ICBBM EcoGRAFI

2nd International Conference on Bio-based Building Materials &
1st Conference on ECOlogical valorisation of GRAnular and FIbrous materials

June 21th - 23th 2017
Clermont-Ferrand, France

CONVENTIONAL AND MICROWAVE-ASSISTED THERMAL TREATMENT OF DENDROCALAMUS ASPER BAMBOO

Thaís Magalhães, Valdemir dos Santos, Christian Gauss*, Holmer Savastano Junior
Universidade de São Paulo, 13635-900 Pirassununga SP, Brazil.
* Corresponding author; e-mail: gausschr@usp.br

Abstract
The thermal treatment process of bamboo or wood can be used to improve the mechanical properties and enhance the dimensional stability. The aim of this work was to investigate the mechanical properties of the bamboo *Dendrocalamus asper* after thermal treatment using a microwave-assisted oven (MO) and a conventional furnace (CF), normally used for this purpose. In the present study, prismatic samples of bamboo were heat treated in the presence of air at the temperatures of 120, 140 and 160°C with heating rate of 1°C/min and isotherm of 10 min. The treatment conditions were evaluated through axial compression tests, density and mass change. The bamboo in the as-received condition showed a mean moisture content of 92.65 %. The experimental results indicated that in average, 51 % more weight loss is observed using the MO than the CF process at the same temperature. However, the compression tests showed similar mechanical resistance after heat treatment in the MO and CF at 120 °C, with a modulus of elasticity MOE of 4.68 GPa and 4.73 GPa and compressive strength MOR of 77.41 MPa and 83.24 MPa respectively. These results suggest an increase of the stiffness and strength after the conducted heat treatments in comparison with the untreated bamboo, which showed a MOE of 3.40 GPa and a MOR of 73.67 MPa. The results of this study showed that the effects of the microwave interfered in the process of removal of compounds with low polarity, without compromising the structure of the material. The performed heat treatments provided materials with similar mechanical characteristics at different treatment temperatures.

Keywords: Natural resources; Bamboo; Dendrocalamus asper; Thermal treatment; Conventional oven; Microwave-assisted oven.

1 INTRODUCTION

The scarce quantity of good quality wood in the Brazilian and world market have directed the search for new opportunities, such as the reforestation with pinus and eucaliptus and the quest for new alternative resources like bamboo and lignocellulosic wastes from the agroindustry. The challenge for the production of those new alternative sources starts with the cost/benefit analysis associated with the production and process operations. In this way, the industry seeks to develop materials that consume less energy such as the recycled materials and cement and composites reinforced with natural fibers [Tonoli 2006].

An adequate material for engineering purposes is bamboo, in particular the species *Dendrocalamus asper*, an herbaceous and woody plant, belonging to the *Graminae* family [Hidalgo-lópez 2003], which presents a long life cycle, rapid growth and does not need special care during its production [Ghavami 2005]. Additionally, bamboo has an excellent capacity for soil regeneration, good mechanical resistance, high productivity and low energy requirements for its production. However, according to Colla et al (2010), bamboo presents several disadvantages such as dimensional variation when exposed to environmental changes and the presence of starch within the parenchyma cells, in which causes frequent attacks of xylophagous organisms that have the starch as a food source. In this context, there are several procedures that enable the minimization of those effects, which is the case of conventional treatment procedures, the vacuum/pressure method, drying process and thermal treatment [Galvão 2004; Beraldo 2009; Hidalgo-lópez, 2003].

Beraldo et. al. (2009) investigated the effect of thermal treatment on the physical and mechanical properties of *Dendrocalamus giganteus* prismatic samples. They observed that the thermal treated bamboo has potential to be used in several applications, depending on the treatment temperature, which is correlated with the improvement of the dimensional stability of the samples.

The thermal treatment of wood or bamboo, without the use of chemical products, can have positive impacts on the mechanical resistance and also in its dimensional stability, mainly because it modifies the hemicellulose and removes the structural water

[Colla 2010] and compounds of low calorific value [Brito 2006]. The hemicellulose is the most hydrophilic and thermally sensitive constituent of wood and the first constituent to be degraded, leading to the disappearance of the water absorption sites, reducing the hydrophobicity of wood [Brito 2006; Esteves 2008]. Since the hemicellulose doesn't have a structural function, its removal allows a better performance of cellulose and depending on the treatment temperature, its removal doesn't affect the mechanical properties of bamboo.

During the process of thermal treatment in a conventional furnace, the structure of the cell vessels expands and the water and the low calorific value components migrate towards the outside of the structure. However, the inconvenient in using the conventional furnace is the structure swelling caused by the removal of water. The swelling process of the cell vessels can be minimized by using a microwave-assisted oven, in which the heating mechanism is related to the activation of polar molecules caused by the interchange of the electromagnetic fields (2.45 GHz) produced by the magnetron [Keyson 2006].

In the microwave-assisted oven, the heating occurs from inside to outside of the structure [MARQUES et al., 2008] due to the high dielectric constant value of water molecules [Byrappa 2011]. This fact contributes for the polarization/depolarization process under the electromagnetic fields. Although the water is present and bound in the wood structure, the microwave heating mechanism contributes to minimize the process of cell wall rupture by the exit of water molecules between the fibrovascular bundles and thus, preserving the bamboo or wood structure. In Figure 1, it is shown a comparison between the heating mechanisms of water molecules in a conventional furnace and in a microwave-assisted oven.

Additionally, the microwaves are characterized to provide more uniform and faster heating of a specific volume. The energy consumption of a microwave treatment can be 60-70 % lower than conventional heat treatments [Metaxas 1982].

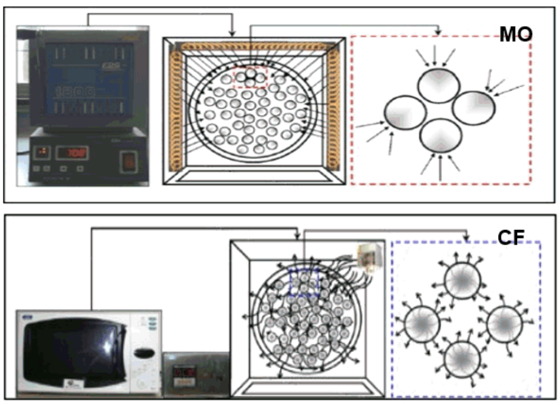

Figure 1: A comparison of the heating mechanism of water molecules in a microwave-assisted oven [MO]and in a conventional furnace [CF].

Within this context, the present work has the main objective of evaluate the effects of thermal treatment on the physical and mechanical properties of the bamboo species *Dendrocalamus asper* using conventional furnace and microwave-assisted oven.

2 EXPERIMENTAL

Bamboo specimens of the *Dendrocalamus asper* species [3 years old, collected at the USP Campus, Pirassununga, SP-Brazil] were studied. 20 specimens with dimensions of 4cm x 1cm x 1cm were extracted from one culm, 5 for each treatment temperature [120,140 and 160 ° C] and 5 as a reference. Before the beginning of the thermal treatments, the samples were placed in an oven at 60 °C for 72 hours for moisture equilibrium.

2.1 Thermal treatment procedure

The thermal treatment was conducted in the Laboratory of Buildings and Ambience of the Department of Biosystems of the Faculty of Animal Science and Food Engineering (FZEA / USP). The bamboo samples were submitted to thermal treatment under an air atmosphere, in a conventional furnace (CF), using a Muffle, Jung, model 10010, and in a microwave-assisted oven (MO), adapted for this experiment. For both types of oven, the working temperatures were 120,140 and 160 ° C, with a heating rate of 1 ° C / min and a 10-minute isotherm.

. Weight loss evaluation

The weight loss was evaluated according to the following equation:

$$WL = \frac{m_f - m_i}{m_i} . 100$$

Where:

WL= weight loss [%]

m_f = final mass [g]

m_i = initial mass [g]

The initial and final mass were obtained before and after the heat treatment in each temperature and type of oven.

2.2 Bromatological analysis

For the analysis of the basic chemical composition of the bamboo, the following components contents were determined: Extractives [TAPPI T 204 cm-97], Lignin [TAPPI T 222 om-02, adapted] Alfacelulose [TAPPI T 203 cm-99] and Holocelulose and Hemicellulose [Marconcini 2010].

2.3 Axial compression test

The compression parallel to the fibers was realized in the laboratory of the Federal University of Lavras - UFLA, in the department of Biomaterials Engineering. The dimensions of the specimens were 4cm x 1cm x 1cm. It was based on an adaptation of the Standard NBR 7190, which presents the method for testing parallel compression of wood fibers. The loading speed employed in the test was 10 MPa/min. The mechanical results were the modulus of rupture (MOR), modulus of elasticity (MOE) and specific energy (EE).

3 RESULTS AND DISCUSSION

The determination of the constituents of lignocellulosic materials is of vital importance to understand the possible degradation mechanisms during heat treatment. In Table 1, the chemical composition of the studied bamboo is shown.

Table 1: Results of the chemical characterization of bamboo (% by mass).

Components of bamboo	
Extractives	10,12
Lignin	24,50
Holocellulose	65,55
Alphacellulose	40,92
Hemicellulose	24,74

According to Correia (2015), the results obtained for the bamboo species Bambusa tuldoides were: 9.2%, 25.0%, 72.2% and 13.2% for extractives, lignin, holocellulose, and hemicellulose, respectively. There was a significant difference in hemicellulose levels, which may be due to the age, maturity of the culms and species. Moreover, José Otávio Brito, Mário Tomazello Filho (1987) obtained 12.9% in the extractive content for the same species and age.

3.1 Weight loss

The weight loss of bamboo or wood in a thermal treatment process is associated with the degradation of its main chemical components and water loss. Although it is not shown in this work, there is also a decrease in the apparent density of the material, which interferes in its physical and mechanical properties. The calculated weight loss for each temperature and mode of treatment are shown in Figure 2.

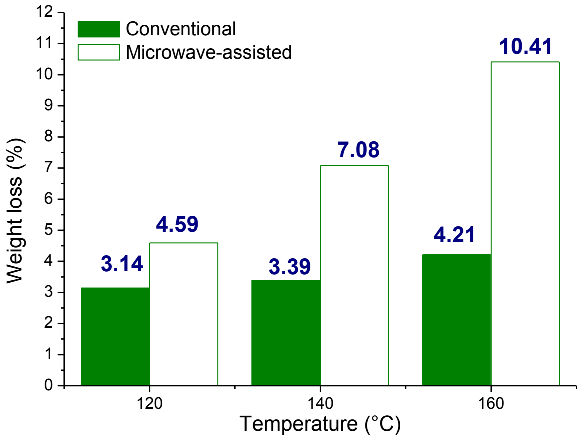

Figure 2: Weight loss after thermal treatment using conventional and microwave-assited oven

The weight loss is more pronounced when the thermal treatment is performed in the microwave-assisted oven (in average 51.7 %) in comparison with the treatment in the conventional furnace at the same temperatures.

According to Hill (2006), the increase in temperature, during thermal treatment generates chemical changes in the macromolecular components of the cell wall, resulting in loss of mass and color change, which leaves the structure of the cellulose less unobstructed.

According to Silva (2012), the mass loss and the consequent reduction in the apparent density of the thermally treated wood are associated with the degradation of the main chemical components of the wood [hemicellulose, cellulose, and lignin] and, the higher the treatment temperatures, the greater the changes.

Esteves et al. (2008) cite a minimum mass reduction of 3% to increase dimensional stability and 5% to improve the natural durability of the wood. In this case, it was possible to observe that all the obtained values for the bamboo samples are superior to those values.

3.2 Axial compression tests

The results obtained through the axial compression tests are shown in Table 2. It is possible to observe that in general, the heat treatment performed between the chosen temperatures using both methods, improved the modulus of elasticity, modulus of rupture and specific energy in relation with the bamboo without heat treatment (reference). Only the samples heat treated at 160 °C using the MO showed a decrease in the mechanical properties. Although the samples treated at 140 °C in the MO also showed a slight decrease on the modulus of rupture, it was observed a small increase on the modulus of elasticity and a considerable increase on the specific energy.

Table 2: Results of the axial compression tests of the heat treated samples using microwave-assisted oven (MO) and conventional furnace (CF).

Temperature [°C]	**MOR [MPa]**	**MOE [MPa]**	**EE [KJ/m²]**
Reference	73,67	3417,07	0,634011
MO-120°C	***77,41***	***4682***	***1,106***
MO-140°C	72,68	3532	1,005
MO-160°C	61,72	3265	0,508
CF-120°C	***83,24***	***4731***	***0,691***
CF-140°C	88,92	4479	0,636
CF-160°C	84,79	5247	0,792

Since microwaves heat polar molecules, which includes cellulose, hemicellulose and lignin, it is possible to observe a decay in the mechanical properties of bamboo at 160 °C using the MO but not using the CF. It also possible to infer that in the MO, the heating flow is more homogeneous and affect the whole sample volume faster than in CF. Probably, the samples heat treated in the CF did not achieved the desired temperature along the whole sample volume and therefore, the samples did not suffer considerable degradation of its components.

It is interesting to notice that similar mechanical properties were obtained at the temperature of 120 °C using both heating methods. Moreover, the samples treated in the MO, showed a higher specific energy, which is related to a higher toughness of the material. This effect can be related with the low cell wall rupture process during the heating with microwaves.

Nevertheless, since the microwave heating consumes between 60-70 % less energy for the same temperature and also provide more uniform heating, it can be considered a good option for the thermal treatment of bamboo in an industrial scale, especially in a long-term period, since it would be required a higher initial investment.

4 SUMMARY AND CONCLUSIONS

The results of weight loss showed that thermal treatment in a MO shows higher weight loss than the thermal treatment performed in a CF. The axial compression tests results showed that the heat treatment affects the mechanical properties of bamboo, enhancing its strength, stiffness, specific energy. The microwave heat treatment bamboo can be an interesting option for industrial scale since it consumes less energy for the same gain in mechanical performance.

5 ACKNOWLEDGMENTS

Thanks to Conselho Nacional de Desenvolvimento Científico e Tecnológico [CNPq] process n° 150384/2016-5 and Fundação de Amparo à Pesquisa do Estado de São Paulo [FAPESP] Process n° 2013/23810-8. Thanks to the Universidade Federal de Lavras – UFLA, and Prof. Rafael Farinassi Mendes, Coordinator of the Post-Graduate Program in Biomaterials Engineering. Thanks to Faculdade de Zootecnia e Engenharia de Alimentos – FZEA-USP, and Prof Dr. Holmer Savastano Jr, Dr. Valdemir dos Santos and MSc. Christian Gauss for all knowledge and development of the research.

6 REFERENCES

ABNT NBR 7190. Projeto de estruturas de madeira, 1996.

Beraldo A. L. ; Azzini A. ; Bambu: Características e Aplicações ; Guaíba: Livraria Editora Agropecuária, 2004. 180p.

Beraldo A. L.; Colla, V. A., Brito, J. O. Properties Evaluation of Dendrocalamus giganteus Treated by Heat. In: VIII World Bamboo Congress Proceedings, Thailand, 2009, Massassussets, USA: World Bamboo Organization, vol. 9, p.63

Brito J. O; Filho M. T.; Salgado, A. L. B.; Produção e caracterização do carvão vegetal de espécies e variedades de bambu. Ipef, 1987, v. 36, p. 13–17.

Brito, J. O.; Garcia, J. N.; Bortoletto, G.; Pessoa, A. M. C.; Da silva, P. H. M. Densidade básica e retratibilidade da madeira de Eucalyptus grandis submetida a diferentes temperaturas de termorretificação. Cerne, 2006, v. 12, p. 182-188.

Carvalho, O. D. Madeira para formas. Escola Politénica da Universidade de São Paulo, Departamento de Engenharia de Construção Civil. PCC 339 - Madeiras para construção Civil, 2000.

Colla, W. A. Efeito do tratamento térmico nas características físicas e mecânicas do bambu [Dendrocalamus giganteus Munro]. Master thesis. Campinas: Universidade Estadual de Campinas, 2010.

Correia, V. C. Produção de celulose nanofibrilada a partir de polpa organossolve de bambu para nanoreforço de compósitos cimentícios. Phd thesis. Pirassununga: Universidade de São Paulo, 2015.

Dundar T.; Buyuksari U.; Avci E.; Akkiliç H.; Effect of heat treatment on the physical and mechanical properties of compression and opposite wood of black pine. Bioresources, vol. 9, p. 5009-5018.

Esteves, B.; Graça, J.; Pereira, H. Extractive composition and summative chemical analysis of thermally treated Eucalyptus wood. Holzforschung, 2008, v. 62, n. 3, p.344–351.

Galvão A. P. M.; Magalhães W. L. E.; Mattos P. P; Processos práticos para preservar madeira. Embrapa, Colombo, 2004.

Ghavami, K.; Marinho, A. B., “Propriedades físicas e mecânicas do colmo inteiro do bambu da espécie Guadua angustifolia”, Revista Brasileira de Engenharia Agrícola e Ambiental, 2005, vol. 9, 1, p. 107-114.

Hidalgo-lópez, O. H. Bamboo The Gift of the Gods, 1ªed. Colômbia: D’VINNI Ltda, 2003.

Hill, C. A. S. Wood modification: chemical, thermal and other processes. Bangor. John Wiley & Sons Ltd., 2006.

Keyson D., Longo E., Vasconcelos J. S., Varela J. A., Éber S., DerMaderosian A. Síntese e processamento de cerâmicas em forno de microondas doméstico, Cerâmica, 2006, vol 53, p. 50-56.

Metaxas A. C.; Meredith R. J. Industrial Microwave Heating, Peter Peregrinus, London, UK, 1982.

Moon R. J.; Martini A.; Nairn J.; Simonsen J.; Youngblood J.; Cellulose nanomaterials review: structure, properties and nanocomposites. Birck and NCN Publications. Paper 769, 2011.

Morais, J. P. S.; Rosa, M. F.; Marconcini, J. M. Procedimentos para Análise lignocelulósica. Embrapa, Campina Grande, 2010.

Silva, M. R. Efeito do tratamento térmico nas propriedades químicas , físicas e mecânicas em elementos estruturais de Eucalipto citriodora e Pinus taeda. Phd thesis. São Carlos: Universidade de São Paulo, 2012.

TAPPI. T 203 cm-99. Alpha-, beta- and gamma-cellulose in pulp. 2009.

TAPPI. T 204 cm-97. Solvent extractives of wood and pulp. 1997.

TAPPI. T 222 om-02. Acid-insoluble lignin in wood and pulp. 2002.

Tonoli, D.; Aspectos produtivos e analise do desempenho do fibrocimento sem amianto no desenvolvimento de tecnologias para telhas onduladas. Master thesis. Pirassununga: Universidade de São Paulo, 2006.