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An appropriate vacuum technology for manufacture of corrugated fique fiber reinforced cementitious sheets

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ABSTRACT

This paper reports the experiences of making Portland cement based corrugated roof sheets with the reinforcement of a Colombian natural fiber, named fique. The sheets were manufactured by a vacuum forming process. The raw material components of the sheets are given. The average flexural load to failure reported 2875 N/m at 14 curing days, which it is considered appropriate for a roofing sheet. Corrugated sheets produced with asbestos fibers using the same variables of processing reported 2400 N/m. Column permeability tests showed satisfactory results for the tried composites. The vacuum cylinder forming process for manufacture of corrugated sheets at the level of small scale production is promissory because is an environmental friendly low cost appropriate technology that does not need skilled labor.

1. Introduction

Ludwig Hatschek, an Austrian engineer made possible the manufacture of pre-formed asbestos-cement products in 1907, when the Hatschek machine, a wet transfer roller, was used to produce the initial asbestos-cement sheets. Later other two manufacturing processes were developed, the Mazza process for pipes, and the Magnani semi-dry process for corrugated sheets [1]. Asbestos-cement was the first fiber reinforced cement composite manufactured in modern times and, up to now, it has been the most consumed material due to the excellent compatibility between the asbestos reinforcement and the Portland cementitious matrix.

The asbestos crystalline fibers, which present high elasticity modulus and high strength, distribute effectively within the cement matrix being possible to add more than 10% of fibers with respect to the total volume [2]. Asbestos-cement building products have highly desirable material characteristics, such as being lightweight, impermeable to water, durable, tough, resistant to rot, termites, soiling, corrosion, warping, fire, and easy to clean and maintain. Additionally, asbestos-cement possesses low thermal conductivity and it is therefore a good electrical insulator.

The demand of asbestos has been reduced, mainly in developed countries, after the Environmental Protection Agency (EPA) implemented the initial ban on this material in 1973 [3]. However, asbestos mining, processing and usage are increasing in developing countries [4]. Researchers as Bernstein and Hoskins [5] comment that the different chemistries of chrysotile and amphiboles – the serpentine chrysotile is a thin walled sheet silicate while the amphiboles are double-chain silicates–result in chrysotile clearing very rapidly from the lung ($T1/2 = 0.3$ to 11 days) while amphiboles are among the slowest clearing fibers known ($T1/2 =$ 500 days to ∞), thus across the range of mineral fiber solubilities, chrysotile lies towards the soluble end of the scale. They conclude that low exposures to pure chrysotile do not present a detectable risk to health, and that the risk of an adverse outcome may be low if even any high exposures experienced were of short duration. By now, the balance of criteria about asbestos utilization is inclined toward the banning of any type of asbestos.

Some fiber reinforced materials have been manufactured to substitute asbestos-cement elements. Fibers that have been investigated include: steel, glass, polypropylene, wood, acrylic, akwara, alumina, carbon, cellulose, coconut, kevlar, nylon, perlon, polyethylene, PVA, rock wool, sisal, and fique. Particularly, vegetable fiber reinforced cementitious materials for corrugate sheets have been an investigation line of Savastano Research Group in the University of Sao Paulo for the last 21 years [6].

Several companies manufacture products that replicate asbestos-cement roofing and siding shingles, flat sheets, and corrugated sheets. Some of these manufacturers include: Supradur Manufacturing Company, Cement Board Fabricators, US Architectural Products, Inc., Re-Con Building Products, and GAF Materials Corp [7]. However, so far, there is not a material that conclusively develops the performance of asbestos-cement.

The research about fiber reinforced thin cementitious corrugate materials moves on the seeking of low cost available chemical stable environmental friendly reinforcing fibers. One of the

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Fig. 1. Corrugated sheets manufactured by members of a native community.

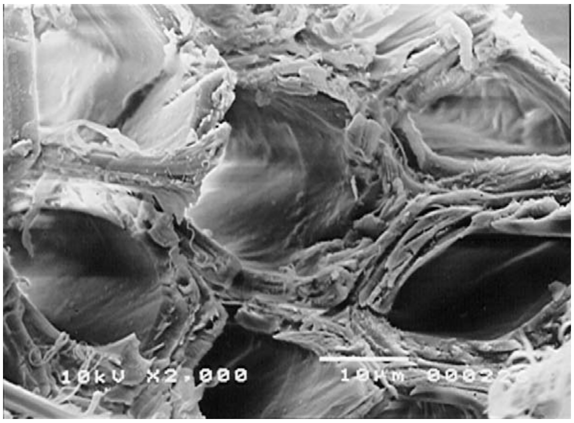

Fig. 2. SEM micrograph of a cross section of a fique fiber.

alternatives is the use of natural fibers, but their durability shortcomings have to be remedied. The Research Group of Composite Materials of the Universidad del Valle has been researched a Colombian native fiber named fique fiber or cabuya in connection with cementitious matrixes since 22 years ago. Essentially, these investigations have been devoted to develop technology for production of materials for housing at low scale level. Their results have been transferred to the community by training leaders in the process of manufacture of building materials (Fig. 1) [8]. However, this small scale production is limited to rural areas, because of this, a more feasible technology, from the point of view of the cost of a material for urban areas, was developed.

In this paper, the experience of applying an appropriate low scale production technology for manufacturing corrugated sheets for roofing using vacuum is presented [9]. However, the result of this experience shows that adjustments have to be done in order to overcome problems related to the parameters of the process and the type and volume fraction of the ingredients of an appropriated mix for that type of technology.

2. Properties and microstructure of the fique fiber

The properties of the fique fibers, determined by this research, are listed in Table 1. The fique fiber or cabuya (*Furcrae gender*) is extracted from the fique plant, which is the most cultivated natural fiber plant of Colombia. It presents similar characteristics to the sisal fibers. There is an important variation in fiber diameter among fique fibers of the same batch and along a fiber, as it is typical for natural fibers. The high Coefficient of Variation (40%) encountered indicates analogue lack of consistency in the geometry of natural fibers as found for sisal fibers by Torres et al. [10] and by Toledo et al. [11] for sisal and coconut fibers. The high variations in the fiber diameter and in the mechanical properties along the length of a fiber are due to the physical necessary response along the length of a leaf for supporting its weight.

A natural fiber changes its dimensions when its humidity varies. This is explained by the fact that polymers that compose its walls contain hydroxyls and other chemical groups with Oxygen that attracts the water throughout the hydrogen bonds [12]. The hemicelluloses are responsible for the water absorption, although other components also play an important role. The process of water absorption is correlated with expansion and shrinkage of the fiber. Shrinkage happens when the humidity of the fiber falls below the water level of saturation. This reversible process is deleterious for a natural fiber reinforced based Portland cement composite because the fiber separates from the matrix. A SEM micrograph of a fique fiber done under cryogenic conditions by Perdomo [13] is presented. It is observed, the similarity between the microstructure of the fique fiber and those of the woods and the cellulose. The cells have hexagonal shape. It is visible the central channel or the lumen and the surface of the inner layer of the secondary wall of the fique fiber.

The free dimension of the lumen channel is approximately 20 μm as seen in Fig. 2, which is sufficiently ample to the ingress of finer particles of Portland cement during the mixing procedure considering that the normal type I Portland cement has approximately a D_{50} of 12 μm. Because of this, it is possible the incorporation of an important content of hydrated cement particles inside the lumen.

Table 1
Characteristics of the fique fibers.

Characteristic	Fique
Equivalent diameter, mm	0.16–0.42 0.236 mm (average) Coefficient of variation: 27%
Apparent density, kg/m^3	723
Specific gravity	1.47
Water absorption, %	60.0
H_2O, %	12
Equilibrium relative humidity, % (absorbency)	8.12
Cellulose, %	70.0
Lignin, %	10.1
Tensile strength, MPa	43–571 132.4 MPa (average) Coefficient of variation: 40%
Ultimate elongation, %	9.8
Elastic modulus, GPa	8.2–9.1

3. Fique fiber reinforced cementitious composites: interface

The fique fiber had been disposed in matrixes of concrete, mortar and paste of Portland cement. In some cases, cement had been blended with pozzolanic additions. The observation of the interface, as presented in Fig. 3, shows a fique fiber being separated from the matrix [14]. The fiber had been pulled out of the matrix. The white particles adhered to the fiber had a Calcium to Silicon ratio of four determined by energy dispersive X-ray spectrometry techniques. The fiber structure of the natural fiber seems to be undamaged and there is not indication of fiber failure after six months of aging. Between the fiber and the cement matrix there was a separation of approximately seven micrometers. This separation was produced probably by a process of swelling and shrinkage of the natural fiber during the first stage of mix setting and indicated that bonding between fiber and matrix was mainly due to