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A new treatment for coconut fibers to improve the properties of cement-based composites – Combined effect of natural latex/pozzolanic materials

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ABSTRACT

This paper presents the results of experimental study with a new coconut fiber-cement composite (CFC). To obtain a material with improved performance in order to decrease the amount of calcium hydroxide present on the fiber surface, four forms of coconut fiber treatment were tested. Some combinations of natural latex, water and pozzolanic materials (silica fume or metakaolin) were evaluated by degradation test and accelerated aging through cycles of wetting and drying CFC samples. To determine the mechanical properties obtained from each treatment, flexural tests on CFC composites were performed. After the flexural tests, the fibers were removed from the specimens and analyzed by scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDX), Fourier Transform Infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA). The results indicate that the treatment carried out with the natural latex polymer film combined with a pozzolan layer improved the performance and durability of the CFC.

1. Introduction

Natural fibers are considered a renewable material and they can be easily found in nature. Its high availability at relatively low cost when compared to other synthetic fibers, encourages its use in several applications. Natural fibers do not have a specific use, being considered a byproduct which cause environmental problems, mainly related to their disposal.

One of the solutions found for the valorization of natural fibers is its use in Portland cement composites. Several papers reported the benefits of using natural fibers such as interesting mechanical and physical properties [24], reduction in the thermoacoustic transfer [25], low specific weight and reduction in the cost of production [9,10].

Nevertheless, the most important factor affecting the large-scale use of natural fibers is associated with their durability. In the strongly alkaline conditions of Portland cement matrix (pH > 12), caused mainly by the presence of calcium hydroxide (portlandite), an interaction between the constituents of natural fibers and portlandite can occur resulting in its degradation [29]. The other main problem associated with the durability of natural fibers is the mineralization process resulting from the migration of hydrated products of Portland cement to the central cavities, walls and voids of the fibers, thus causing their weakening [33].

Recently, Wei and Meyer [39] proposed two new concepts of mineralization mechanism (calcium hydroxide mineralization and self-mineralization) and four interactional alternate steps for the degradation of natural fibers in cement matrix: degradation of lignin and of part of the hemicellulose leading to the exposure of the holocellulose, degradation of hemicellulose causing a decrease in the integrity and stability of the cell walls, degradation of the intra-molecular hydrogen bonding leading to the dispersion of cellulose microfibrils and alkaline hydrolysis of amorphous regions (complete degradation of cellulose microfibrils).

For all cases of degradation of natural fibers, authors are in agreement that natural fibers lose their reinforcement capacity, especially after long curing periods - long periods exposed to alkaline environment [36–38].

To diminish this problem, several efforts have been performed. Most studies are centered on the use of supplementary cementitious materials [5,8,36–38,40] or on the reduction of alkalinity matrix by means of carbonation process [2,20,28,41]. At any rate, the natural fiber is in safety conditions since the composite production phase. In both cases,

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the natural fibers are degraded during the first curing period, a fact that inhibits the complete action of natural fibers on the composites.

There are several types of natural fibers that have been used in the production of Portland cement composites [3]. Among these fibers, the use of coconut fibers should be taken into account due to the large volume of residue generated annually. According to the Brazilian Institute of Geography and Statistics [12], the Brazilian coconut production was about 2 million tons in 2015 and approximately 970,000 m^3 of coconut residue, being the fiber the main residue.

The use of coconut fibers in composites has been investigated by several researchers [35]. John et al. [13] observed the durability of cementitious matrices with coconut fibers and natural fibers compared with fibers extracted from the mortar of a wall built 12 years previously. In this study, they reported that the fiber of the wall samples contained less lignin, indicating that it had been degraded.

In order to attenuate the propagation of cracks in high performance concrete marine structures, Ramli et al. [23] incorporated coconut fiber into the composition of composites. The experimental results showed that the compressive and flexural strengths of the structures improved up to 13% and 9%, respectively, with the incorporation of coconut fibers. However, in terms of durability, the chloride penetration, intrinsic permeability, and carbonation depth increased with the increase in fiber content. The authors recommend that the coconut fiber undergo treatment prior to its application in concrete to protect it against degradation.

A possibility, however insufficiently studied, which could eliminate the use of these additives, is the use of natural latex along with pozzolans. In contact with the cement matrix, the latex causes a decrease in the ion transport in the aqueous medium that fills the pores of the cement paste. This may be related to the adsorption of CH in the polymeric film [1,6]. This characteristic, combined with the latex adhesive power to adsorb the pozzolan around the fiber, can provide local pozzolanic reactions in the interior of the cementitious matrix that can protect the coconut fiber surface from the alkaline attack.

Hence, the aim of this paper is to show a new treatment for coconut fibers combining the use of natural latex and pozzolanic materials in order to improve the durability of natural fibers in Portland cement composites. In this way, it is intended to find a solution to the degradation of the fiber inserted into the cementitious matrix.

2. Experimental program

2.1. Materials

Coconut fibers were supplied by Coquefibras S.A. located in the city of Una Brazil. Coconut fibers present a mean diameter about 0.2 mm. Before their use, fibers were cut with 25 mm length [30] and, subsequently, dried for 2 h in an oven at 100 °C.

Natural latex extracted from rubber trees (*Hevea brasiliensis*) was supplied by Mucambo S.A. and present a concentration of 53%. The specific gravity of natural latex is 0.97 kg/cm^3. A Brazilian standard Portland cement type V, characterized by its rapid strength development and by the absence of mineral addition on its composition (95% of clinker), was used.

A densified silica fume supplied by Tecnosil Ltda and a metakaolin supplied by Metacaulim do Brasil Ltda were used as pozzolanic materials. It is important to note that the selected pozzolanic materials present different chemical composition: the former is a siliceous pozzolan (91.73% of SiO_2, 0.29% of Al_2O_3, 0.54% of SO_3, 0.37% of CaO and other minor components) whereas the latter is an aluminosilicate material (58.39% of Al_2O_3, 35.47% of SiO_2, 2.71% of Fe_2O_3, 1.44% of K_2O and other minor components). The silica fume has a fineness of 21,000 m^2/kg and the metakaolin 12,000 m^2/kg. Both pozzolans are amorphous materials and several studies have been certified their effectiveness in blended Portland cement mortars and concretes [17].

Sodium hydroxide (98% purity) supplied by Vetec Ltda was used in the preparation of sodium hydroxide solution (1.7% of NaOH) in order to simulate the degradation of coconut fibers in high alkaline environments.

2.2. Equipment

The flexural strength on thin slabs (15 × 25 × 100 mm) was carried out on a Universal Testing Machine EMIC DL500 using a 0.1 mm/min stress rate. The flexural strength was an average of 5 values.

A scanning electron microscopy (SEM) Quanta 250 model associated with X-ray dispersive energy (EDX) was used to assess the structure of natural fibers after exposure to alkaline conditions. Thermogravimetric analysis (DGT-60H model from Shimadzu) of the natural fibers was carried out at 10 °C/min in nitrogen atmosphere in the range of 25–550 °C using alumina crucible. Fourier transformed infrared spectroscopy (FTIR, Nicolet IS10 model) with a wavenumber spectrum between 4000 and 400 cm^{-1} was used to assess the microstructure of the natural fibers.

2.3. Coconut fiber treatments

Different treatments were performed in order to study the durability of coconut fiber. At first, each coconut fiber was immersed in an adherent solution (deionized water or natural latex) for 1 min. In this step, the adherent solution surrounds the coconut fiber generating bonding layers. After that, pozzolanic materials (silica fume or metakaolin) were used as coating agent. Pozzolans adhere to the coconut fiber through the adherent solution. The methodology of this new treatment is similar to the preparation of "chicken fingers".

The different combinations of both the adherent solution and coating agent are the treatments proposed for coconut fiber (Table 1). The nomenclature adopted for the different treatments is X-Y, where X is related to the pozzolanic material (S for silica fume and M for metakaolin) and Y is associated with the adherent solution: A for deionized water and L for natural latex. Another sample used in this study, in order to assess the effectiveness of coconut fiber, is called F-N (Table 1). In this case, the coconut fiber is inserted in the Portland cement composite as-received, it means, there is no adherent solution and no pozzolanic material.

For degradability tests, a coconut fiber sample called NAT was used

Table 1
Treatments carried out on the surface of the coconut fibers.

Treat.	Coating	Adherent solution	Details
S-A	Silica fume	Water	Coconut fibers inserted into a deionized water solution for 60s under constant agitation. Subsequently, the fibers were placed in a recipient filled with silica fume. The coconut fiber started to be coated with a layer of silica fume on its surface.
S-L	Silica fume	Latex	Same S-A treatment procedure, but replacing the deionized water solution with a natural latex solution of 1% concentration.
M-A	Metakaolin	Water	Same S-A treatment procedure, but substituting silica fume for metakaolin.
M-L	Metakaolin	Latex	Same M-A treatment procedure, but replacing silica fume with metakaolin.
F-N	No	No	Natural coconut fiber (without any treatment) but inserted into the cementitious matrix for the production of specimens used in the durability test and, subsequently, removed for FTIR, SEM, EDX and TGA analyses.