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Effect of fiber treatments on the sisal fiber properties and fiber–matrix bond in cement based systems

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HIGHLIGHTS

- Significant improvements in the fiber–matrix interface were verified by the used treatments.
- The polymer coating resulted in a better frictional mechanism and in a slip-hardening behavior.
- The alkali treatment removed the amorphous constituents of the fiber and increased its crystallinity.
- The hornification increased the elastic and frictional fiber–matrix bond.

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ABSTRACT

This experimental research investigation aims to explain the influence of several treatments on the sisal fiber properties and bonding strength with a cement based matrix free of calcium hydroxide. Four different treatments were studied: hornification, alkali treatment with calcium hydroxide, polymer impregnation with styrene butadiene and a combination of hornification and polymer impregnation. Modifications in the sisal fiber structure were investigated by X-ray diffraction (XRD), thermogravimetric analysis (TGA), Fourier transform infra-red spectroscopy (FTIR) and scanning electron microscopy (SEM). Water absorption and direct tensile tests were performed on the fibers to determine the influence of the treatments on their physical and mechanical properties. In order to study the sisal fiber–matrix bond, pullout tests were performed in fiber embedment lengths of 5, 10, 25 and 50 mm. All applied treatments resulted in a reduction of the water absorption capacity and increase in tensile strength and stiffness. Significant improvements in the fiber–matrix interface were verified through the pullout test for the several used treatments. The hornification treatment increased the elastic and frictional bond, whereas the polymer and hybrid treatments resulted in a fiber slip-hardening behavior.

1. Introduction

In the line of development of materials reinforced with vegetable fibers, many studies have been carried out on cementitious and polymeric matrix composites and promising results have been achieved, showing an improvement in durability, strength and ductility [1–5]. There are many beneficial aspects in using vegetable fibers including sustainability, and low energy consumption. Vegetable fiber reinforced composites have the potentiality to become the sustainable option for the construction industry. Due to its wide availability, especially in tropical countries, these fibers have a low cost and present the great advantage of being renewable.

Sisal has been one of the most used fibers in the production of cement-based composites, especially due to its excellent tensile strength, around 400 MPa [6,7]. However, it has a weak chemical bond to cement based matrices, which according to the literature varies between 0.32 and 0.72 MPa [8,9]. Due to chemical incompatibility, the chemical bonding between fiber and matrix is mainly due to Van der Waals force and –OH interactions from cellulose and calcium hydroxide. In addition to a low chemical bond, the high water absorption capacity of sisal fibers causes volume expansion when fibers are added to the fresh cementitious matrix and contraction when the matrix dries, resulting in a partial loss of physical contact with the matrix.

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Different procedures to reduce the water absorption capacity of natural fibers and to improve the fiber–matrix bond have been pursued by applying chemical and physical treatments, both in the matrix and in the fiber [5,9–14]. The partial replacement of cement by microsilica resulted in an increase of the pullout resistance by about 24% [9]. This increase is related to the fineness of the microsilica which reduced the porosity of the fiber matrix interface, improving its bond. The use of alkaline solutions [10,15,16] removes most of the surface non-cellulosic substances and increase the roughness of the fiber surface increasing the fiber–matrix bond. Simple treatments such as soaking the fibers in distilled water followed by a drying process also resulted in improvements in the fiber–matrix bond [17].

A reduction in the fiber hydrophilicity can be achieved by rewetting and drying cycles to promote hornification which is the stiffening of the polymeric structure present in lignocellulosic materials [11]. This treatment promoted a reduction in volumetric changes of pulps and fibers of natural origin strengthening their interfacial bond. Polymer coating treatments reduce the water absorption and are effective in the sealing process of natural fibers [18]. Styrene butadiene polymers are used to improve the mechanical and physical properties in cement pastes as a result of the chemical reactions with calcium hydroxide and silicates [19,20]. Therefore, the simultaneous use of the two treatments may result in a better fiber–matrix interface based in the cross-linking formed between the polymer coating and the cement matrix.

However, there still exists a lack of information on the use of such treatments to improve the interface of natural vegetable fibers with a Portland cement based matrix. Therefore, the objective of the present research is to investigate the effect of different treatments on the sisal fiber physical and mechanical properties and fiber–matrix interface behavior with a cement based matrix.

2. Experimental program

2.1. Materials and processing

The sisal fibers used in the present study were obtained from the sisal plant cultivated in farms located in the Bahia state, Brazil. They were extracted from the sisal plant leaves in the form of long fiber bundles. The fiber extraction from the leaf was done by semi-automatic scrapers. These fibers characterized mechanically by Silva et al. [6,7,21] presents a fiber microstructure formed by numerous individual fibers (fiber-cells) which varies from 6 to 30 μm in diameter. The individual fiber-cells are linked together by means of the middle lamella. The chemical composition of the sisal fiber includes approximately 60.5% cellulose, 25.7% hemicellulose, 12.1% lignin, 1% pectin and 1.6% ash [18]. More information on the sisal fibers microstructure can be found in the author's previous works [2,3,7].

A matrix with a mix design of 1:0.5:0.4 (binder:sand:water/binder ratio) by weight was used. The binder was composed by a combination of 30% of Portland cement CP-32 F II, 30% of metakaolin and 40% of fly ash. This ratio of metakaolin and fly ash guarantee the durability of the fiber once a matrix free of calcium hydroxide is obtained, as shown in previous works [1,22]. The fly ash also ensures greater workability to the matrix that, in the context of high-performance composites, is a desirable property as it ensures a better homogenization of the vegetable fibers [23]. The used fly ash has an amount of 74% of CaO, 13.6% of SiO_2, and 4% of SO_3 and Al_2O_3. The used sand was ground to obtain a maximum diameter of 840 μm. The granulometric composition was performed according to the Brazilian standard [24]. The used superplasticizer was the Glenium 51 (type PA) with solids content of 31%. A viscosity modifier Rheomac UW 410, (manufactured by BASF), at a dosage of 0.8 kg/m^3 was also used in order to avoid segregation and bleeding during molding. The matrix used in this study showed a flow table spread value of 450 mm according to the Brazilian standard NBR 13276/05 [25] and compressive strength at 28 days of 31 MPa, according to NBR 7215/96 [26].

The mixture were produced in a room with controlled temperature (21 ± 1 °C) using a mixer with capacity of 5 L. The mixing procedure is described as follow. All dry components were homogenized in the mixer. The water and superplasticizer were added and mixed for 2 min at a speed of 125 RPM. After that, the process was stopped during 30 s to remove the material retained in the mixer. Then, the mixing procedure continued for 2 min at 220 RPM and, finally for a further 5 min at 450 RPM.

To mold the pullout specimens a special mold was developed (see Fig. 1(a)). After filling the mold with the matrix, the top cap was fixed and the fiber stretched slightly for alignment. The mortar was placed in plastic bags before being placed in the mold as to facilitate the casting process (Fig. 1(b)). Embedment lengths of 5, 10, 25 and 50 mm were studied. After 24 h, the specimens were demolded and placed in a fog room (HR% ⩾ 95%) to moist curing for 7 days for the pullout test.

2.2. Sisal fiber treatments

The methodology used to apply the several treatments used in the present paper as described as follow:

(i) *Hornification:* The sisal fibers were placed in a container with water (T = 22 °C) during three hours to reach its maximum water absorption capacity. The drying process was carried out in a furnace at a temperature of 80 °C. The furnace used is equipped with an electronic temperature control and connected to a scale, with a precision of 0.01 g to record

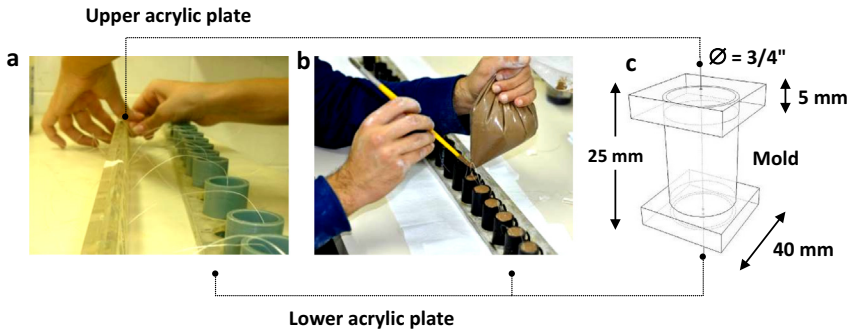

Fig. 1. Casting procedure of specimens for the pullout test: (a) positioning the fiber in the mold, (b) filling the mold with the matrix and (c) detail of the mold.