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BAMBOO PANELS TO CONTROL MOISTURE LEVEL OF BUILDINGS

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Abstract
The traditional use of bamboo throughout South East Asia is very diverse: fences, scaffolding, kitchen equipment, furniture, mats, blinds, toothpicks, paper pulp… Some applications use bamboo cane as such, however the current tendency is also towards an unstructured use of bamboo in the form of fibers or chips or even ashes. From strips, a wide variety of boards and plywood are made. Panels from bamboo fibers compressed in the presence of an organic resin are also in development for earthquake-resistant structures of the building market. But in most cases, the bamboo is used for its structural properties, of bamboo cane itself or of particles or fibers from bamboo. Some works only focus on moisture absorption but they mainly concern the bamboo charcoal. Works on thermal insulation bamboo fibers are still rarer. This study focuses on the development and characterization of particle boards which will have the specificity to participate both in thermal insulation and control of humidity inside the building. The advantage is to obtain materials with low environmental impact and to reduce energy consumption due to the reduction of the moisture content. First of all, the conditions for producing fiberboards are studied to obtain panels without glue or using environmentally friendly adhesives. These panels are then characterized according to the criteria required for panels used in buildings (bending, swelling). Finally, their ability to absorb and desorb moisture and their thermal conductivity are investigated.

Keywords:
Bamboo; Particle boards; Hygrometry; Building

1 INTRODUCTION

Particle and fiberboards based on wood and formaldehyde adhesives has been studied long time ago [M.Guru 2006, Biswas 2011, Guru 2008]. However, formaldehyde resins release toxic chemical products from the boards into environment. It is dangerous for human health (nose congestion, headache, as well as an increased risk of cancer) [Meyer 1985]. Nowadays, there are a lot of studies about fiber or particleboards based on environmental friendly adhesives in order to reduce or eliminate formaldehyde emission into the environment [Ciannamea 2010, Kymalainen 2008]. The natural fibers based boards are becoming more and more popular due to their low density, cell structure, low thermal conductivity and also because they are issued from renewable materials. Therefore, they can be used as insulation materials for building with low impact on environment. Current researches about these boards deal with different natural sources as for example rice straws fibers [Zhang 2014], corn cobs [Faustino 2012, Pinto 2011] or hemp fibers [Zach 2013, Kymalainen 2008]. All these researches tend to improve the materials properties such as: mechanical strength, thermal conductivity or moisture absorption, as well as to develop the use of post-products from agriculture.

Furthermore, a lot of environmental friendly glues, considered as biological agents that could replace formaldehyde adhesives, are tested to elaborate the boards: modified soybean oil and proteins [Zhang Y.H. 2014, Ciannamea 2010, Khosravi 2010, Khosravi 2011], palm oil [Hashim 2010, Jumhuri 2014], sunflower oil [Evona 2014], lignin [Hamidrez 2014, Huijgena 2014, Laurichesse 2014]. A few studies focus on boards without glue [Halvarsson 2009]. Nevertheless, the main disadvantages of these panels are a weak adhesion and a low water resistance.

In this study, we manufacture and characterize panels based on bamboo powder, fiber and biological glues such as glues based on bone or nerve in order to create materials with low thermal conductivity and more especially able to regulate humidity level in buildings. Until now, only a few studies deal with the ability of these materials to regulate humidity and still less with bamboo fibers.

However, the moisture rate is a great factor linked to the buildings durability and their energy performance. High moisture levels favor the growth of micro-organisms on the walls and increase the energy consumption required to heat or cool the buildings. Moreover, indoor moisture content is closely linked to the air quality and to the health (cough, dry skin, allergies, breathing difficulties and eye irritation) [Rao 2012, Subramanyam 2004]. To regulate the humidity level, besides ventilation and heating, the most currently method is the air-conditioning, but this method uses electricity. Nowadays, the studies focus on passive regulation by using hygroscopic materials able to absorb and desorb moisture when needed. If they are correctly used, these materials can lead to energy saving due to the limitation of the use of air-conditioning systems

2 MATERIALS AND EXPERIMENTATION

2.1 Materials

Bamboo used in this study is Bambusastenostachya from Research Center Scientific for Conservation of Natural Resources, Phu An (Vietnam). Bamboo fibers are prepared by rolling method [Tran 2013] and cut into 15 cm length. Homogeneous powder bamboo is obtained by grinding with a coffee mill and sifting through a 1 mm diameter sieve. The components of bamboo are tested according to ASTM standards and listed in table 1.

Nerve and bone based glues are natural adhesives produced from nerves and bones of animals provided by Briançon, France. They are used for wood and other woodworking. They swell with moisture and shrink when dry. They follow the hygrometry of wood. Nerve glue provides a more flexible adhesion than bone glue.

Tab. 1: Components of bamboo

Component	Rate (%)	ASTM Standards
Cellulose	47.1	D 1103-60
Hemi-cellulose	16.1	D 1104-56
Lignin	20.2	D 1106-56
Ash	1.1	D1102-84

2.2 Panel samples processing

Samples of panels are manufactured from mixture of bamboo fiber and powder within or without glues. The weight ratio between fiber and powder is 1: 2 and that between (fiber + powder) and glue is 1:1. All bamboo panels are shaped in a mold with inner dimensions 150mm x 150mm x 6mm. Firstly, 10g of fibers are distributed with the same orientation in the mold. Subsequently, another layer of fiber (same as the first) is dropped perpendicularly to the first layer and so on. Between each layer of fiber, 20g of bamboo powder are randomly dispersed to fill the spaces between the fibers, and if necessary, the glue is also added on each powder layer. Then the sample is molded under different pressures and temperatures with a hydraulic press 916/A/E from AEM3. The process parameters (time, temperature and pressure) are listed in table 2. After shaped under pressure, the samples without glue are removed from the mold after cooling to room temperature, while the samples with glue stay in the mold during 24 hours before being removed.

2.3 Mechanical properties

Mechanical properties of the panels are determined by bending test using an equipment homebuilt at the University of Savoy. The specimens are cut into rectangles 25 mm wide and greater than 20 times the thickness long according to EN 310 standard. At least five pieces of each panel are measured to obtain the average value of elastic modulus and bending strength.

2.4 Swelling and water absorption

The swelling of panels is determined from the thickness change after immersion in water during 24 hours according to EN 317 standard. Before thickness measurement and swelling test, the samples are cut into squares of 50 ± 1 mm side and conditioned until saturation under a humidity level of 65 ± 5% and a temperature of 20 ± 2°C. After 24 hours of immersion at 20°C, the pieces are removed from water and their thickness is measured again. All the specimens are also weighed before and after immersion to test the water absorption property of panels. The swelling rate (S) of samples is calculated according to the formula:

$$S = [(e2 - e1)/e1] \times 100$$

e1 and e2 are respectively the sample thicknesses before and after swelling.

2.5 Density

The panels' density is determined according to EN 323 standard. The specimens are cut and conditioned with the same conditions as the samples for swelling and water absorption testing. At least five specimens of each component are tested. Density values are calculated with the formula:

$$\rho = W / (a \times b \times c)$$

a is the length, b the width, c the thickness and W the weight.

2.6 Thermal conductivity

Thermal conductivity of boards is measured at room temperature using the C-Therm (TCi Thermal Conductivity Analyzer) equipment supplied by Setaram. The C-ThermTCi is based on the Modified Transient Plane Source (MPTS) technique. It employs a one-sided, interfacial heat reflectance sensor that applies a momentary constant heat source to the sample. Thermal conductivity is measured directly. At least 5 specimens (squares of 50 ± 1mm side) are analyzed to obtain the thermal conductivity range.

2.7 Sorption/ desorption ability

This experiment is done in order to determine the ability of the bamboo panels to control humidity level in buildings. 5 pieces of panels (50 x 50 mm) are cut and conditioned at 57.6% RH and 30°C (57.6 % RH is around the common humidity level inside a house and 30°C is the temperature easiest to control near the room temperature in buildings). Saturated salt solutions are used to regulate the moisture rate in airtight boxes. Each salt leads to one humidity level (table 3).

Tab. 2: Components and manufacturing conditions of panels

Name of samples	Components				Press conditions		
	Bamboo powder (g)	Bamboo fiber (g)	Bone glue (g)	Nerve glue (g)	Temperature (^{0}C)	Pressure (bar)	Time (min)
B13030	60	30	0	0	190	130	30
B15010	60	30	0	0	190	150	10
B15030	60	30	0	0	190	150	30
B15060	60	30	0	0	190	150	60
BB15030	40	20	60	0	60	150	30
BN15030	40	20	0	60	60	150	30

Tab. 3: Salt used to regulate the humidity rate in the boxes.

Salt	KOH	$MgCl_2$	NaBr	NaCl	K_2SO_4
RH level %	9	32.8	57.6	75.3	97.3

After saturation at 57.6 % RH and weighing, the samples are distributed in the five airtight boxes: 1 sample in 1 box. They are regularly weighed during several days until a constant weigh is obtained (Constant mass is considered to be reached when the results of two successive weighing operations, carried out at an interval of 24 h, do not differ by more than 0,1 % of the mass of the test piece). When this state is obtained, the sample is changed to another humidity level.

3 RESULTS AND DISCUSSION

3.1 Thermal conductivity of panels

Thermal conductivity (k) range of each panel is showed in table 4. This range is relatively large but all the samples without glue have the same thermal conductivity range. Thus, the process conditions (pressure and temperature) don't appear to have a significant effect on the thermal conductivity of panels. The thermal conductivity range of panels with glues (0.047 to 0.069 $W.m^{-1}.K^{-1}$) is included in those of panels without glue (0.05 to 0.095 $W.m^{-1}.K^{-1}$) but it is narrower and located in the lowest part of the range. The conductivity range of our panels is close to that found in other studies for natural fiberboards (table 4). In the literature, some authors [Zhou 2010, Suleiman 1999] show a linear relationship between thermal conductivity and density for wood panels. They explain that by the fact that the decrease of the density is due to a porosity increase. The air thermal conductivity at 20°C being 0.024 $W.m^{-1}.K^{-1}$, small porosities contribute to the low thermal conductivity. But the influence of the density on the thermal conductivity is not so clear. Indeed, other authors show that the conductivity decreases when the panel's density increases or that the variations are random [Ashrae 2013, Wahlgren 2002, Langlais 1990]. Densities of our panels are included in the table 4.

The density range of panels with glue is higher than for samples without glue although density of glue (< 1) is less than that of bamboo fibers (≈ 1.5). This would suggest that the porosity amount is very great in the panels without glue, especially as in the literature, high density is significant of small pores [Suleiman1999]. Although the conductivity range of panels is large, it can be seen that the thermal conductivity of the panels with glue is lower than that of the panel without glue and their density is greater. The thermal conductivity is a complex phenomenon which comprises several modes of heat transfer such as convection, radiation, etc. For the panel without glue, the porosity seeming to be very great and in a large quantity, it is difficult to know the comportment of the heat transfer (for example convection can appear in the large porosities and thus increase the thermal conductivity).

Tab. 4: Thermal conductivity of panels

Materials	Apparent density (kg/cm^3)	Thermal conductivity λ ($W.m^{-1}.K^{-1}$)	References
B13030	437 - 486	0.058–0.095	
B15010	413-507	0.058-0.093	
B15030	338-384	0.051-0.068	
B15060	341 - 405	0.050-0.078	
BB15030	621	0.047–0.065	
BN15030	535	0.065–0.069	
Binderless coconut husk board	250–350	0.046–0.068	[Panyakaew 2011]
Binderless bagasse board	250–350	0.049–0.055	[Panyakaew 2011]
Kenaf board	150–200	0.051–0.058	[Xu 2004]
Cotton stalk board	150–450	0.058–0.081	[Zhou 2010]
Expanded perlite boards (EPB)	90–490	0.045–0.070	[Pfundstein 2008]

3.2 Swelling and water absorption of panels

The percentage of swelling and water absorption are listed on table 5. Firstly, if we consider the panels without glue processed at 150 bars, it can be seen that the press time have a considerable effect on these panels' properties. The sample with the lowest press time shows the highest water absorption and swelling at 256 and 97% respectively. Considering all the samples, the panels without glue have the greatest swelling rate (from 65 to 97%) and water absorption (from 149 to 256%).The both panels using bone and nerve glues have a swelling rate of 47% and 57% and a water absorption of 82% and 98% respectively, which are substantially lower than those of the panels without glue. The high swelling and water absorption values of panels without glue can be linked to the high hydrophilic character of bamboo fibers and powder as well as to the weakest cohesion of these panels. The glues significantly improve the adhesive interface between fiber and powder of panels and prevent water from diffusing and absorbing inside panels which results in an increase water resistance [Zhang Y.H. 2014].The nerve glue seems to lead to panels with a lowest water resistance than bone glue.

Tab. 5: Swelling and water absorption of panels.

Names of sample	Swelling (%)	Water absorption (%)
B13030	66 ± 2	188 ± 12
B15010	97 ± 1	256 ± 17
B15030	58 ± 2	197 ± 7
B15060	65 ± 2	149 ± 6
BB15030	47 ± 1	84 ± 5
BN15030	57 ± 1	98 ± 5

3.3 Bending property

The elastic modulus and bending strength average values of panels are reported in Table 6 and figures 1 and 2. These results show that the press time has a great influence on the bending properties of panels. The sample pressed during 10 minutes under 150 bars has the lowest values of modulus and bending strength. When the press time is increased to 30 min (for the same pressure), the modulus and the strength are both greatly increased (from 199 to 5374 MPa and from 2 to 7MPa respectively) but no significant difference can be seen between the samples pressed during 30 and 60 min. The panel processed with 130 bars and 30 min have bending properties a little more higher than the panels pressed with 150 bars. In all the panels without added glue, adhesion between powder and fibers is performed by lignin available inside bamboo [Hamidreza 2014, Laurichesse 2014].

Depending on the process conditions, the lignin can flow throughout the panel and stick the fibers together. A press time of 10 min is not enough to allow the lignin to flow enough and to act as glue. Moreover, the 150 bars pressure seems to be too high and to lead to a degradation beginning of the lignin.

Bone and nerve glues used in this study seem to influence clearly the bending properties of the panels (table 6 and figures 1 and 2). But it is difficult to compare the measured modulus between the panels with and without glue due to the different rate and orientation of fibers. So, in order to try to eliminate these differences, the modulus has been normalized with the mass ratio of fibers and the quantity of fibers in the same orientation.

The samples without glue contain 3 layers of fibers: in the first and the third layers the fibers are in the length of the bending samples. The samples with glue contain 2 layers of fibers, so only 1 layer has fibers oriented in the length of the bending samples.

The normalization is done with the following equations and the results are in the table 6:

$E_n = E / M_F$ for samples without glue

$E_n = (E / M_F) * (66/50)$ for samples with glue

E_n is the measured modulus of samples

M_F is fiber weight ratio

66/50 refers to the ratio of the fiber layers oriented in the length for the two bending samples.

Tab. 6: Bending properties of panels

Names of samples	Elastic modulus (MPa)	Bending strength (MPa)	Normalized modulus (MPa)
B13030	6862 ± 1148	12 ± 2	20793
B15010	199 ± 27	2 ± 1	600
B15030	5374 ±1369	7 ± 2	16284
B15060	5282 ± 845	8 ± 1	16006
BB15030	1296 ± 623	27 ± 5	10062
BN15030	1374 ± 623	27 ± 8	10660

The measured modulus of the panels without glue are 4 times higher than for the samples with glue but it can be due to the higher fiber rate (the elastic modulus of the bamboo fiber is around 11000 MPa) [Janssen 1991]. If the normalized modulus are compared, the multiplying factor is reduced to 2 but the modulus of the panels without glue remain higher than those of samples with glue. This is due to the great rate and the low modulus of the glue.

In the literature, vegetable fiberboards have modulus between 1300 and 5000 Mpa whether for panels with "green" glue or for those without adhesive [Halvarsson 2009, Ciannamea 2010, Hidayat 2014, Quintana 2009, Mancera 2012]. And in the Japanese standard for particleboards [JIS A 5908 2003], they mention a bending elastic modulus between 2000 and 3000 MPa.The measured bending strengths are between 2 and 3 times higher for the panels with glue because of the improved adhesion due to the glue. In the Japanese standard for particleboard [JIS A 59082003], the bending strength required is between 8 and 17.5 Mpa depending on the kind of board. Nearly all our panels (with or without glue) have bending strength included in this range.

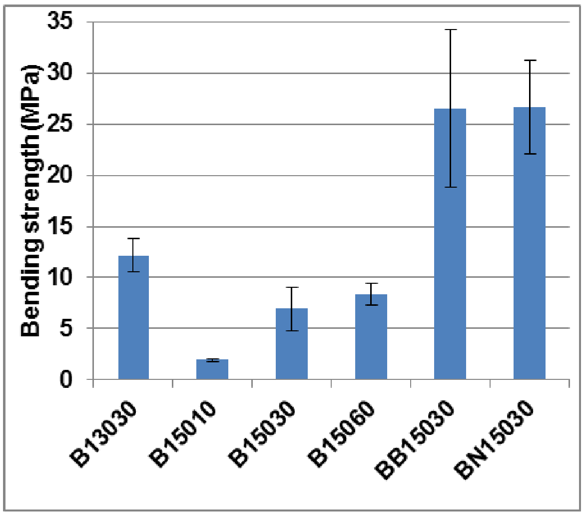

Fig. 1: Bending strength properties of panels

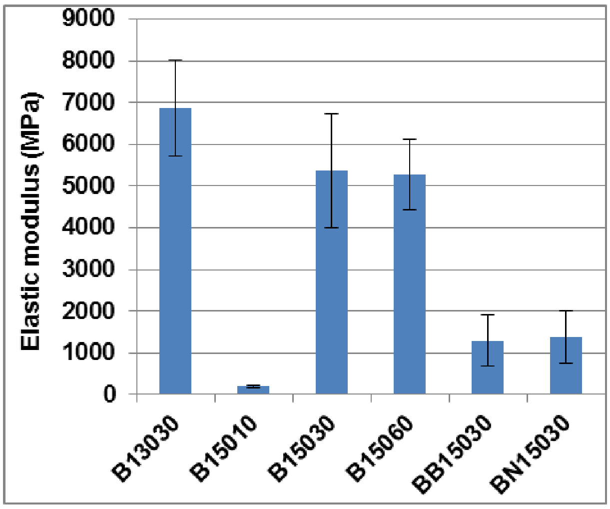

Fig. 2: Elastic modulus of panels

3.4 Vapor sorption/ desorption properties of panels

Water vapor sorption phenomenon occurs when water molecules attach to the material until saturation. Conversely, desorption is when the water saturated material reject vapor in the surrounding environment. Sorption and desorption of water vapor is measured and the sorption isotherm of the panel without glue B15030 is presented figure 3.The chosen reference is the sample conditioned at a humidity level of 57.6% RH until saturation. This curve can be used to determine the ability of the panel to participate to the moisture level regulation in the buildings.

An interesting phenomenon is observed: the ability of the panel to absorb and desorb moisture is not linear but nearly regular; the curve doesn't have a very flat zone for the low moisture rate and a really steep slope for the highest humidity levels, it increases relatively slowly and regularly. So it can be thought that this panel can easily be an actor of the moisture control in all the humidity range and not only for the highest levels. On the contrary, moisture levels highest than 90% must be avoided due to the risk of mold. Another interesting result is that the hysteresis between sorption and desorption seems to be small, so the panel can desorb nearly all the vapor which has been sorbed just before.

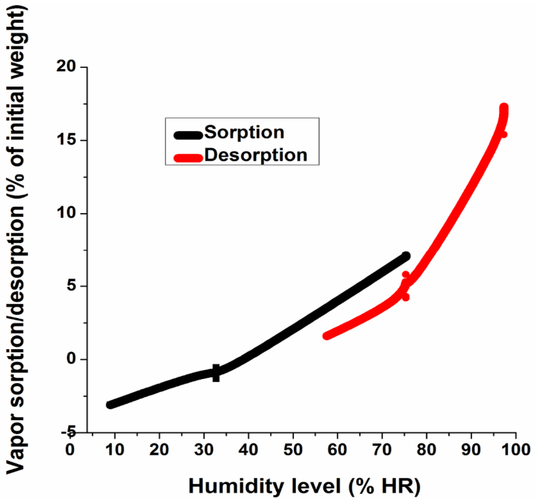

Fig.3: sorption isotherm of the panel without glue (B15030)

4 CONCLUSION

In this research, panels based on bambo fiber and powder and used to regulate humidity are successfully manufactured with or without adding glue. The press parameters influence the characteristics of the materials (bending, swelling…) and more especially the press time. However, the process conditions require further studies to determine more precisely the optimized parameters leading to the best panel and to improve the understanding of the effect of all these parameters on the panels' properties. But for now, the results are really encouraging. Indeed, at the end of this first study, the panels obtained have nearly the required properties in the standards for particleboards. The panels without glue have high bending modulus and those with glue have high bending strength but the swelling must be improved for the both. The main idea for these fiberboards being to participate to the humidity regulation in the building (they can be included in a wall), the first results obtained really suggest that they are able to act as buffer materials. This study will be continued to improve our knowledge on the interactions between all the parameters such as process, morphology, mechanical, thermal and hygrometric properties.

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