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SUGAR CANE BAGASSE FIBRES REINFORCED CEMENT COMPOSITES: THERMAL CONSIDERATIONS

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Abstract.

This paper examines the thermal properties of cement composites reinforced with vegetable bagasse fibres (1.5 and 3% wrtc).

Thermal properties have been correlated to macroscopic density and porosity in order to estimate thermal conductivity of fibres using a calculation inspired from Maxwell Eucken modelling.

Experimental investigations reveal that adding retified bagasse fibres reduces composites thermal conductivity and yields a weaker specific heat in comparison with composites made with alkaline bagasse fibres. Moreover, the more the fibres, the lighter the specimen; lower its thermal conductivity and lower its specific heat. Thermal conductivity of alkaline fibres is lower than retified fibres one.

Keywords: A. fibres; A. composites; B. Thermal properties; D. Thermal analysis

1. Introduction.

In order to reduce electricity consumption in houses, due to air-conditioning, cement/vegetable fibres composite materials have known an increasing interest during the past few decades [1-9]. These materials display many advantages such as they are environmentally friendly, they are cheap [6] and they allow reduction of electrical consumption by air conditioning. In developing countries, there is a large availability of tropical plants and agricultural wastes and the use of cheap vegetable fibres in replacement of expensive synthetic fibres is a good alternative. Since 1973, due to health reasons, various regulations are applied to restrict and ban the use of asbestos in France and other developed countries [5].

In our research group, bagasse fibre reinforced cement composites have been studied for more than 10 years [4, 5], the fibres having a random distribution in the composites. They have been prepared for being used in construction area in tropical regions such as Guadeloupe (French West Indies). Bagasse is the solid lignocellulosic residue left after extraction of juice from the sugar cane stalk and is cheap compared to synthetic fibres.

A low thermal conductivity [10] and a low specific heat (in our country) are required to have a good thermal insulation of buildings. Many studies have shown that, regarding the mechanical behaviour, vegetable fibres are an interesting alternative to asbestos in fibre reinforced cement products manufactured by the Hatcheck process [2, 8, 9]. But few works have demonstrated the low thermal conductivity of such vegetable fibre/Portland cement based composite materials resulting from effect of the mixture fibre/matrix [1, 8] but, to our knowledge, there is no published result concerning specific heat of bagasse reinforced cement composites.

These composites are well known for durability problem that hinders their development [1]; indeed, the lignin in natural fibres is attacked by alkaline cement, hence degradation in composites strength [11]. Use of pozzolans for reduction of matrix alkalinity [7], immersion

of fibres in slurred silica fume [1] or carbonation of the matrix represent ways to solve this problem and have been investigated. In this paper, in order to improve the strength of bagasse fibres and also try to limit the reaction between fibres and matrix, thermal treatment [3] and chemical treatment have been applied to the fibres before incorporating them into the cement matrix.

2. Materials and methods.

2.1. Materials

Bagasse fibres used in this study have been obtained from Montebello sugar cane factory (Petit-Bourg, Guadeloupe). This waste has been cut and fibres with diameters ranging from 0.4 to 1 mm have been selected and thermally or chemically treated, they are named “BAG”. Two fibres treatments have been performed at COVACHIMM laboratory (Université des Antilles et de la Guyane, Guadeloupe):

- ✚ Heat-treatment: pyrolysis under controlled atmosphere (N_2 flow, 2L/h) during 2 hours at $200^\circ C$ which is the best compromise between mass loss and degradation of sugars [12]. The pyrolyzed fibres are named “BAGP”.
- ✚ Chemical treatment: attack by a 5% by mass alkaline solution of $Ca(OH)_2$. The alkali treated fibres are named “BAGB”.

The cement used was a Portland cement marketed as ASTM 1.

Matrix is made of cement, sand, water, $CaCO_3$, bentonite, silica fume, acrylic styrene polymer and cellulose pulp.

2.2. Composites preparation

Composites have been elaborated in GMC laboratory (Universidad del Valle, Colombia).

The process used is inspired from Hatcheck process and is well established in Universidad del Valle [7].

The composites will be noted “CBAGP” and “CBAGB” for composites reinforced with retified bagasse fibres and composites reinforced with alkaline bagasse fibres, respectively.

The content of sand and calcium carbonate were kept constant at 50% and 30% by weight of cement respectively. 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 content of sand and calcium carbonate was kept constant at 50% and 30% by weight of cement respectively. The amount of fibres was varied from 0 to 3 % wrtc. Slurry of each mix contains a water/cement ratio of 0.9 (weight by weight) being prepared before the 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 mm³) 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.

Five mixes were elaborated: 2 samples for the 2 types of fibres for each fibre contents and 1 as control (reference without any fibre). Proportions of mixes are shown in Table 1.

2.3. Thermal conductivity measurements

Thermal tests were carried out under controlled laboratory conditions (temperature = 298 ± 1 K and 70–80% relative humidity) on 365 days old specimen in COVACHIMM group (Université des Antilles et de la Guyane). The apparatus used was a thermal conductimeter “CT–mètre” with a thermal probe commercialized by Controlab (Saint–Ouen, France). At least six measurements per composite were conducted with one hour interval between each measurement in order to evaluate the standard deviation of the results.

2.4. Isothermal calorimetry measurements

Isothermal calorimetry has been carried out on a C80 calorimeter (Setaram, France) at Université des Antilles et de la Guyane. Calorimetry is a very strong investigation method and is usually used to determine specific heat of cement composites under air atmosphere [13].

All measurements were carried out at least two times, as usually proposed in previous work. The apparatus consists of 4 parts: the calorimeter where the signal comes from, the power module which provides steady power supply, the controller which serves as an interface transforming the voltage signal into digital signal, the computer which records and processes the signal [14].

The C80 calorimeter is the core part of the whole system. The Setaram C80 differential heat-flux apparatus is based on the Calvet principle. Two identical wells for inserting the removable confinement cylinders with cells are located in a heated calorimetric block fixed inside a cylinder surrounded by insulating material. The heat evolved or absorbed during the process is transferred between the cell and the calorimetric block through the thermopiles surrounding the wells.

Thermopiles consist of thermocouples connecting the outer surface of the well wall with the block. Due to fast transport of the heat through the thermocouples the difference of

temperature between the cells and the block is negligible.

The two thermopiles are connected differentially and the resulting signal is proportional to the difference in the heat exchange between the cells and the block. In C80 system the signal will enter the controller at first, the special program in the computer will process the signal, the computer displays results in the form of a temperature line and a heat flux line which represents the heat flux difference between the two wells.

The C80 calorimeter is a very precise instrument for the enthalpy measurement. It has a resolution of 0.001°C for temperature and a resolution of 0.001 mW for heat flux.

Specific heat (J/g.K) is defined as the amount of heat required to raise the temperature of the unit mass (1 g) of a substance by a unit temperature increase (1 K). The specific heat capacity C_p at constant pressure and the specific heat capacity C_v at constant volume for solids at room temperature are equal to within < 1%.

This parameter is related to thermal conductivity λ , thermal diffusivity κ and macroscopic density ρ by the equation:

$$= \frac{\lambda}{\rho \kappa} \quad \text{Eq. 1}$$

All measurements were carried out at least two times, as usually proposed in previous work.

2.5. Macroscopic density measurements

Composites porosity has been measured using helium gas intrusion under helium gas flow with a “Pycnomatic” Thermo Electron Corporation equipment (France) pycnometer. Five measurements were conducted for each composite at 298 K, relative humidity of 70–80%.

2.6. Mercury intrusion porosimetry measurements

Porosity of the composites has been studied by mercury intrusion porosimetry from 0.1 to 200 MPa with mercury porosimeters Thermofinnigan (France) Pascal 140 and Pascal 240. This range of pressure corresponds to pore radius from 58 μm to 37 \AA .

At least, two measurements were carried out.

3. Results and discussion.

3.1 Fibres and matrix characterization

Bagasse is a natural lignocellulosic fibre, that is to say that each unit of bagasse fibre is composed of crystalline cellulose surrounded and cemented together with hemicellulose and lignin [15]. The sugar cane bagasse chemical composition has already been characterized [4], it is summarized in Table 2.

Pyrolysis does not affect general composition of fibres (weak variation of hemicellulose, cellulose and lignin amounts) except for extractives amounts. The alkaline pre-treatment decreases mainly lignin, extractive and hemicellulose amounts.

Surface of raw and treated fibres has been observed by SEM.

Mild pyrolysis is known to mainly affect hemicellulose (in less proportions, lignin) and creates a new “pseudo-lignin” more hydrophobic and rigid than the initial one [16]. Figure 1 shows the dissolution of hemicellulose and delignification process generated by pyrolysis and alkaline attack [3].

The surface of pyrolyzed fibres is less damaged than BAGB one, as confirmed by chemical composition showing large weight loss of hemicellulose (around 37 wt% for BAGB) and

lignin (around 11 wt%), according to raw bagasse. $\text{Ca}(\text{OH})_2$ reacts with hydroxyl groups of hemicellulose (cementing material) and it contributes to the destruction of the structure and thereby the fibres split into filaments. This fibrillation increases surface area and then increases the contact and adhesion with matrix.

Physico-chemical properties of cement, presented in Tables 3 and 4, have also been determined according to technical Colombian norms (NTC).

93.5% by weight of the limestone filler is CaCO_3 . The particle size distribution of the powdered Portland cement and the limestone filler are shown in Figure 2.

50% by weight of limestone powder used has a particle size below 2 micrometers and the Portland cement average particle size is 15 micrometers.

The characteristics of sand are given in Table 5. As we can see, the Portland cement has factory additions that are calcareous materials and the sand seems appropriated for use in cement-based materials. The size distribution was determined using a Malvern laser diffraction analyser.

3.2 Thermal conductivity (λ)

Figure 3 reports evolution of 365 days old composites thermal conductivity according to fibre content and fibre treatment.

In our experiment, thermal conductivity of matrix (without fibre) is about 0.6188 W/m.K.

According to Xu and al. [10], thermal conductivity of cement paste (Portland type I + water) is 0.53 W/m.K and thermal conductivity of mortar (cement + sand + water) is 0.58 W/m.K.

Here, we can see the effect of all the additives (cellulose pulp, bentonite, silica fume and

polymer) in our matrix. They contribute to the 6% of increase of thermal conductivity compared to mortar prepared by Xu et al. [17]. Comparison of the results on matrix without fibre and those on matrix with fibres shows that generally, fibres addition decreases the thermal conductivity; a quadratic polynomial decrease is correlated for BAGP and BAGB composites. The best effect is observed when adding 3% wrtc of fibres. This result is already known in the literature [18, 19]: by increasing fibre content, there is a progressive decrease of thermal conductivity. The thermal conductivity of composites decreases from 0.62 W/m.K for CBAGB1.5 to 0.46 W/m.K for CBAGP3. This indicates a promising potential for development, indeed Asasutjarit and al. reported that thermal conductivity of cellulose commercial board is 0.68 W/m K [18].

The effect of fibres treatment on thermal conductivity is stronger for retified bagasse fibres than for alkaline bagasse fibres maybe because of the difference observed between the chemical composition of BAGP and BAGB showing for basic bagasse fibres higher amount of cellulose and lower extractives one for pyrolyzed bagasse fibres.

The most insulating composite is observed with 3% wrtc of bagasse fibres because the resulting thermal conductivity is 25% lower than matrix one. For 3% wrtc addition of bagasse fibres, fibre treatment does not seem to have any influence on thermal conductivity: the observed thermal conductivities of CBAGP3 and CBAGB3 are quite equal according to standard deviation.

3.3. Specific heat (Cp)

Figure 4 presents evolution of specific heat according to fibre content and fibre treatment. Specific heat of matrix without any additive is 0.2673 J/g.K. According to others [10], specific heat of cement paste is 0.736 J/g.K and that of mortar is 0.642 J/g.K. We can see that

the effect of additives (particularly silica fume [10]) in matrix is very important because our specific heat is by 41% lower than mortar one.

When fibre content increases, there is a progressive quadratic polynomial decrease of specific heat for both types of fibres. The lowest value is obtained for CBAGP3. Usually, literature reports that with increasing synthetic fibre content, there is an increase of specific heat [20]. There is no published result concerning vegetable fibres reinforced cement composites in order to compare our results. We thought that with increasing fibre content, we would observe an increase in specific heat according to a classical rule of mixture extrapolating from wood and concrete data. This unexpected result can be explained by presence of porosity due to alveolar of fibres and also by lack of fibre/matrix adhesion. Figure 5 presents SEM pictures of CBAGB and CBAGP with fibre content of 3% wrtc. We can see that there are some fragments of CaCO_3 packed onto fibre surface. This packing is thought to be responsible of a smaller contact zone between fibre and matrix and, as a consequence, loss of specific heat.

3.4. True density and porosity

Table 6 reports main results of macroscopic density and porosity measurements of bagasse composites.

Even if the morphologies of pyrolyzed and chemically treated bagasse fibres are different, true density of CBAGP and CBAGB are similar according to standard deviation.

The thermal conductivity is inversely proportional to the voids in the composites. The packing of fibres into matrix generates the voids. This is why, as shown by Table 6, the more the fibre content (3% wrtc), the lower the density. These results confirm the data in the literature: heat-insulating properties of composites is opposite to its density [21] that is to say that heat-

insulating properties are enhanced when density decreases. We notice that the density values of composites reinforced with 1.5% wrtc of fibers are slightly higher than that presented by the reference and that the composites reinforced with 3% wrtc of fibers are only 3-10 % higher than reference density value. This behaviour may be related to the nature of density measured (true density). Indeed, we suppose that the matrix density is lower than the fibers one. It may exist non-connected pores or pores that are not reachable by helium gas.

The porosity of the matrix (control specimen) is decreased with the addition of fibres. In the range of our study, whatever the fibre content, the porosity values are of the same order.

As shown in Figure 6, thermal conductivity and specific heat are related to true density by a quadratic polynomial equation. An optimal true density, that is to say an optimal amount of fibres for heat-insulation, corresponding to a minimal thermal conductivity and a minimal specific heat, exists. For CBAGP, this optimal density is around 2.56 g.cm^{-3} and for CBAGB 2.58 g.cm^{-3} .

The trend of our results is coherent with those of commercial insulating materials that associate low thermal conductivity and low specific heat. For example, commercial cellulose pads show $C_p = 1.9 \text{ kJ/kg.K}$ and $\lambda = 0.04 \text{ W/m.K}$ or polystyrene exhibits $C_p = 1.2 \text{ kJ/kg.K}$ and $\lambda = 0.032 \text{ to } 0.038 \text{ W/m.K}$.

4. Estimation of thermal properties of bagasse fibres.

4.1. Thermal conductivity

According to Wang and al. [22], thermal conductivity of cement/fibre composite can be determined using the Maxwell-Eucken equation:

$$K = \frac{k_m v_m + k_f v_f \frac{3k_m}{2k_m + k_f}}{v_m + v_f \frac{3k_m}{2k_m + k_f}} \quad \text{Eq.2}$$

where K is the effective thermal conductivity of the composite,

k_m and v_m are respectively the thermal conductivity and volume fraction of the continuous phase i.e. the matrix,

k_f and v_f are respectively the thermal conductivity and volume fraction of the dispersed phase i.e. the fibres.

We assume that $v_m + v_f = 1$.

This expression can be formulated as:

$$\frac{K - k_m}{k_m} = \frac{3(k_f - k_m)v_f}{(k_m - k_f)v_f + 2k_m + k_f} \quad \text{Eq.3}$$

If we suppose v_f very small, we can write:

$$\frac{K - k_m}{k_m} \cong \frac{3(k_f - k_m)}{2k_m + k_f} v_f \left[1 - \frac{(k_m - k_f)}{2k_m + k_f} v_f \right] \quad \text{Eq.4}$$

First, we will neglect the right term, in order to find an expression of $\frac{K - k_m}{k_m}$ according to v_f .

If %f is the weight percentage,

$$v_f = 1 - \frac{\rho}{\rho_m} \left(1 - \frac{\%f}{100} \right) \text{ Eq. 5}$$

where ρ is the composite bulk density and ρ_m matrix bulk density. These values are obtained via mercury porosity measurements.

Modelling results.

If $A = \frac{3(k_f - k_m)}{2k_m + k_f}$, it follows $k_f = k_m \frac{3+2A}{3-A}$ (A is the coefficient director of the curves).

The main results, with a good correlation ($R = 0.99$) are in Table 7.

We notice that our v_f values are quite high, v_f is considerable regards to 1. Indeed, true density of light wood, as balsa, is approximately 0.1 g.cm^{-3} (density of balsa ranges from 0.04 to 0.38 g.cm^{-3} [23]). Considering this theoretical value, we would find corrected v_f values around 0.06 and 0.12 (6% and 12%, respectively). This suggests two hypotheses, either density of vegetable fibre is lower than the density 0.1 g.cm^{-3} of light wood or either the model is not fully adapted to study this composite material.

As there is no information about thermal conductivity of vegetable fibre, the Maxwell-Eucken equation allows determination of the thermal conductivity of pyrolyzed and alkali-treated bagasse fibres with a good correlation.

k_f , thermal conductivity of fibres, is calculated without any approximation and by using our experimental values.

Figure 7 presents the trend of the calculated curve for BAGP composites. The linear trend of the curve shows that the model is convenient for BAGP composites.

We can check that the term $B = \left(\frac{k_m - k_f}{2k_m + k_f} \right) v_f$ is negligible regards to 1.

For retified bagasse fibres $B_{\max} = 0.08$! (that is to say a precision of 8.5% on A_{vf}) and for alkaline bagasse fibres, $B_{\max} = 0.05$! (precision of 5.7% on A_{vf}).

4.2. Perspectives of application of these materials

The thermal diffusivity of the composites is an important parameter in order to estimate their potential use in housing and building [24].

Thermal diffusivity κ of a material can be obtained by the use of the following calculation:

$$\kappa = \frac{\lambda}{\rho C_p} \quad \text{Eq.6}$$

where λ is thermal conductivity (W/m.K)

ρ is density (kg/cm³)

C_p is specific heat (J/ kg.K)

Calculated thermal diffusivity for BAGP and BAGB composites are shown in Table 8.

Thermal diffusivity measures the rapidity of heat propagation through a material.

Addition of fibres increases thermal diffusivity of composites. The effect is higher for retified bagasse fibres. When increasing fibre content, there is a decrease of this parameter.

According to these results, we can say that the optimal fibre content is around 1.5 wrtc % because this composition allows the highest thermal diffusivities.

Assuming that our composite is a semi-infinite material [25], initially isotherm at T_0 and we choose to impose a temperature T_e at the moment $t = 0$ on the surface at $x = 0$.

According to $u = \frac{x}{2\sqrt{\kappa t}}$ Eq.7 and $T^+ = \text{erf}(u)$ if $T^+ = \frac{T - T_e}{T_0 - T_e}$ Eq.8

Where x is the material thickness measured from the surface; the thickness is supposed to be infinite,

t is the time,

T is the temperature corresponding to the material thickness,

erf is Gaussian error function.

This approximate model supposes that the real thickness L verifies $L^2 \gg \kappa t$.

When adding fibres, there is an increase of thermal diffusivity that is to say that for the same material thickness, the same temperature T is reached while diminishing time t . It would mean that when adding fibres, there is no storage of heat or that heat is dissipated more quickly.

Decrease of λ while κ increases means that, according to Eq. 6, ρC_p is clearly decreased when adding fibres into matrix.

We suppose that this behaviour could be explained by the raising of porosity due to the incorporation of fibres.

If we consider a sample composite with a total volume V as $V = V_1 + V_2 + V_3$ Eq. 9

with V_1 : volume of completely compacted matrix

ρ_1 : matrix density

Cp_1 : specific heat of matrix

V_2 : volume of completely compacted fibres

ρ_2 : fibres density

Cp_2 : specific heat of fibres

V_3 : pores volume

ρ_3 : density of air included into pores

Cp_3 : specific heat of air included into pores

We assume that ρ and Cp are respectively composite density and specific heat.

We can write that composite specific heat $V\rho Cp$ is the sum of specific heat of each component :

$$V\rho Cp = V_1\rho_1Cp_1 + V_2\rho_2Cp_2 + V_3\rho_3Cp_3 \quad \text{Eq.10}$$

$$\text{so } \rho Cp = \frac{V_1}{V}\rho_1Cp_1 + \frac{V_2}{V}\rho_2Cp_2 + \frac{V_3}{V}\rho_3Cp_3 \quad \text{Eq. 11}$$

$$\text{We pose: } \frac{V_2}{V} = v_f \quad \text{volume fraction of fibres}$$

$$\frac{V_3}{V} = \varepsilon \quad \text{composite total porosity}$$

$$\text{It comes: } \rho Cp = (1 - v_f - \varepsilon)\rho_1Cp_1 + v_f\rho_2Cp_2 + \varepsilon\rho_3Cp_3 \quad \text{Eq. 12}$$

$$\text{And finally } \rho Cp = \rho_1Cp_1 - v_f(\rho_1Cp_1 - \rho_2Cp_2) - \varepsilon(\rho_1Cp_1 - \rho_3Cp_3) \quad \text{Eq. 13}$$

The term $\varepsilon(\rho_1Cp_1 - \rho_3Cp_3)$ comprises the increase of porosity with adding fibres and consequently explains the effect on diffusivity κ .

It is difficult to estimate this term because it may exist different porosities :

- Fibres internal porosity,
- Matrix porosity (excluding fibres presence)
- Matrix preexisting porosity (before adding fibres).

5. Conclusion.

Thermal conductivity of vegetable fibres/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 bagasse fibres and fibres treatment. Composites elaborated with retified bagasse fibres are weaker heat conductor materials than those

elaborated with alkaline bagasse fibres. Therefore, CBAGP could be preferred to CBAGB and used to prevent heat transfer into building and consequently to save energy. Regarding the specific heat, the best results are obtained with CBAGB but both types of composites show weaker specific heat than matrix alone. As a result, it is possible to construct a quite good insulating wall for housing using retified or alkaline bagasse fibres (approximately 1.5 % wrtc).

The thermal behaviour of these cement composites reinforced by bagasse fibres show a quite good correlation with Maxwell-Eucken modelling if we assume that the density of bagasse fibres is lower than light wood (balsa) one.

This study has to be supplemented by additional experiments on specimen containing higher fibre content and special attention should be accorded to fibre/matrix interface. This problem could be solved by the addition of silica fume, for example. Indeed, silica fume is well known in the literature to decrease the thermal conductivity.

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Figures caption.

Figure 1: SEM pictures of (a) raw bagasse fibres, (b) retified bagasse fibres and (c) alkali-treated bagasse fibres.

Figure 2: Particle size distribution of the limestone filler and the Portland cement.

Figure 3: Evolution of thermal conductivity according to fibre content and fibre treatment.

Figure 4: Evolution of specific heat according to fibre content and fibre treatment.

Figure 5: SEM pictures of CBAGP (a) and CBAGB (b) with fibre content of 3% wrtc.

Figure 6: Relation between thermal conductivities, specific heat and true densities of composites.

Figure 7: Thermal modelling of BAGP composites.

Figures.

Figure 1:

(a) (b) (c)



Figure 2

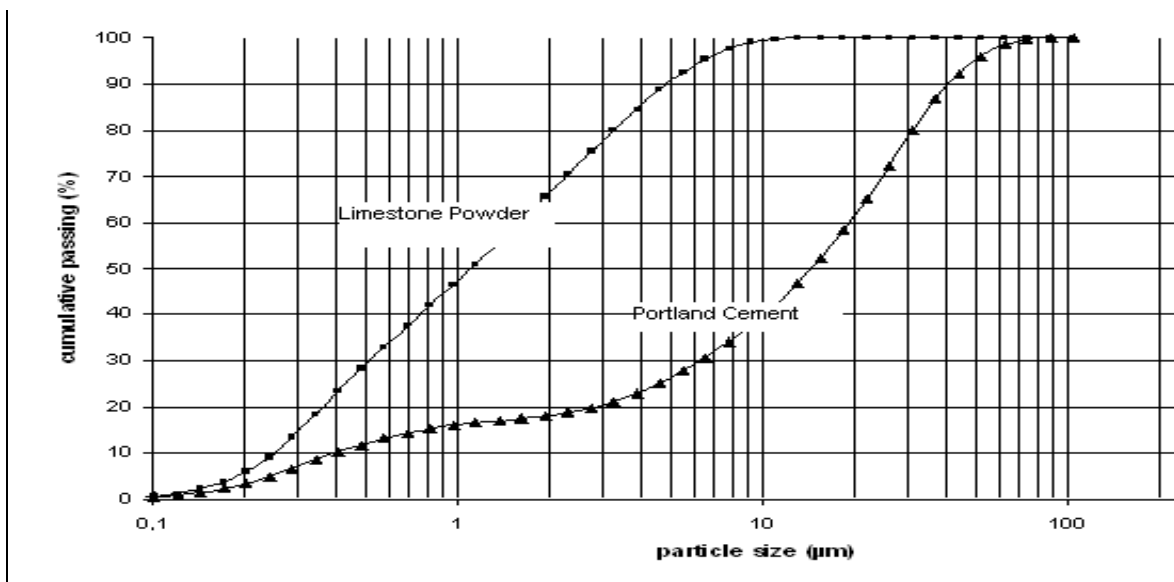


Figure 3.

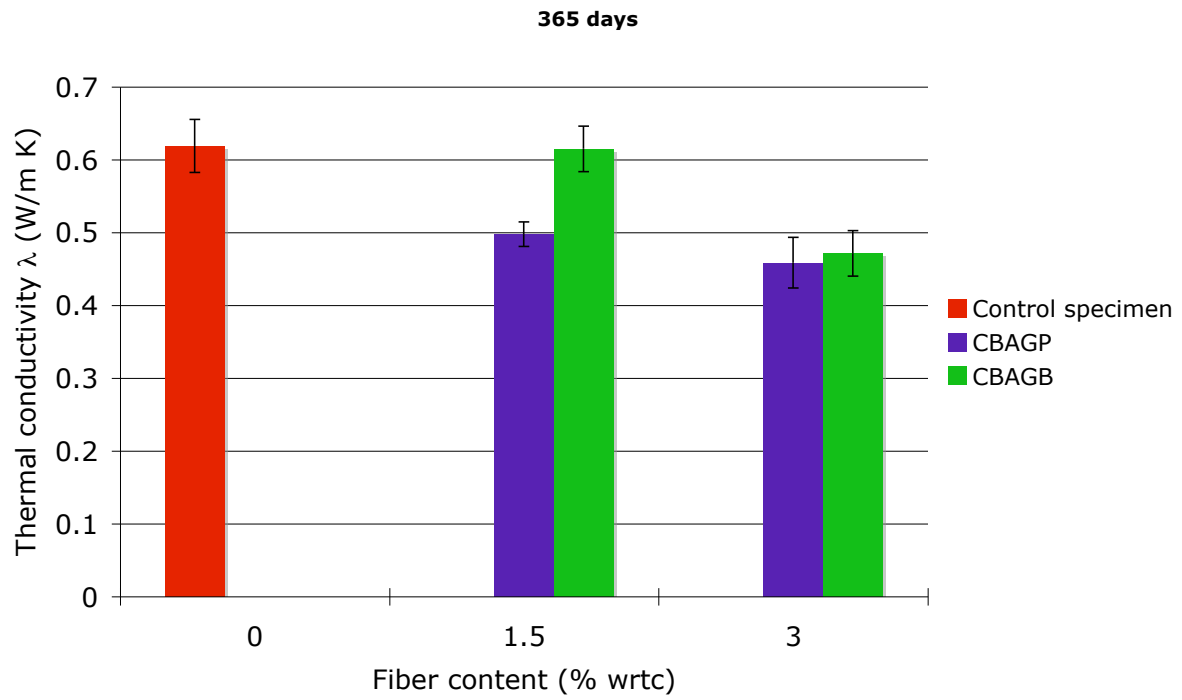


Figure 4.

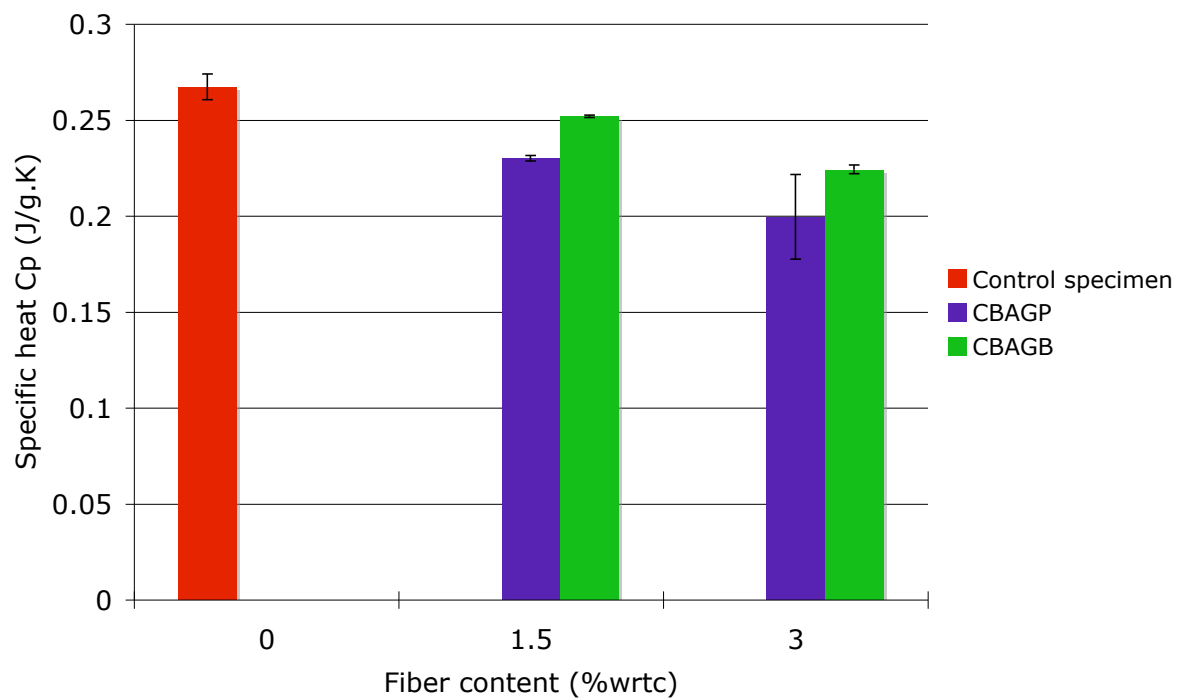


Figure 5.

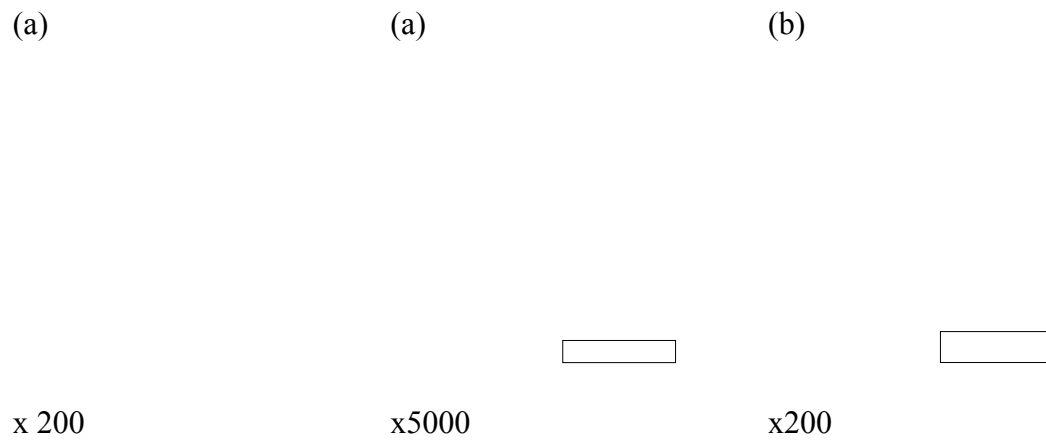


Figure 6.

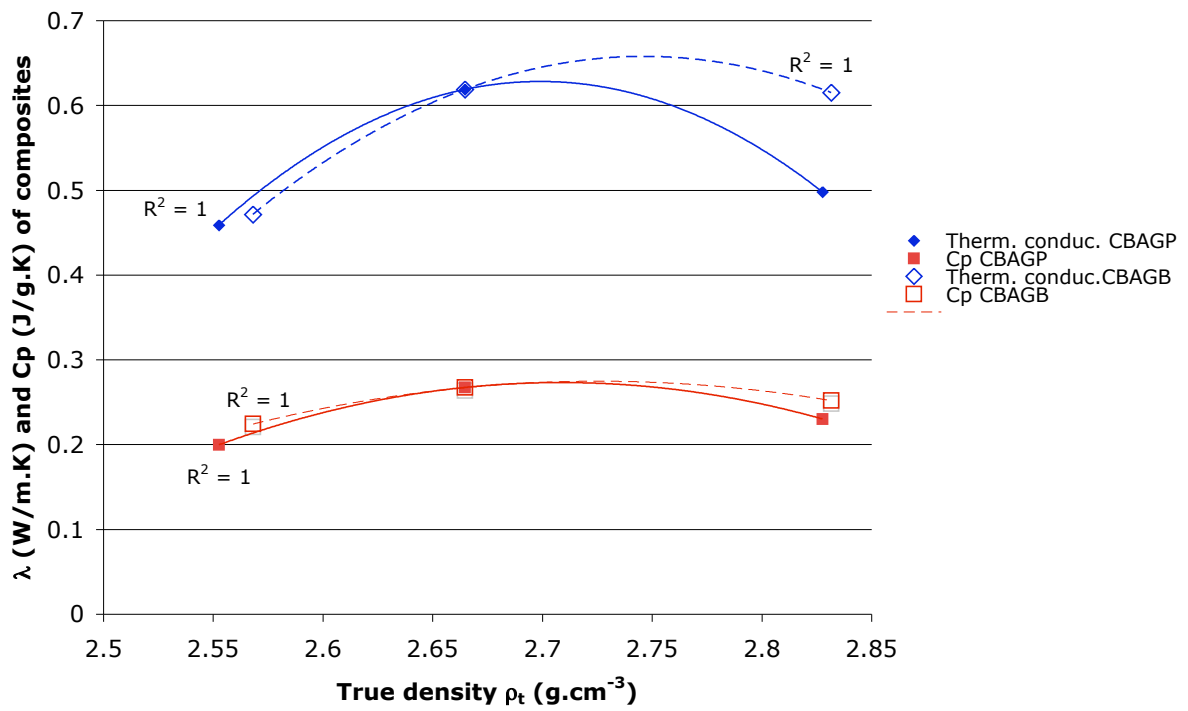
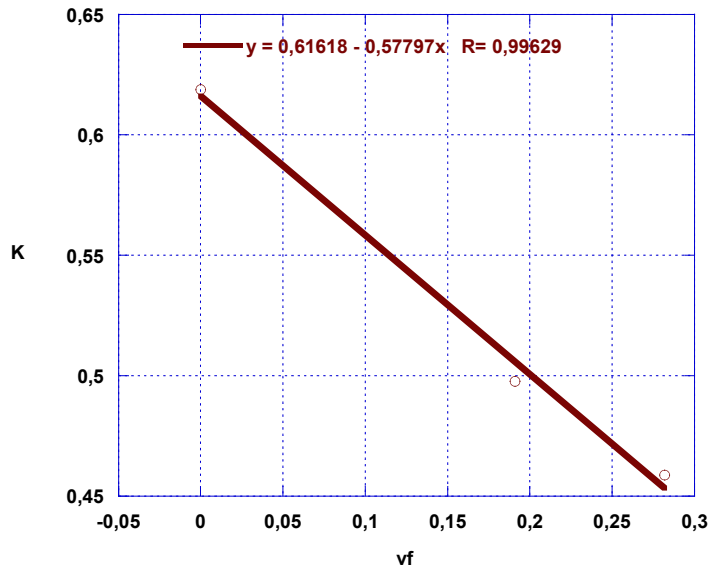


Figure 7.



Tables.

Table 1- Proportions of composites mixes.

Composites	Fibre and treatment	Fibres %wrtc	Bentonite %wrtc	Polymer %wrtc	Silica fume %wrtc	Paper pulp %wrtc
Control		0	3	7.5	5	4
CBABP1.5	BAGP	1.5	3	7.5	5	4
CBAGP3	BAGP	3	3	7.5	5	4
CBAGB1.5	BAGB	1.5	3	7.5	5	4
CBAGB3	BAGB	3	3	7.5	5	4

Table 2- Botanical analysis of studied fibres.

Fibres	Humidity (weight %)	Extractives (weight %)	Cellulose (weight %)	Hemicellulose (weight %)	Lignin (weight %)	Sum (weight %) except humidity
BAGRaw	7.50	3.92	48.68	25.46	21.94	100
BAGP	12.21	1.88	49.38	25.62	23.12	100
BAGB	5.17	2.75	59.02	18.46	19.76	100

Table 3- Physical properties of Portland cement.

Blaine m ² /g	Size greater than 45 µm %	Normal Consistency %	Initial Setting min	Final Setting min	Compressive Strength (MPa)				Density kg.m ⁻³
					1 day	3 days	7 days	28 days	
423	3.08	27.70	159	312	7.30	19.80	nd	nd	3030

nd: non determined

Table 4- Chemical composition of Portland cement.

CaO %	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	SO ₃ %	MgO %	K ₂ O %	Na ₂ O %	C2S %	C3S %	L.O.I. %	I.R. %	Cal %
57.81	22.05	4.23	4.23	1.98	1.52	0.18	0.17	42.34	27.67	7.96	5.94	0.55

% are expressed according to total weight cement; L.O.I. Loss On Ignition; I.R. Insoluble Residue

Table 5- Sand characteristics.

Characteristic	Results
Apparent density (kg.m ⁻³)	2605
Water absorption (wt %)	2.54
Organic matter (Gardner scale)	2
Ignition loss (%)	2.32
Humidity (%)	0.86
Granulometry (cumulative passing, %)	

ASTM N° 4 (opening: 4,760 mm)	94.23
ASTM N° 8 (opening: 2,380 mm)	88.11
ASTM N° 16 (opening: 1,190 mm)	65.52
ASTM N° 30 (opening: 0,595 mm)	37.59
ASTM N° 50 (opening: 0,297 mm)	12.00
ASTM N° 100 (opening: 0,149 mm)	2.05

Table 6: True density and porosity of cement composites reinforced with bagasse fibres.

Method	Sample	Control	CBAGP		CBAGB	
			% wrtc fibre	0	1.5	3
He	True density ρ_t (g.cm ⁻³)	2.6648 [±0.0108]	2.8277 [±0.0223]	2.5526 [±0.0091]	2.8316 [±0.0045]	2.5681 [±0.0186]
	Bulk density ρ_a (g.cm ⁻³)	2.49923	1.6155	1.4561	1.5744	1.6024
Hg	Apparent density (g.cm ⁻³)	3.7246	2.8771	2.6108	3.0707	3.0751
	Porosity (%)	64.98	43.85	44.23	48.73	47.89

Table 7: Thermal conductivity modelling results.

	Retified bagasse fibres		Alkaline bagasse fibres	
	1.5	3	1.5	3
V_f	0.1909	0.2818	0.2115	0.2096
$\rho_{composit}$ (g/cm ³)	1.6155	1.4561	1.5744	1.6024
k_f (W/m.K)	0.1781		0.1092	

Table 8: Composites thermal diffusivities.

Composites	Control	CBAGP1.5	CBAGP3	CBAGB1.5	CBAGB3
$\kappa \cdot 10^6$ (m ² s ⁻¹)	1.1771	1.5856	1.4228	1.5504	1.3114