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Mechanical behavior of plaster reinforced with abaca fibers

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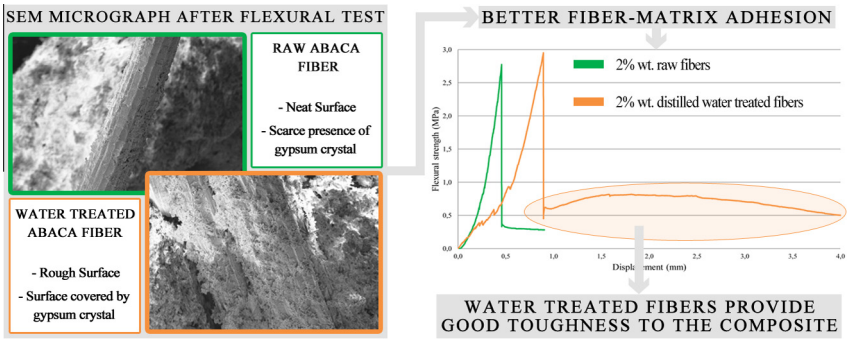
HIGHLIGHTS

- The addition of abaca fibers didn't involve any delay on the plaster setting time.
- Abaca fibers treated with distilled water showed a better adhesion with gypsum matrix.
- An addition of 2 wt.% of abaca fibers leads to an enhanced toughness of the composites.

GRAPHICAL ABSTRACT



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ABSTRACT

In the last decades, eco-friendly materials are playing an increasingly important role in the building industry. Particularly, many studies deal with the use of natural fibers as replacement to synthetic fibers in reinforced composites. Natural fibers are already employed in many building materials, due to their attractive features, such as good mechanical properties, low cost, low density, low thermal conductibility and recyclability.

In this research, the interaction between abaca fibers and gypsum matrix was studied, in order to produce fiber-reinforced plasterboards with enhanced toughness performances.

Firstly, the influence of some parameters (i.e. fibers dimensions, amount of fiber addition, water to gypsum ratio) on physical and mechanical behavior of the plasters was evaluated.

In order to improve the composite performances, the fibers were subjected to different chemical treatments (with distilled water, NaOH solution and EDTA solution) to modify the surface characteristics and to improve the adhesion with the gypsum matrix. Their effects were explored by scanning electron microscope and mechanical tests, such as pull-out and flexural strength tests.

The treatments with NaOH and EDTA solutions resulted in a worsening of the mechanical behavior of the composites, while the fibers treated with distilled water gave a better adhesion with the inorganic matrix.

1. Introduction

Since ancient times, gypsum has been used as finishing material for walls and ceilings in many countries. Its excellent performance, attractive appearance, easy application, and its healthful contribution to living conditions have made gypsum a most popular finishing material for these applications [1]. In addition, the large availability, relative low cost, easy handling and mechanical characteristics suitable for different uses, makes the gypsum a widely used construction material [2]. However, gypsum presents some undesirable characteristics, as brittleness and weakness in tension,

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coupled with a high water solubility, hindering outdoor application.

Generally adding fibers to a binder materials can improve its mechanical properties, especially to the post-cracking behavior [3–7]. In particular, brittleness may be appreciably reduced by combining gypsum with mineral particles or natural fibers [8].

The competition in the industrial field, looking for materials that meet both socioeconomic expectations and environment preservation, drives toward the utilization of natural fibers [9,10]. Advantages of natural fibers, such as good mechanical properties, low cost, low density, low thermal conductibility and recyclability make them a good potential replacement for synthetic fibers in composite materials [11,12]. Many applications of natural fiber-reinforced composites can be found in building, packaging industries, furniture and auto-motive fields [13].

Natural fibers are mainly composed of hemicellulose, lignin and pectin [14], moreover the composition can more or less change according to the growing conditions, the location and the age of the plant.

In the last years, many studies tried to estimate the influence of adding natural fibers in gypsum matrix, mainly in terms of mechanical properties of the composite material [15–17]. Abaca, a particular variety of banana-tree native to the Philippines, has been recently studied for the flexible and very resistant fibers extracted from its trunk [18].

The main drawback in the use of natural fibers as reinforcement in composite materials is the weak interaction between fibers and matrix. Therefore, many studies were carried out on suitable chemical treatments on fibers to improve the adhesion between fiber and matrix, in order to increase the composite strength [19,20].

In the present paper, the effect of abaca fibers on the mechanical properties of gypsum based composite was investigated. In particular, the role of different treatments on fibers and the consequent morphologic surface modification were evaluated, with the aim to obtain preliminary indications about the use of abaca fibers as a sustainable opportunity to manufacture plasterboards with enhanced toughness performances.

2. Experimental

2.1. Materials

Gyproc Saint Gobain (Termoli, Italy) kindly provided the gypsum used in the present research. As reported in the technical sheet, it was obtained by calcination of natural gypsum (calcium sulfate dehydrate, $CaSO_4\ 2H_2O$) at $T = 120–150\ °C$, in order to obtain a mixture mainly consisting of hemihydrate, with some amount of anhydrous gypsum (anhydrite).

Fiber Industry Development Authority of the Department of Agriculture, Republic of the Philippines, supplied the abaca fibers. An average chemical composition of abaca fibers was reported by Li et al. [21].

After preliminary runs, 10 mm length fibers, obtained by means of an automatic cutter, were selected both to give a "bridge action" effect during the flexural failure and to be consistent with the dimensions of typical plasterboard panels commercially available. In addition, 150 mm length fibers were used for pull-out test.

Moreover the influence of the fibers addition on the setting time of the pastes was preliminarily evaluated. In fact a recent research on gypsum products reinforced with hemp and flax fibers showed that this addition could considerably delay the setting time of the pastes. The reason of this phenomenon is to be found in the chemical composition of the natural fibers. They contain a considerable fraction of pectin, soluble in water, and capable of trapping the calcium ions present in solution, so preventing the hydration of the hemihydrate [15]. Therefore, the setting time of two different pastes, with 2 wt.% of short fibers or without fibers, were evaluated according to the Vicat test [33].

Sodium hydroxide (NaOH) and ethylene diamine tetraacetic acid (EDTA) used for the chemical treatments of the abaca fibers were Carlo Erba reagents.

2.2. Characterization of the raw materials

The chemical composition of the binder was evaluated by simultaneous thermal analysis (DSC-TGA), using a Netzsch STA409 PCLuxx apparatus. In particular, weighted samples were heated on alumina pans from 20 to 1000 °C with heating rate of 10 °C/min under N_2 atmosphere.

X-ray diffraction analysis was performed to evaluate the mineralogical composition of the binder, using a XRD Philips PW 1730 apparatus (rad. CuKα1). The density of the abaca fibers was evaluated with a helium pycnometer (MultiVolume Pycnometer 1305, Micromeritics).

Morphology and size of the natural fibers was evaluated by means of scanning electron microscope analysis (SEM, Cambridge S440).

Mechanical characterization was performed by Tensometer 2020 testing machine (Alpha Technologies), equipped with a 100N load cell equal and a deflection rate equal to 10 mm/min, according to the Standard ASTM-D3822 [22]. Tensile strength, Young's modulus and failure elongation were evaluated as average on thirty samples.

2.3. Chemical treatments of the fibers

In order to modify the surface characteristics and to improve the adhesion with the gypsum matrix, abaca fibers were subjected to different chemical treatments. Short (10 mm) and long fibers (150 mm) were treated with: (a) distilled water for 24 h at 20 °C, (b) sodium hydroxide (NaOH) and (c) ethylene diamine tetraacetic acid (EDTA).

The treatment with distilled water allows to softly clean fiber surface by removing all the water-soluble organic compounds (e.g. the weakly linked pectin, extremely soluble in water due to a high methyl esterification coefficient [15,25]). This treatment enhances the surface roughness, improving the fiber–matrix adhesion and increases the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction sites.

Alkaline treatment is one of the most common chemical treatment of natural fibers when they are used as reinforce in composite materials; it involves the break of hydrogen bonding in the network structure, increasing fiber surface roughness and improving mechanical interlocking with the matrix [15,21]. In addition, this treatment could enhance the rigidity of the fiber itself [27].

Fibers were immersed in sodium hydroxide solution (0.5 M; pH = 13.7) for 2 h and then washed with distilled water. In order to neutralize the alkalinity of the treated fibers an additional washing step with acetic acid was performed.

Last treatment was carried out with EDTA on fibers pretreated with NaOH solution. The EDTA, a strong chelating agent, could potentially react with calcium ions and solubilize a great fraction of pectin, bringing to the separation of fiber bundles and so enhancing the fiber–matrix adhesion [26,28,29]. Abaca fibers were first soaked in NaOH solution as above reported and then they were immersed for 2 h in a $13.5{\cdot}10^{-3}$ M EDTA solution. The pH was adjusted at 11 with sodium hydroxide). Fibers were washed with distilled water, to neutralize the alkalinity of the treated fibers. For each treatment the fiber-to-solution ratio was fixed at 30 g/l, and after the treatments the fibers were dried at 40° C for 24 h. Finally, the weight loss of the fibers due to the soluble fraction was evaluated after each treatment. All the treatment conditions were summarizes in Table 1.

2.4. Fiber reinforced plasters characterization

2.4.1. Chemical characterization (SEM–FTIR)

In order to evaluate the effects of different surface treatment on the morphology of the fibers, scanning electron microscopy (SEM) was performed. Characterization was carried out on both treated and untreated fibers. Moreover, the adhesion between fiber and matrix was verified controlling the microstructure of the fracture surfaces of the hardened compacts. Abaca fibers and fracture surfaces were coated with gold and then analyzed using a SEM Cambridge S440 equipment.

The chemical surface modifications were also evaluated by means of Fourier Transform Infrared Spectroscopy (FT-IR) [30], using a Nicolet apparatus (Thermo Scientific, Italy) and a standard KBr pellet technique. For each sample 64 scan were acquired between 4000 and 400 cm^{-1} with a wavenumber resolution of 4 cm^{-1}. Abaca fibers were chopped to a length less than 1 mm and mixed with 200 mg of KBr. The resulting powder was then pressed into a pellet with a diameter equal to 16 mm and subjected to FTIR analysis.

2.4.2. Mechanical characterization

2.4.2.1. Pull-out test. The pull-out test is a method used for the characterization of the fiber–matrix interphase. It allows measuring the tensile load necessary to extract a single reinforcing fiber by the matrix in which it is immersed, and therefore lets to estimate the quality of fiber–matrix adhesion [31].

Table 1
Treatments conditions.

Fiber typology	Treatment agent	Residence time	Molarity	Soluble fraction [%]
F	–	–	–	–
FW	H_2O	24 h	–	6
FS	NaOH	2 h	0.5 M	10
FSE	NaOH + EDTA	2 h + 2 h	0.5 M + $1.35{\cdot}10^{-3}$ M	10