly. The addition of high content of wood aggregates (> 10% by volume) needs an increase in W/P ratio due to the high hydrophilic character of natural fibers. That is why; W/P will be equal to 0.8 for all coming experiments.

The flexural strength test was performed to investigate the mechanical behavior of wood aggregate/ plaster mortars and to investigate the effects of NaOH treatments and the volume fraction of WA on its mechanical properties. The flexural strength of composites with various wood aggregates volume contents (treated or not) is shown in Fig. 3. For each treatment and different volume fractions, it can be concluded that the flexural strength values of proposed composites are lower than the reference plaster paste. For

Table 5 Thermo-physical properties of treated wood aggregate/ plaster mortars as a function of different NaOH concentrations

Composites	WA content (%)	Water uptake (%)	Density (kg m^{-3})	Thermal conductivity (Wm^{-1} K^{-1})
WAP 0	20	43.13	993.30	0.141
WAP 1	20	43.62	950.52	0.132
WAP 2	20	43.29	924.52	0.123
WAP 6	20	45.86	992.54	0.107
WAP 10	20	48.65	952.57	0.105

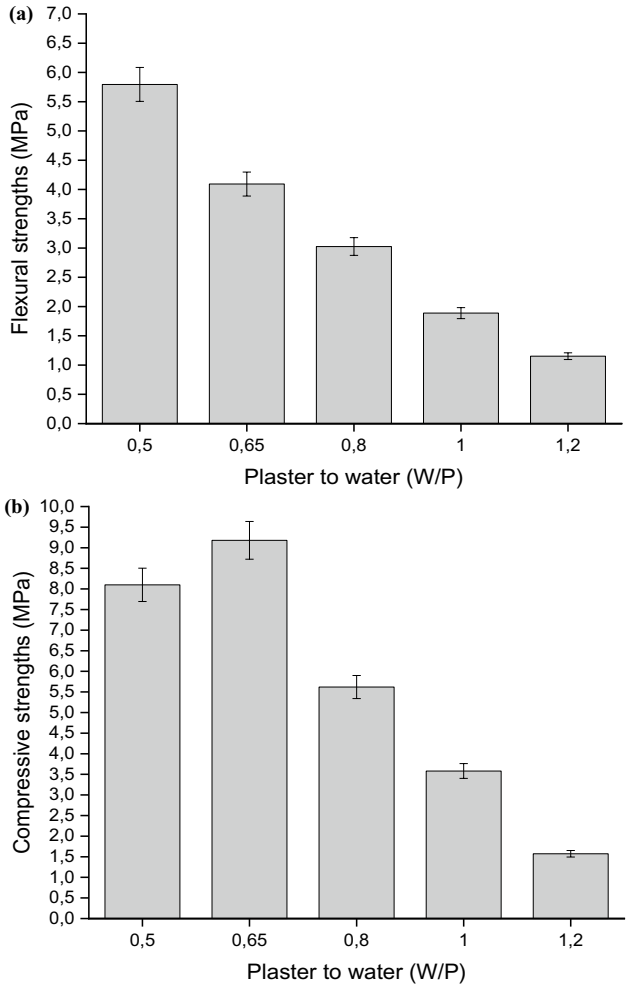

Fig. 2 Effect of W/P ratio on the mechanical properties of plaster paste using **a** flexural strength and **b** compressive strength

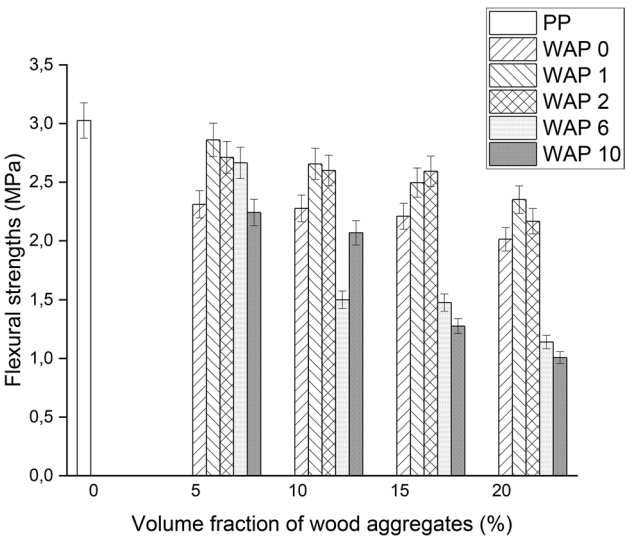

Fig. 3 Flexural strength of composites as a function of fiber content for treated and non-treated fibers

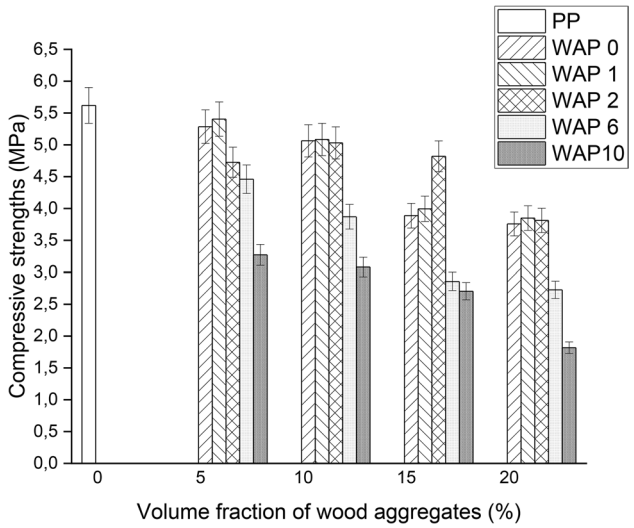

Fig. 4 Compressive strength of composites as a function of fiber content for treated and untreated fibers

each treatment, the flexural strength decreases as the fiber content increases. The same behavior is found in the work by Boustingorry (2002). Only WAP 1 and WAP 2 had enhanced flexural strength when compared to untreated composite samples for different fiber content. The flexural strengths of treated composite materials, such as WAP 6 and WAP 10 are lower than those of untreated ones (WAP 0). The low value of their water uptake revealed this improvement in flexural strength (Table 5). The negative impact of using a higher mass concentration of NaOH (6% and 10%) in wood aggregates is explained by the weak interfacial bonding and the important air voids inside the wood aggregates/plaster mortar. However, the treatment of wood aggregates with low mass concentration improves the flexural strengths of composites for different volume fractions.

Figure 4 shows the compressive strength values obtained from compression tests for different treatments and different volume fractions. The addition of wood aggregates to the plaster paste causes a decrease in compressive strengths. This is due to the increased porosity of the mixture, which reduces wood aggregates/plaster cohesion. It is noticed that the compressive strength increases slightly when the 1% and 2% NaOH were applied and decreases when 6% and 10% NaOH were applied compared with the raw state (WAP 0). This increase can be explained by enhanced adhesion between WA 1; WA 2 and the plaster paste. It is possible to denote that the treatments 1% and 2% NaOH are better than 6% and 10% NaOH for all volume fractions. The higher mass concentration of NaOH can cause a weak interaction between WA and plaster paste as well as an increase in the porosity of the material.

To test the plasticity of composite materials, the applied load–displacement and load-strain curves for reference

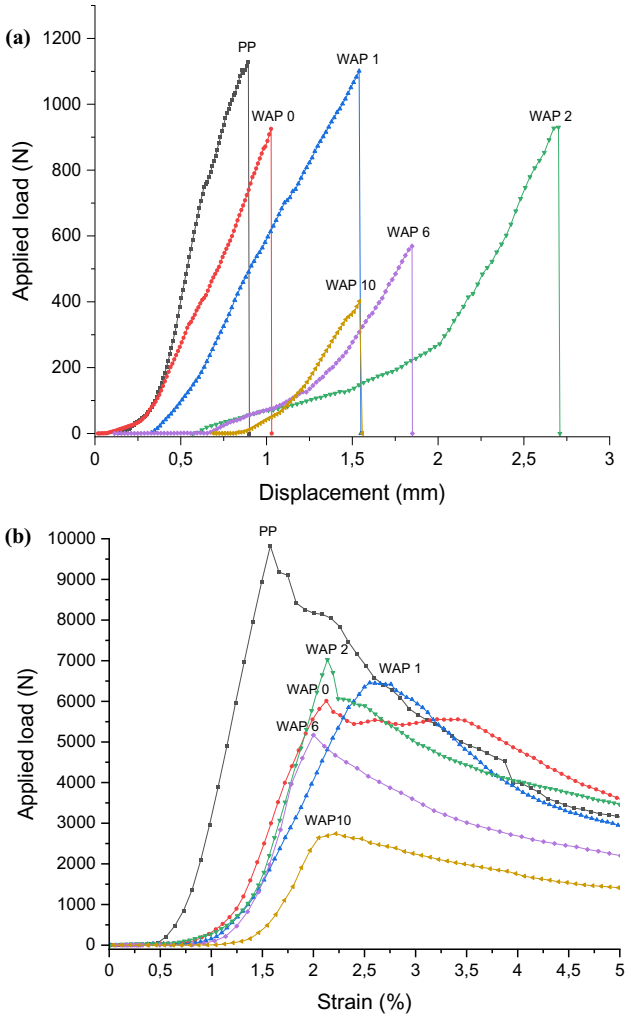

Fig. 5 Applied load vs. **a** displacement (flexure test) and **b** strain (compression tests) of plaster paste, treated and untreated wood aggregate mortars with 20% volume fraction

mortar, untreated, and treated wood aggregates/plaster mortars are illustrated in Fig. 5. In contrast to the reference plaster (PP), the displacement values of all reinforced plaster mortars with untreated (WAP 0) and treated (WAP 1, WAP 2, WAP 6, and WAP 10) wood aggregates were significantly higher than the reference plaster (PP). According to Fig. 5a, the displacement of WAP 0, WAP 1, WAP 2, WAP 6, and WAP 10 rises during the flexion test by 15%, 78%, 200%, 105%, and 78%, respectively. The maximum displacement was observed for aggregates that had been treated with 2% NaOH solution (approximately 2.71 mm), which can result in a solid composite. The same trend was observed in Fig. 5b, the strain of WAP 0, WAP 1, WAP 2, WAP 6, and WAP 10 rises during the compression test by 31%, 77%, 40%, 27% and 33%, respectively. The maximum strain was observed for aggregates treated with 1% NaOH solution (approximately 2.8%).

Many authors (Fiore et al. 2015; Gu 2009; El Oudiani et al. 2011; Gwon et al. 2010a,b; Chang et al. 2009) investigated the effect of NaOH treatment on natural fibers at different conditions. Heavily NaOH-treated fibers are not recommended. Fiore et al. (2015) investigated the effect of the treatment immersion time. They concluded that the tensile properties of kenaf fibers were strongly decreased when treated with a 6% NaOH solution at room temperature for 144 h. Gu (2009) demonstrated that using a 10% NaOH concentration results in a decrease in the tensile strength of coir fiber treated at room temperature of 20 °C for 48 h when compared to cases of 2%, 4%, 6%, and 8%. This showed how bad the fiber degradation was in the 10% case. The crystallinity index of agave Americana fibers increases for alkali treatments not exceeding 2% NaOH solution at 30 °C for 1 h, as shown by El Oudiani et al. (2011), whereas higher NaOH concentrations (> 2%) result in a considerable decrease in the crystallinity index. However, Gwon et al. (2010a,b) confirm that the chemical modification increased adhesion between wood fibers and polypropylene matrix. Chang et al. (2009) showed that the removal of hemicellulose and lignin by alkali treatment (15.3 wt % of NaOH at 25 °C for 30 min) of wood also increases the number of hydroxyl groups on the surface of the cellulose. In the current investigation, wood aggregates were treated at 80 °C for 2 h at different NaOH solution concentrations. The specified mechanical properties of WAP composites (Sect. 3.2) agree with the literary review. Current results have demonstrated a significant reduction in the flexural and compressive strengths of suggested composites prepared with treated wood aggregates at higher concentrations (greater than 2% NaOH solution concentration).

3.3 Microstructure properties

Figure 6 reveals the difference between treated and untreated surfaces of wood aggregates (WA). Figure 6a presents the morphology of the raw WA surface. Contrary to all treated fibers, raw fibers are not pigmented. WA is composed of a straight set of micro-fibrils. Waxes, oils, and other impurities are present on the fiber's surface.

The surface morphology of slightly NaOH-treated WA (1% (Fig.6b) and 2% (Fig.6c)) is cleaner and rougher compared to WA raw surface. The obtained rougher surface of slightly NaOH-treated WA will promote interlocking the bonding between the treated wood aggregates and the plaster paste which explains previously obtained mechanical results. However, the surface morphology of heavily NaOH-treated WA (6% (Figs.6d) and 10% (Fig. 6e)) was destroyed, and many cracks appeared on its surface. Which explains the high sensitivity of treated fibers to water uptake, and their weak adhesion to the plaster paste.

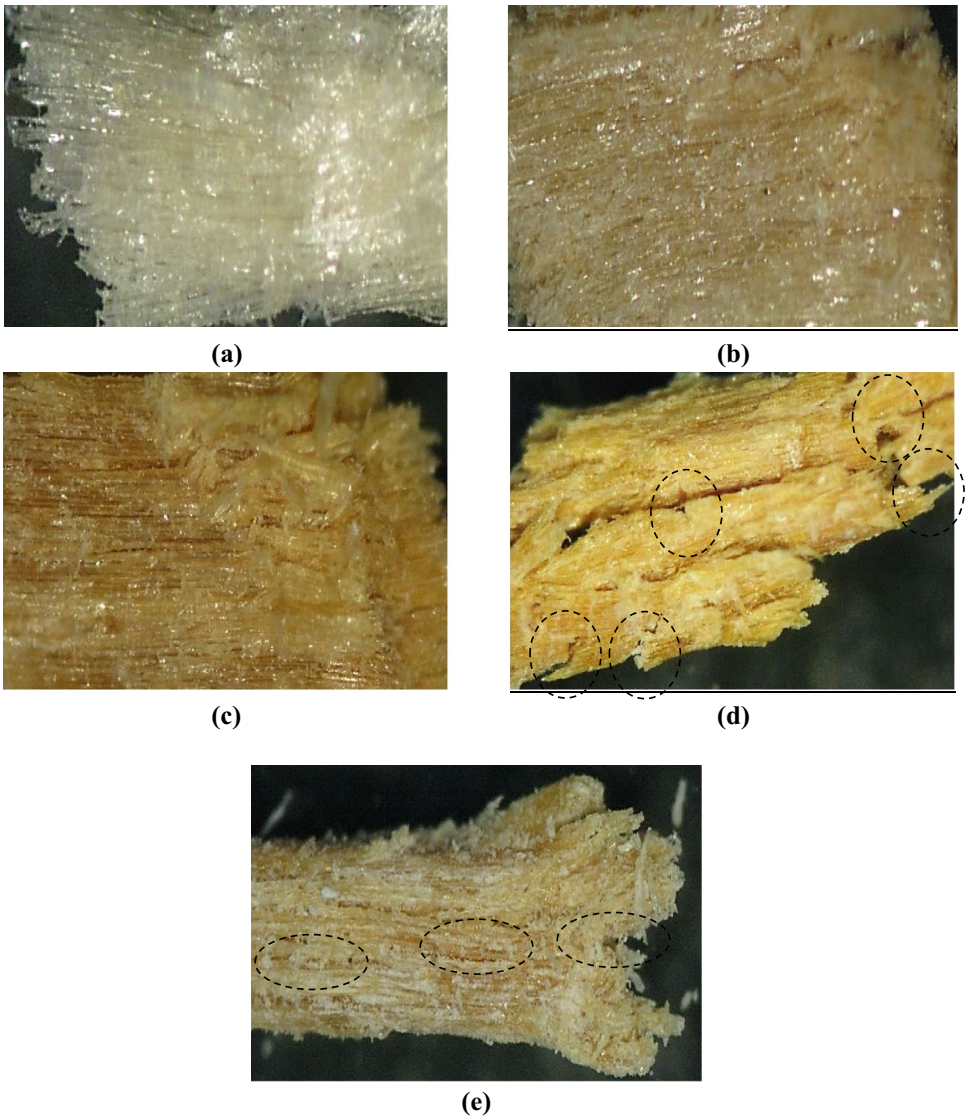

Fig. 6 Surface modification of untreated and treated wood aggregates **a** raw, **b** 1% NaOH, **c** 2% NaOH, **d** 6% NaOH and **e** 10% NaOH

In general, chemical treatments are considered to remove impurities and contaminants from raw fiber surface. The treatment breaks the wood aggregate's structure due to the reaction of sodium hydroxide with cellulose, shown in Eq. 7 (Rebelo et al. 2019). However, a moderate concentration is required at each treatment condition and for each natural fiber property.

$$\begin{aligned}&\text{Cellulose} - \text{OH} + \text{NaOH} \rightarrow \text{Cellulose}\\&\quad - \text{O}^{-}\,\text{Na}^{+} + \text{H}_2\text{O} + \text{surface impurities}\end{aligned} \tag{7}$$

3.4 Crystallinity characterization

Figure 7 shows X-ray diffraction (XRD) patterns of untreated and treated wood aggregates. All XRD patterns of treated and untreated wood fibers represent two

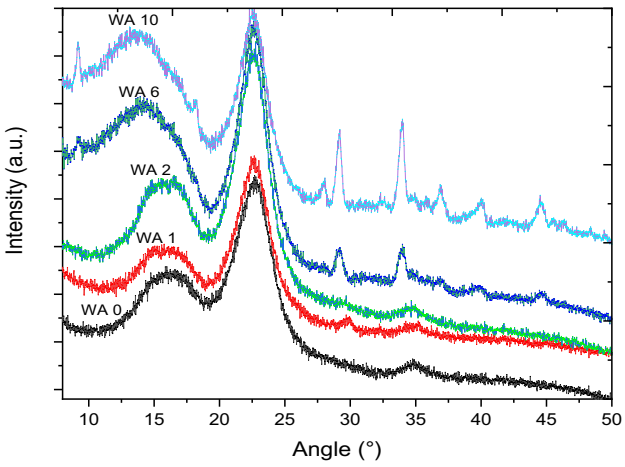

Fig. 7 Xray diffraction pattern of untreated and treated wood aggregates

Table 6 Infrared band assignments for untreated and treated wood aggregates

Fiber designation	NaOH treated solution concentration (%)	Crystallinity index (CI) (%)
WA 0	0	48.46
WA 1	1	54.41
WA 2	2	56.10
WA 6	6	39.80
WA 10	10	22.10

diffraction peaks at $2\theta = 18°$ and 22°, which correspond to the (110) and (200) crystallographic planes of cellulose diffraction peaks. More peaks appear at heavily NaOH-treated WA. As shown in Table 6, there is a rise in crystallinity index for slightly NaOH-treated fibers (WA 1 and WA 2) due to the removal of major impurities during the treatment process. This phenomenon is approved in references (Ben Sghaier et al. 2012; Joonabi et al. 2010). The X-ray analysis also demonstrated that the crystallinity index of heavily NaOH-treated fibers (WA 6 and WA 10) decreases due to a higher concentration of sodium hydroxide solution as approved by surface modification results.

4 Conclusion

The wood aggregates have been frequently used to manufacture building insulation materials. However, the main problem of the obtained composite is the weakness of its mechanical properties. Hence the interest of this present experimental study consists in the comparison of different concentrations of NaOH treatment to ameliorate both the thermal and mechanical properties of the proposed plaster mortar.

In a preliminary study, the effects of the water to plaster ratios (W/P) on the mechanical strengths of plaster paste were investigated. Their porosity increases with significant W/P (higher than 0.8) and consequently the cohesion and compactness of the plaster paste are significantly reduced (mechanical strengths decrease).

Thermal analysis shows that the use of untreated and treated wood aggregates to prepare composites reduces their thermal resistance compared to plaster paste. However, composite materials using wood aggregates are an example of building materials that have a low water uptake and provide better thermal insulation.

Mechanical analysis shows that the addition of treated wood aggregates with low mass concentration (1% and 2% NaOH at 80 °C during 2 h) presents a sustainable and ecological way to improve the flexural and compressive strengths of wood aggregates/plaster mortar compared to untreated wood aggregates/plaster mortar. The morphological surface of composite made with treated wood aggregates has a beneficial impact on the displacement of wood aggregates/plaster for all NaOH treatments.

Microstructural analysis shows that the 1% and 2% NaOH treatments improve the surface adhesive characteristics of wood aggregates by eliminating impurities and creating a rough surface. The performed XRD analysis of treated and untreated fibers comparison confirms that 1% and 2% NaOH have the optimum results.

At the end of this experimental study, the optimum composite is WAP 2 with 20% content of treated wood aggregates: density and thermal conductivity decrease by about 13% and 8% respectively, displacement, strain, flexural and compressive strengths increase by about 170%, 50%, 10% and 3%, respectively, compared to the untreated one.

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