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Sugar cane bagasse fibre reinforced cement composites. Part I. Influence of the botanical components of bagasse on the setting of bagasse/cement composite

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Abstract

Various bagasse fibre/cement composites have been prepared, the fibres having a random distribution in the composites. The influence of different parameters on the setting of the composite material has been studied: (1) botanical components of the fibre, (2) thermal or chemical treatment of the fibre, (3) bagasse fibre content and (4) added water percentage. This study shows a retarding effect of lignin on the setting of the composite, for small amount of heat-treated bagasse (200 °C) the behaviour of the composite is closely the same as the classical cement or cellulose/cement composite.

Keywords: Sugar cane bagasse fibre; Composite; Building materials; Renewable resources

1. Introduction

Increasing attention should be paid to natural fibres with a view to conserving energy and protecting the environment. It is well known that softwood pulp fibres can replace asbestos fibres in fibre reinforced cement products manufactured by the Hatsckek process [1]. Other natural fibres such as banana fibres have also been extracted for the elaboration of cement composites [2]. In this work (natural, chemically treated and heat-treated) sugar cane bagasse fibres have been utilised for similar study. Bagasse is the solid lignocellulosic residue left after extraction of juice from the sugar cane stalk. In Guadeloupe (The French West Indies), the principal use of bagasse is as a combustible material for energy supply in sugar cane factories as in thermal power station, but in many other countries such as Egypt, Cuba, etc. it is used in pulp and paper industries and for fibre board materials [3].

The aim of the present work is to study the influence of the (water extractives, hemicellulose, cellulose and lignin) botanical components on the setting properties of bagasse/cement composites with a view to using them as building materials to save energy, if their mechanical characteristics are not too poor. This aspect of the problem and structural study of bagasse fibres and composites will be dealt with in a further work.

2. Experimental

2.1. Materials

The precursors are sugar cane bagasse provided by the Gardel sugar cane factory (Le Moule-Guadeloupe) and Portland cement from Ciment Antillais (Lafarge group).

The sugar cane bagasse composition has already been determined [4]:

- for elemental analysis (in weight percent): C: 45.5; H: 5.6; O: 45.2; N: 0.3;
- for botanical analysis (in weight percent): cellulose: 41.8; hemicellulose (as pentosan): 28.0 and lignin: 21.8.

Pure cellulose, xylan (as hemicellulose) and lignin provided by the Sigma-Aldrich firm have been used as well.

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Table 1
Characteristics of the various composites prepared

Sample	Cement content (g)	Bagasse fibre content (g)	Mass of water (g)	Content of other additives (g)	Treatment of additives
Reference	125	–	50	–	–
Cellulose	125	–	50	1.250	–
Hemicellulose	125	–	50	1.250	–
Lignin	125	–	50	1.250	–
BAG Brute	125	1.250	50	–	–
BAG TC	125	1.250	50	–	Chemical
BAG TT 1	125	1.250	50	–	Thermal (175 °C)
BAG TT 2	125	1.250	50	–	Thermal (200 °C)
BAG TT 3	125	1.250	50	–	Thermal (225 °C)
BAG TT4	125	1.250	50	–	Thermal (250 °C)
BAG 0.5	125	0.625	50	–	Thermal (200 °C)
BAG 1.4	125	1.750	50	–	Thermal (200 °C)
BAG 2	125	2.500	50	–	Thermal (200 °C)
REF E2	125	–	75	–	–
BAG E1	125	1.250	75	–	Thermal (200 °C)
BAG E2	125	2.500	75	–	Thermal (200 °C)

The Portland cement CPJ 32.5 corresponds to the AFNOR NF P15-301 norm.

2.2. Sample preparation

Bagasse/cement composites of various compositions have been prepared. Their characteristics are reported in Table 1. Blended cement composites were prepared, mixing Portland cement with bagasse fibres and water. Many of these samples have been obtained from heat-treated bagasse (175–250 °C) whose peculiarities compared with natural raw bagasse have already been described in a previous paper [5]. BAG TC samples were obtained from chemically treated bagasse fibres. The chemical treatment has already been described [4], it enables to eliminate the pentosan, a major component of hemicellulose, from raw bagasse; thus the solid residue almost contains nothing but cellulose and lignin. In order to study the effects of the botanical components of bagasse fibres on the setting, other blended cements were made by mixing Portland cement with cellulose and water, hemicellulose and water or lignin and water (Table 1).

2.3. Methods

A thermos bottle is used as an adiabatic chamber. Time and temperature (±0.1 °C) were measured all along the setting. The setting temperature (the highest temperature of hydration) and the setting time (time to reach the highest temperature of hydration) were recorded down (Tables 2 and 3).

Table 2
Influence of the additive bagasse fibre before mixture with cement and water on the setting of the composites

Sample	Composition	Time to reach the highest temperature of hydration (h)	Highest temperature of hydration (°C)
Reference	125 g cement 50 g water	15.5	39.3
BAG 0.5	125 g cement 50 g water 0.625 g heat-treated bagasse (200 °C)	15.5	38.8
BAG TT2	125 g cement 50 g water 1.25 g heat-treated bagasse (200 °C)	15.5	37.0
BAG 1.4	125 g cement 50 g water 1.750 g heat-treated bagasse (200 °C)	15.5	33.4
BAG 2	125 g cement 50 g water 2.50 g heat-treated bagasse (200 °C)	17.0	33.5

Table 3
Influence of the amount of water on the setting of the composite

Sample	Composition	Time to reach the highest temperature of hydration (h)	Highest temperature of hydration (°C)
Reference	125 g cement 50 g water	15.5	39.3
REF E2	125 g cement 75 g water	17.0	37.6
BAG TT2	125 g cement 50 g water 1.25 g heat-treated bagasse (200 °C)	15.5	37.0
BAG E1	125 g cement 75 g water 1.25 g heat-treated bagasse (200 °C)	21.0	30.0
BAG 2	125 g cement 50 g water 2.50 g heat-treated bagasse (200 °C)	17.0	33.5
BAG E2	125 g cement 75 g water 2.50 g heat-treated bagasse (200 °C)	21.0	30.0

Differential scanning calorimetry (DSC) of composite powder samples was conducted with a SETARAM TG-DSC111 thermoanalyser, composed of a G11 pilot unit connected with a DSC111 calorimeter. These instruments were driven by an EPSON computer. Temperature was recorded with an approximation of ±0.5 °C. The precision of the enthalpy measurement was about 5%.

3. Results and discussion

Plot of temperature versus setting time for the different samples prepared leads to similar profile curve as can be seen in Fig. 1(a). Similarly, the respective influence of each botanical component and of raw whole bagasse on the setting time of the vegetal fibre/cement composite is displayed. Fig. 1(b) shows the thermal effects associated with the temperature treatment of those samples. The following observations can been made:

The setting of raw bagasse/cement composite is delayed compared with cement–water mixture (reference), it is probably due to the presence of some water soluble sugars. The botanical components of raw bagasse do not offer the same setting behaviour. For cellulose and lignin additions, with time an increase in hydration temperature is observed. The maximal hydration temperature is similar for both components but the setting is slower for lignin than for cellulose. Thus lignin has a retarding effect on setting. For hemicellulose, the temperature remains constant, showing that the composite does not set for 30 h. The composites made with components of bagasse exhibit setting temperatures which are lower than the reference. Thus there are two phenomena, the reaction between water and cement which is exothermic and the reactions between water and components of fibre bagasse which are endothermic [6]. Other components like sucrose, as shown by Abdelraziz et al. [7], can also have a retarding effect on setting. Raw bagasse contains sugar which may delay setting. Delay can also be due to lignin hydrolysis [7]. The influence of the soluble sugars on the setting of the composite is noticeable when observing the setting of a composite made of cement, raw bagasse and water saturated in soluble sugars (Fig. 1(c)). Comparison between the setting curves of cement/bagasse composite made with natural water and cement/bagasse composite made with saturated water shows that soluble sugars have a retarding effect on the setting as well as decrease hydration time. The presence of hemicellulose has a detrimental effect on the setting due to its partial solubility in water [8].

The thermal decomposition of the bagasse/cement composite is represented in Fig. 1(b). It shows first a local maximum negative value near 120 °C, a peak near 300 °C, a third one close to 500 °C and the last one near 600 °C. All the additive components except for lignin exhibit the four peaks but at temperatures depending on the additive; for lignin, there is no third peak near 500 °C. The first endothermic peak corresponds to the release of the water adsorbed and evaporated near 120 °C but also to the decomposition of components of Portland cement like $CaSO_4 \cdot \frac{1}{2}H_2O$ as proposed by Abdelraziz et al. [7] and $CaO \cdot H_2O$ as suggested by Taylor [9]. At near 500 °C, they indicate the dehydration of $CaO \cdot H_2O$ phase. Above 500 °C, Taylor [9] proposes the degradation of $CaO \cdot SiO_2 \cdot H_2O$ and hydrated aluminate

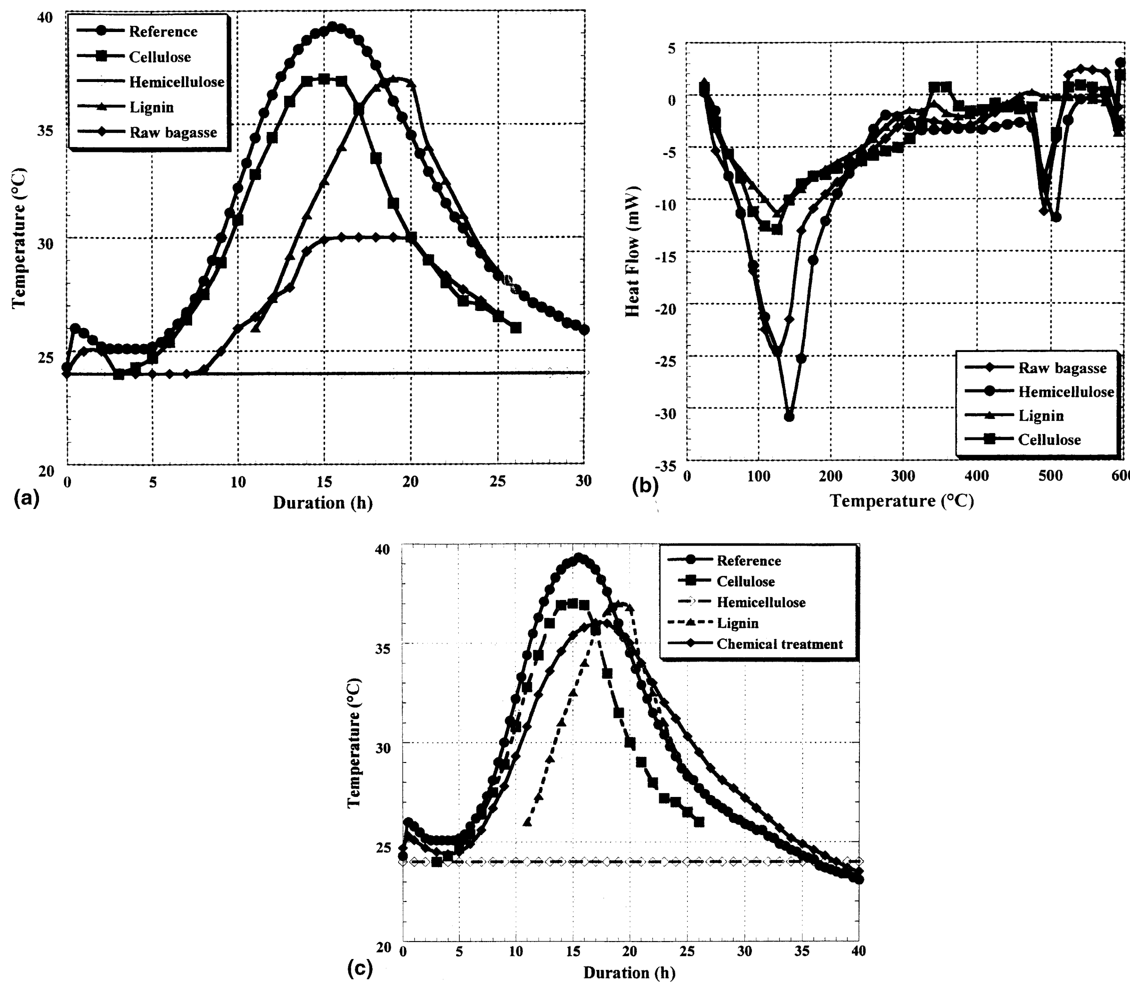

Fig. 1. (a) Influence of the different botanical components of bagasse fibre on the setting of composite material. (b) Influence of the different botanical components of bagasse fibre on the thermal degradation of composite material. (c) Effect of the soluble sugars on the setting of composite material.

phases. It seems that the peak at 300 °C corresponds to the decomposition of the additives.

As can be seen in Figs. 2(a) and (b), the bagasse/cement composite has the behaviour of a statistical composite constituted by the following individual composites: cellulose/cement (41.8%), hemicellulose/cement (28%) and lignin/cement (21.8%). Indeed, when a pattern of the behaviour of temperature and time of the setting of the bagasse/cement composite on one hand and a pattern of thermal degradation of this composite on the other hand are thanks to respective curves of cellulose/cement composite, lignin/cement composite and hemicellulose/cement composite weighted by botanical components amount in bagasse and curves of water extractives/cement composite, these patterns are in good agreement with experimental results.

In Fig. 2(a), the setting time is identical as for experimental and simulated curves and there is only a difference of 0.5 °C between both the highest temperatures of hydration, showing good compatibility.

For DSC experimental and simulated curves (Fig. 2(b)), we note differences for areas of the peaks and for temperatures corresponding to the minimal heat-flow. The raw bagasse/cement composite is made of fibres whose structure of botanical constituents is organised while the simulated composite is made of mixed powders. They have different kinds of exchanges, surface and bulk ones. Comparison of Figs. 1(b) and 2(b) shows that the temperature corresponding to the minimal heat-flow is directly in relation with the distribution of the botanical constituents in the fibres. The external surface of the fibre is composed essentially of cellulose and lignin, thus the raw bagasse/cement, cellulose/cement and lignin/cement composites decomposed at the same temperatures, except at 500 °C for lignin/cement mixture because lignin is thermally stable.

The results of the chemical treatment of bagasse on the setting of the composite (BAG TC) are reported in Fig. 3. It shows that the consequences of the chemical treatment are a diminution in the hydration temperature

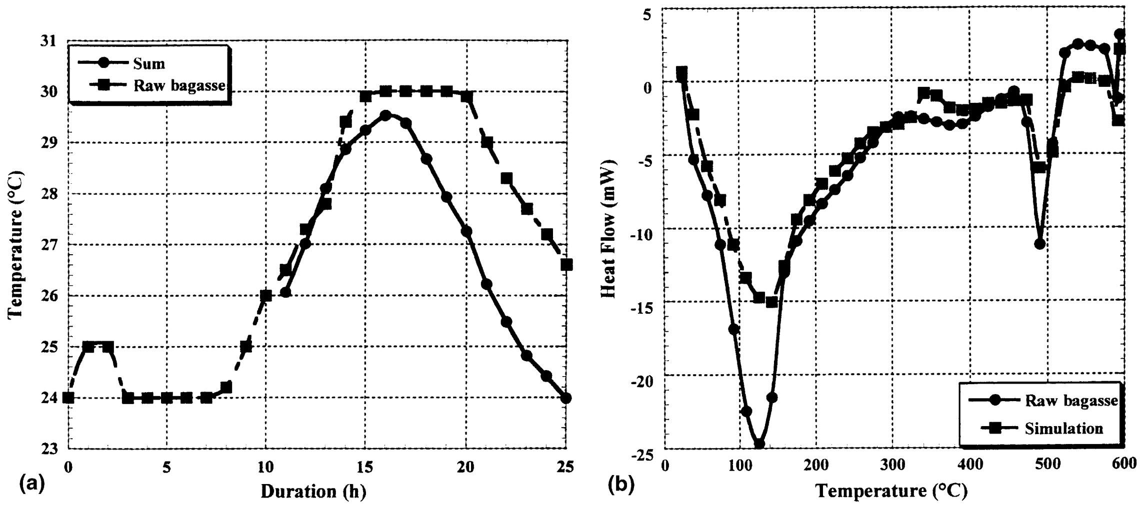

Fig. 2. Pattern of experimental and theoretical curves of: (a) setting of composite material; (b) thermal degradation of composite material.

and an increase in the setting time. The behaviour of the BAG TC composite is approximately the results of weighted addition of curves of cellulose/cement sample and lignin/cement sample for the setting time. The difference observed for hydration temperature can be explained by the presence of hemicellulose in the solid residue in spite of chemical treatment.

The influence of thermal treatment of bagasse before mixture with cement and water has also been studied. The results obtained are presented in Fig. 4. The thermal treatment of bagasse improves the setting of the composite material, the setting time being lowered. The maximum hydration temperatures of composites are obtained for bagasse fibre samples heat-treated at 200 and 250 °C (BAG TT2 and BAG TT4). As shown in a previous study [5], pyrolysis of bagasse at these temperatures destroys the water extractives and hemicellulose compounds unfavourable to the setting. The best compromise for the best setting in the shorter time is obtained for a mixture with a bagasse fibre which is heat-treated at 200 °C.

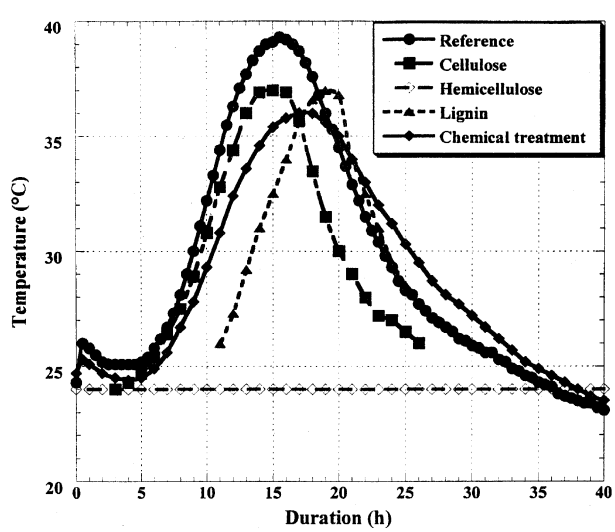

Fig. 3. Influence of the chemical treatment of the bagasse fibre on the setting of the composites.

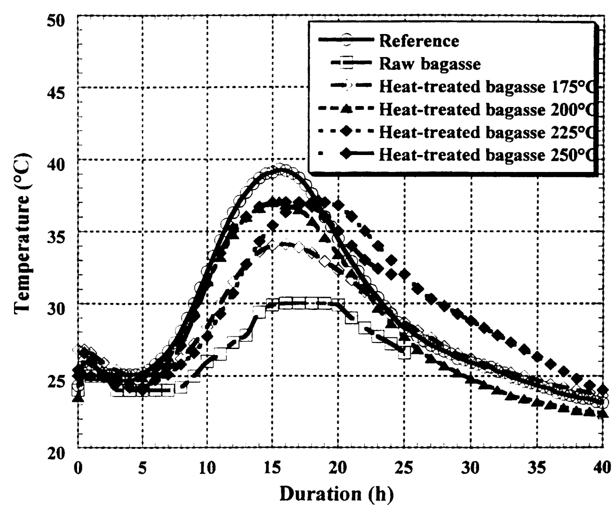

Fig. 4. Influence of the thermal treatment of the bagasse fibre on the setting of the composites.

The results of the influence of the weight percentage of additive heat-treated (200 °C) bagasse fibres are reported in Table 2. They show that increasing the amount of heat-treated bagasse in the composite leads to a decrease of the maximum hydration temperature and beyond 1.4% (wt/wt or 1.75 g) a delay of the setting time. This behaviour illustrates again the influence of the botanical components of bagasse on the setting of the composites. Indeed until 1.4% (wt/wt) of additives, the composites have behaviours close to that of cellulose

(Fig. 1(a)) and beyond 1.4% the behaviours of BAG 2 and lignin composites are the same. In BAG 2 composite, the amount of lignin becomes sufficient to have a sensitive effect on the setting of the material.

Also are reported in Table 3, the results of the influence of the amount of water during the elaboration.

In the reference sample, there is a very light excess of water for hydration of cement. Indeed, Taylor [9] indicates that the minimum water/cement ratio for complete hydration of cement is 0.38 whereas in the reference sample case this ratio is 0.40. For BAG TT2 sample, the heat-treated bagasse adsorbs excess of water probably due to van der Waals linking, the reaction between bagasse and water being less exothermic than that of cement and water. Temperature of hydration of BAG TT2 is lowered and its setting time still the same because of the low amount of excess water. For BAG 2 sample, the amount of bagasse fibres is twice as important as in BAG TT2. The content of water required for hydration of both cement and bagasse fibres seems to be insufficient. There is a competition between these two phenomena and the setting is slow.

In REF E2 sample, the high amount of excess water leads to a longer setting time and a lower setting temperature, thanks to adsorption of the excess water by bagasse fibres, compared with the reference sample. Comparison of BAG E1 and BAG E2 samples shows that there is no competition in hydration of cement and bagasse in both composites, and that the amount of water is sufficient. Two phenomena account for the differences observed for setting of REF E2 and BAG E1 (or BAG E2) samples, the adsorption of water by bagasse fibres and mainly the retarding effect on setting of the remaining soluble sugars released by heat-treated bagasse with excess water.

4. Conclusion

The effect of mixing raw whole bagasse to commercial cement delays the setting times and decreases the maximum hydration temperature of setting. This can have a real interest for building materials by offering a good compromise between setting duration and hydration temperature, the setting of the new material becoming less expansive in the mass. The principal botanical compounds having a negative impact on the setting are water soluble sugars, hemicellulose and lignin [6,10,11].

Contrary to raw bagasse, bagasse which is heat-treated at 200 °C seems to lead to a vegetal fibre/cement composite having a similar behaviour compared with that of classical cement.

A DSC study of the samples indicates that the bagasse/cement composites thus obtained are thermally stable from room temperature to nearly 450 °C.

This work will continue with the study of some mechanical and structural properties of bagasse/cement composites. The thermal treatment of bagasse fibres before mixing it in cement is still expansive, a study of the influence of chemical admixtures in raw bagasse fibres/cement composites will be performed in order to make low cost materials. In our region the seismic risk is important, the use of bi-dimensional natural local fibres will be studied for incorporation in cement.

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