Influence of Fibers Weight Fraction and Nature of Fibers on Thermal and Mechanical Properties of Vegetable Fibers / Cement Composites

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ABSTRACT

Nowadays, in the purpose of energy saving and eco-friendly technologies and materials, increasing interest is accorded to natural vegetable fibers. Many studies have shown that vegetable fibers are an alternative to asbestos in fiber reinforced cement products manufactured by the Hatscheck process. Few works have demonstrated the low thermal conductivity of such composite materials resulting from effect of the mixture fiber/matrix.

The aim of this study is to produce low–cost building materials in the purpose of saving energy using heat-treated and chemically treated sugar cane bagasse and fique fibers as reinforcement in cement (OPC) based materials. Consequently, the influence of the type and weight of additives on the insulating thermal properties (conductivity) and on the mechanical properties (flexural strength) are prospected.

This study evidences that composites composed with pyrolyzed bagasse fibers have better thermal properties than others composites. The higher mechanical properties are noted for composites manufactured with alkali treated fibers.

KEYWORDS

Vegetable fibers/cement composites, Thermal properties, Flexural strength, Alkali treatment, Heat treatment

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1 INTRODUCTION

Composite materials incorporating vegetable natural fibers have known an increasingly interest during the past few decades [Toledo Filho et al. 2003, Savastano et al. 2000, Savastano et al. 2003, Bilba et al. 2003, Arsène et al. 2007, Coutts 1988]. These environmentally friendly materials are low-cost [Coutts 1988] and offer advantages such as reduction of electrical consumption by air conditioning. Moreover, the use of vegetable fibers in replacement of synthetic fibers is interesting in developing countries where the availability of tropical plants and agricultural wastes is important. Due to health reasons, since 1973, various regulations are applied to restrict and ban the use of asbestos in France [Bilba et al. 2004] and other countries. Many studies have shown that, regarding the mechanical behaviour, vegetable fibers are an interesting alternative to asbestos in fiber reinforced cement products manufactured by the Hatscheck process [Savastano et al. 2000, Savastano et al. 2003, Savastano et al. 2001] although few works have demonstrated the low thermal conductivity of such vegetable fiber-Portland cement based composite materials [Toledo Filho et al. 2003, Savastano et al. 2001] resulting from effect of the mixture fiber/matrix.

The aim of this study is to produce low–cost insulating materials for building construction in order to obtain habitability and to save energy. Although thermal properties are really involved in applications of such materials, it is essential to evaluate if their mechanical properties are in good agreement with the civil engineering codes [Blankenhorn et al. 2001]. Consequently, the influence of the type of treatment and amount of fibers on the mechanical and thermal properties are prospected.

2 MATERIALS AND METHODS

Samples were elaborated at Universidad del Valle (Cali, Colombia) using a process followed by Delvasto [2006] and de Gutiérrez and al. [2005] while the thermal and mechanical studies were developed at Université des Antilles et de la Guyane (Guadeloupe, France).
Two types of vegetable fibers were used: bagasse, solid residue of sugar cane after juice extraction (provided by Sugar Cane Factory in Guadeloupe) and Colombian plant fique (provided by a Colombian Fique sacks factory). They will be noted respectively "BAG" and "FIQ".

Two types of treatments were applied:

- Heat–treatment : pyrolysis under controlled atmosphere (N_2 flow, 2L/h) during 2 hours and at 200°C which is the optimal temperature to obtain retified fiber without formation of char [Bilba & Ouensanga 1996]. The pyrolyzed fibers will be named "BAGP".
- Chemical treatment: attack by a 5% by mass alkaline solution of $Ca(OH)_2$ for bagasse and fique fibers. The alkali treated fibers will be named "BAGB" and "FIQB".

A Portland cement marketed as ASTM type I usually used in Colombia, a graded natural river sand, a limestone filler and water were used as the matrix. 93.5 % by weight of the limestone filler is Calcium carbonate ($CaCO_3$). The size distribution, determined by using a Malvern laser diffraction analyzer, of Portland cement gives an average granulometry of 15μm and the limestone filler has an average particle size about 1 μm.

According to these results, the Portland cement has a factory addition what is a calcareous material. The sand is appropriated for use in cement based mortars, its apparent density is about 2605 kg/m³ and its average particle size is approximately 0.6 mm.

2.1 Composites Preparation

The content of sand and calcium carbonate were kept constant at 50% and 30% by weight of cement respectively. The composites studied were elaborated with a matrix based on Portland cement. The

proportions of the matrix compounds were in weight percent with respect to Portland cement (wrtc): sand 50 %, limestone powder 30 %, bentonite 1.5 and 3 %, cellulose pulp 4 %, silica fume 5 %, an aqueous copolymer dispersion of butyl acrylate and styrene from BASF (Acronal® 296 D) 7.5 %. The amount of fibers was changed from 0 % to 3 % wrtc. Slurry of each mix contains a water/cement ratio of 0.9 (weight by weight) being prepared before its pouring on a casting bed that was subjected to vacuum to obtain a flat sheet. After the slurry dewatering process, pads (160 x 50 x 8 mm^3) cut from the fresh laminate were cured for 21 days at 100% of relative humidity and left to air dry in the laboratory for 7 days at room temperature.

About 19 mixes were elaborated: 3 samples for the 3 types of fibers for 2 fiber contents and 1 as control (without any fiber). The detail of the mixes is shown in [Table 1]. The mixes reinforced with fique alkali treated (FIQB) correspond to codes: M86, M90; The mixes reinforced with bagasse alkali treated (BAGB) correspond to codes: M71, M74. The mixes reinforced with pyrolyzed bagasse (BAGP) correspond to codes: M80, M83. The composites will be noted "CBAGP", "CBAGB" and "CFIQB".

Table 1: Proportions of the mixes elaborated.

Composites	Fibres and treatment	Bentonite (% wrtc)	Fibres (% wrtc)	Acrylic Polymer (% wrtc)	Silica Fume (% wrtc)	Pulp (% wrtc)
Control (M 75)		3	0	7,5	5	4
CFIQB (M90)	FIQB	3	1,5	7,5	5	4
CBAGB (M74)	BAGB	3	1,5	7,5	5	4
CBAGP (M83)	BAGP	3	1,5	7,5	5	4
CFIQB (M86)	FIQB	3	3	7,5	5	4
CBAGB (M71)	BAGB	3	3	7,5	5	4
CBAGP (M80)	BAGP	3	3	7,5	5	4

2.2 Thermal conductivity testing

Thermal tests were conducted under controlled laboratory conditions (temperature ~ 20°C and relative humidity of 70–80%) on 112 days old specimen. The apparatus used was a thermal conductivimeter "CT–mètre" with a thermal probe commercialized by Controlab (Saint–Ouen, France). Six measurements were conducted for each composite with one hour interval between each measurement in order to evaluate the standard deviation of the results.

2.3 Flexural strength testing

Composites flexural strength was measured under three-point bend loading with a span of 50mm. The tests were conducted 112 days after specimen fabrication. The specimens were loaded continuously to failure at a speed rate of 0.5 mm/minute. The tests were carried out in an Instron (model 3367 - Guyancourt, France) testing machine equipped with a 500N load cell.

3 RESULTS AND DISCUSSION

In this paper, results of the tests on 112 days old specimen are presented. At this age, the principal hydration processes of cement have almost completely been done and the formulations of the composites are very stable [Bilba et al. 2004, Taylor 1997]. The evolution of thermal conductivity according to the amount of fibers is reported in [Figure 1]. Dash lines correspond to control specimen. The thermal conductivity values are of same order of magnitude whatever the type of fibers. Evolution of mechanical properties determined by three-point bending test is presented in [Figure 2].
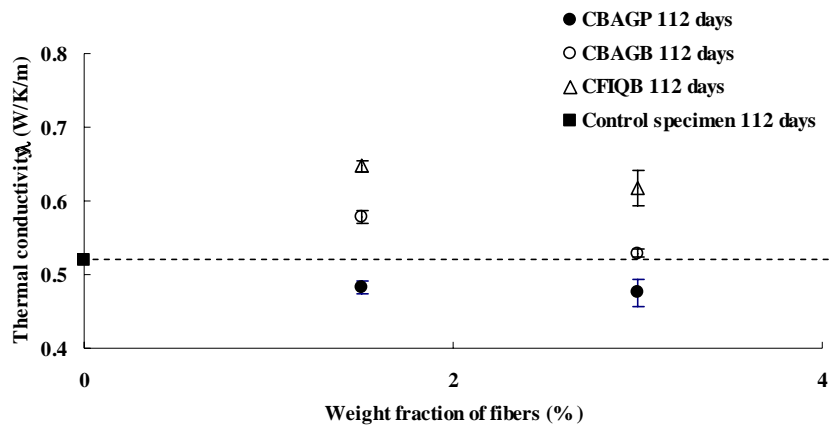
Figure 1. Evolution of thermal conductivity of 112 days old vegetable fibers/cement composites according to weight fraction of fibers.
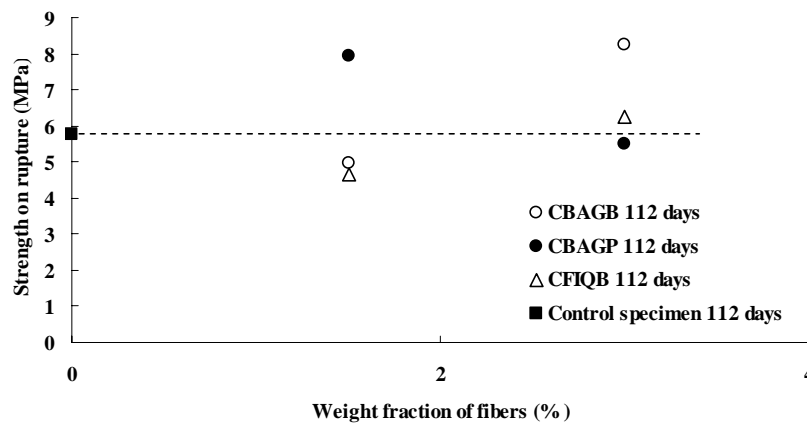

Figure 2. Evolution of flexural strengths of 112 days old vegetable fibers/cement composites according to weight fraction of fibers.

3.1 Influence of weight fraction of fibers

By increasing the weight fraction of fibers, there is a progressive decrease of the thermal conductivity. This result is in good agreement with Asasutjarit et al. [2007] results: when cement/fiber is higher, the thermal conductivity of a cement board increases. The weaker heat conductor materials are CBAGP because the more pronounced addition of fibers effect is for those composites; indeed all the thermal conductivity values of CBAGP are lower than the control specimen one.

The effect of fiber content has been correlated with the treatment. At low fiber content (1.5% wrtc), strengthening effect is observed only for composites with pyrolyzed bagasse fibers. On the contrary, at 3% (wrtc) of fibers, the better mechanical properties are measured for composites elaborated with bagasse and fique fibers using alkaline treatment.

In case of thermally treated fibers, the flexural strength decreases with increasing fiber content. A strengthening effect of mechanical properties, with increasing fiber content, is noted for composites containing chemically treated fibers. However, at low content of chemically treated fiber (1.5 %), the composites flexural strength is lower than for the control specimen. This behaviour with 1.5% weight fraction of fibers points out the importance of fiber adhesion and porosity.

Between 1.5% and 3% (wrtc) of fiber content, mechanical properties are supposed to follow a linear variation. By extrapolation, a fiber content of 2% is found. In these conditions, flexural strengths are closer for the two composites made of bagasse fibers and remain higher than the control specimen one.

These results are confirmed by former results **[5]** that evidence an optimal pyrolyzed bagasse fiber content of 2% (wrtc) for improved mechanical properties and an increase of mechanical strength thanks to the addition of pyrolyzed bagasse fibers or alkali treated fique fibers.

3.2 Effects of fiber treatment

As shown in [Figure 3], pyrolysis at 200°C significantly improves thermal properties of these composites because thermal conductivity values of CBAGP are lower than the control specimen one. The value of thermal conductivity is more than 20 % lesser for the CBAGP than for the commercial cellulose boards which report 0.68 W/K/m [Asasutjarit et al. 2007].

The most important decrease of thermal conductivity values is noted for alkali treated fibers/cement composites. Nevertheless, up to 3% of alkali treated fibers, the values keep higher than for the control specimen. This means that the inclusion of pyrolyzed fibers limits the heat transfer.

With 3% of pyrolyzed bagasse fibers, the composites do not offer greater mechanical properties because the strength of CBAGP is lower than the control specimen, whereas strengths of alkali treated fibers/cement composites are higher than the control specimen one. At 3% weight fraction of fibers, CBAGB and CFIQB behave better and seem to be well designed for improved mechanical properties of building materials.
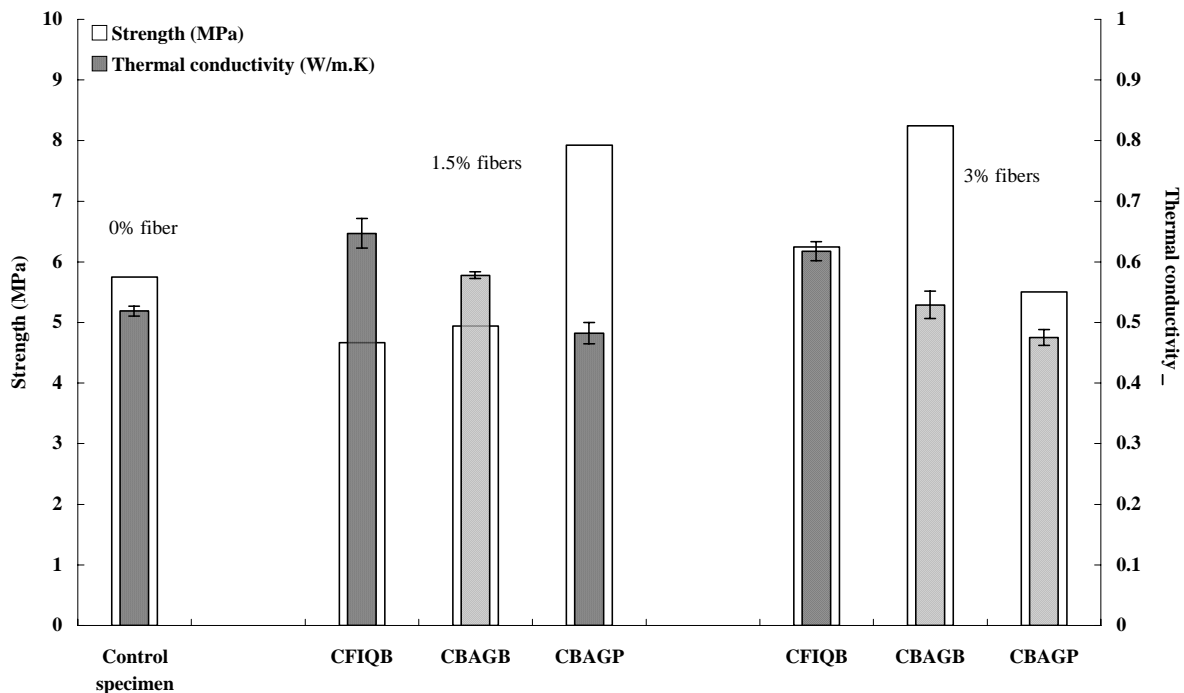

Figure 3. Comparison of thermal conductivity and flexural strengths of 112 days old vegetable fibers/cement composites according to weight fraction of fibers.

3.3 Influence of nature of fibers

A comparison of mechanical and thermal properties of CFIQB and CBAGB allows an assessment of effect of botanical origin of fibers.

According to Fig. 3, the less insulating materials are elaborated with alkali treated fique fibers as all thermal conductivity values for CFIQB are higher than the others.

Regarding the strength values (Fig. 2 and 3), its trend according to the weight fraction of fibers is similar for CBAGB and CFIQB but we note that CBAGB present higher flexural strength than CFIQB.

Alkali treatment dissolves the hemicellulose matrix of vegetable fibers and thus, increases surface roughness. However, it improves little or degrades slightly the vegetable fibers properties. While heat treatment (pyrolysis), which increases significantly fibers mechanical strength, increases in a less way the vegetable fibers roughness in comparison with alkali treatment [Arsène et al. 2007]. Thus, these two factors allow the interpretation of the flexural strength according to fiber weight fraction and nature of fibers.

4 CONCLUSIONS

Thermal conductivity of vegetable fibers/cement composites is an important parameter in the use of such materials in construction for saving energy. In this study, particular attention is given to the influence of weight fraction of fibers, fibers treatment and nature of fibers on thermal properties. Composites elaborated with bagasse fibers are weaker heat conductor materials than those elaborated with fique fibers. Although for thermal insulating applications, one should prefer the weaker heat conductor that is to say CBAGP. But if requirements on mechanical strength are more severe, composites with alkali treated fibers have to be preferred.

Treatment effectiveness can be limited by roughness or fiber/matrix adhesion problems.

In order to evaluate the interest of a treatment or the nature of reinforcement, we have to compare the composites characteristics to control specimen (without any fiber) characteristics. In this study, the reference specimen contains aggregates and plasticizers and fiber content is limited to 3% (wt). In such conditions, improving effect of alkali treatment is not noted, at the contrary of results reported by Arsène et al. [2007] in the case of an ordinary Portland cement paste.

This study allows the determination of an "optimal" weight fraction of fibers. Indeed, if one wants to find a good deal between great thermal and mechanical properties, a formulation within 2.25% of bagasse fibers appears to be optimal.

Composites with fique fibers present weaker mechanical properties than composites with bagasse fibers.

This study has to be supplemented by additional experiments on specimen containing higher fiber content. Indeed, it will be useful in order to determine the potentialities of use of these composites as insulating materials.

ACKNOWLEDGMENTS

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