EFFECTS OF THERMAL TREATMENT ON THE PHYSICOCHEMICAL CHARACTERISTICS OF GIANT BAMBOO

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ABSTRACT: Despite countless use possibilities for bamboo, this material has two major disadvantages. One drawback is the low natural durability of most bamboo species due to presence of starch in their parenchyma cells. The other equally important drawback is the tendency bamboo has to present dimensional variations if subjected to environmental change conditions. In an attempt to minimize these inconveniences, strips (laths) of *Dendrocalamus giganteus* Munro were taken from different portions of the culm and subjected to several temperatures, namely 140 °C, 180 °C, 220 °C, 260 °C and 300 °C under laboratory conditions, at the ESALQ-USP college of agriculture. The thermal treatment process was conducted in noninert and inert atmospheres (with nitrogen), depending on temperature Specimens were then subjected to physicomechanical characterization tests in order to determine optimum thermal treatment conditions in which to preserve to the extent possible the original bamboo properties. Results revealed that there is an optimum temperature range, between 140 ° and 220 °C, whereby thermally treated bamboo does not significantly lose its mechanical properties while at the same time showing greater dimensional stability in the presence of moisture.

Key words: Thermal treatment, *Dendrocalamus giganteus*.

EFEITOS DO TRATAMENTO TÉRMICO NAS CARACTERÍSTICAS FISICO-MECÂNICAS DO BAMBU GIGANTE

RESUMO: *Embora possam ser atribuídas ao bambu inúmeras possibilidades de utilização, duas grandes desvantagens são apresentadas por esse material. A primeira refere-se à baixa durabilidade natural da maioria das espécies, em razão da presença de amido em suas células parenquimáticas. A outra desvantagem, não menos importante, é a tendência apresentada pelo bambu de apresentar variações dimensionais, quando exposto a mudanças ambientais. Na busca da minimização de tais inconvenientes, taliscas (ripas) de Dendrocalamus giganteus Munro foram coletadas de diversas partes do colmo e foram submetidas, em condições de laboratório, na ESALQ-USP, a diversas temperaturas: 140 °C, 180 °C, 220 °C, 260 °C e 300 °C. Dependendo da temperatura, o processo de termorretificação foi realizado em ambientes de atmosfera não inerte e inerte (com nitrogênio). A seguir, os corpos-de-prova foram submetidos a ensaios de caracterização físico-mecânica, buscando-se avaliar as condições ideais da termorretificação e que, ao mesmo tempo, não implicassem em redução acentuada das características originais do bambu. Os resultados permitiram detectar a existência de uma faixa ótima de temperatura, de 140 ºC a 220 ºC, na qual o bambu termorretificado não perde significativamente suas características mecânicas e, ao mesmo tempo, apresenta maior estabilidade dimensional em presença da umidade.*

Palavras-chave: Termorretificação, Dendrocalamus giganteus.

1 INTRODUCTION

Bamboos are woody, herbaceous plants belonging to the grass family, with over 700 classified species being distributed across 50 distinct genera (HIDALGO-LÓPEZ, 2003). It is a perennial plant reasonably easy to cultivate, with a long useful life and capable of promoting great soil regeneration, having accompanied mankind from the beginning of time, providing shelter, food, household utensils, charcoal, paper, fabric, irrigation, musical instruments as well as other artifacts.

Difficulties related to bamboo use are often associated with its properties, unsuitable for certain purposes. Therefore, a deeper understanding of the relationships between structure, behavior, quality and properties of bamboo throughout the processing phase is a critical issue if bamboo use is to be disseminated on a large scale (LIESE, 1992). It can be drawn, from the above considerations, that bamboo treatment processes should be improved prior to being reliably applied to construction engineering, furniture making, laminated products and other applications,

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bringing benefits at the economic level and speeding up the processing phase (APUAMA, 1999).

Treatment possibilities for lignocellulosic material may include use of heat, referred to here as thermal treatment. The action of heat can be relatively intense in wood, on account of the structural changes that occur during combustion (BRITO, 1992).

One of the most important stages in thermal treatments is selecting the temperature range. Pessoa et al. (2006) tested temperatures of 30 °C (room temperature), 120 ºC, 140 °C, 160 °C, 180 °C and 200 °C on wood of *Eucalyptus grandis*. After undergoing thermal treatments, samples were subjected to decay conditions. A favorable effect was noted of the higher temperature on the mortality of drywood termites.

Due to high sugar, carbohydrate, resin and starch contents in its composition, bamboo is highly vulnerable to insects, bacteria and fungi (PEREIRA; BERALDO, 2007). These damaging organisms include bamboo borer (*Dinoderus minutus* Fabricius), which causes substantial mass loss, particularly affecting tropical bamboos. The intensity of the damage will depend on starch content, culm age, harvest season and treatment type applied to the bamboo species (HIDALGO-LÓPEZ, 2003).

Structural change to materials, following physical or chemical treatments, is usually assessed by physicomechanical tests. Ultrasound, however, is a relatively quick, nondestructive testing method for verifying internal discontinuities and changes caused to the properties of materials. Velocities of wave propagation are dependent on the direction of propagation and on elastic constants of materials, not always isotropic, as is the case of wood (NOGUEIRA; BALLARIN, 2007). As with other natural materials, bamboo properties vary widely, mainly on account of the specific condition of growth. In order to evaluate bamboo properties, it is necessary to apply physicomechanical tests. Nondestructive testing (END), in particular through ultrasound, is a viable alternative to classic mechanical testing because the ultrasonic pulse velocity (VPU) traveling into a specimen potentially detects structural changes caused by the effect of high temperatures (DEL MENEZZI et al., 2007).

2 MATERIAL AND METHODS

2.1 Preparation of strips for thermal treatments

Two bamboo culms of species *Dendrocalamus giganteus* Munro, at around age 5 years, were collected at the Faculdade de Engenharia Agrícola, Campus of the Universidade Estadual de Campinas. Using a device, as illustrated in Figure 1a, the culm was split into 6 (six) sections, referred to here as strips, as is illustrated in Figure 1b. The strips were then machined so as to obtain uniform specimens 30 cm long x 2 cm wide x 1 cm thick. The strips were left to dry in a protected environment until they reached a 10% to 15% moisture content.

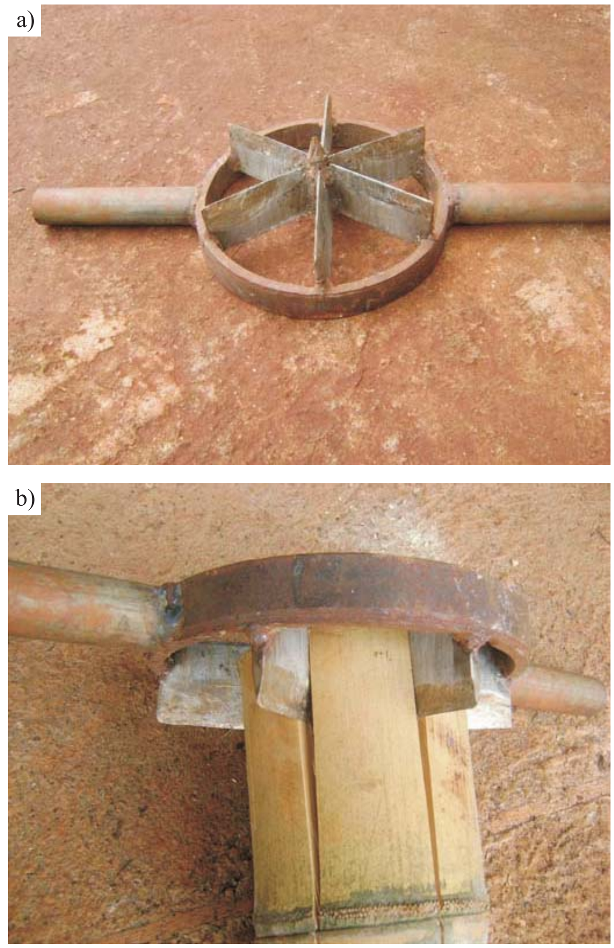


Figure 1 – Device for cutting strips.

***Figura 1 –** Dispositivo para produção de taliscas.*

In order to eliminate the effect of moisture on the thermal treatment, the strips (except the control sample) were initially dried at 100 °C and then placed in plastic bags. To start with, 110 strips were picked at random and subjected to thermal treatment at five selected temperatures (22 samples for each temperature).

The thermal treatments were performed at the Laboratório Integrado de Química, Celulose e Energia, of the Departamento de Ciências Florestais, Escola Superior de Agricultura Luiz de Queiroz (ESALQ-USP). The strips were heated at 140 ºC, 180 ºC, 220 ºC, 260 ºC and 300 °C. To avoid combustion, N_2 was used for the latter three temperatures. The starting temperature was 100 ºC, adopting a heating rate of 0.1388 °C/min, according to Pessoa et al. (2006). The specimens were kept in the oven for 1 hour to reach the desired temperature; then they remained in the oven for the time required to reach an equilibrium temperature. Figure 2 provides the evolution of temperature as a function of heating time.

Mass loss was assessed in the specimens by comparing mass percentages before and after the completion of thermal treatments.

2.2 Tests applied to thermally treated bamboo (BTR)

In evaluating the properties of thermally treated bamboo an optimum temperature range was sought, in an attempt to obtain a more suitable product for each specific use, for instance, furniture making. To the extent possible, specimen evaluation followed the guidelines set out in the Brazilian wood standards (ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS - ABNT, 1997).

2.2.1 Bulk density

Bulk density (in $g.cm^{-3}$) was obtained before and after the thermal treatments, by measuring the volume and the mass of specimens.

2.2.2 Swelling and water absorption

Specimens were prepared after determination of breaking strength under static bending testing. Samples 5 cm (long) x 2 cm (wide) x 1 cm (thick) were taken from undamaged portions of specimens, away from the central, damaged parts. Once weight and size measurements were taken, specimens were immersed in water for 24 hours. Mass gain and swelling after 24 hours, in all three anatomical directions (axially, radially and tangentially), were compared with the control sample.

2.2.3 Nondestructive ultrasonic testing (END)

The ultrasonic pulse velocity (VPU) running through specimens was measured before and after the thermal treatment was applied. A Steinkamp-BP7 device with exponential transducers was used, with a resonance frequency of 45 kHz. The ultrasonic pulse velocity was derived by dividing distance (in millimeters) by propagation time (in µs). With the density and VPU of strips, before and after the thermal treatments, the dynamic modulus of elasticity (E_d) was derived by:

$$E_d = \rho.(VPU)^2.10^{-9}(GPa)$$

ρ = bulk density (kg/m^3);
VPU = ultrasonic pulse velocity (m/s).

2.2.4 Static bending

For the modulus of rupture (MOR) in static bending, 10 samples were selected at random from each

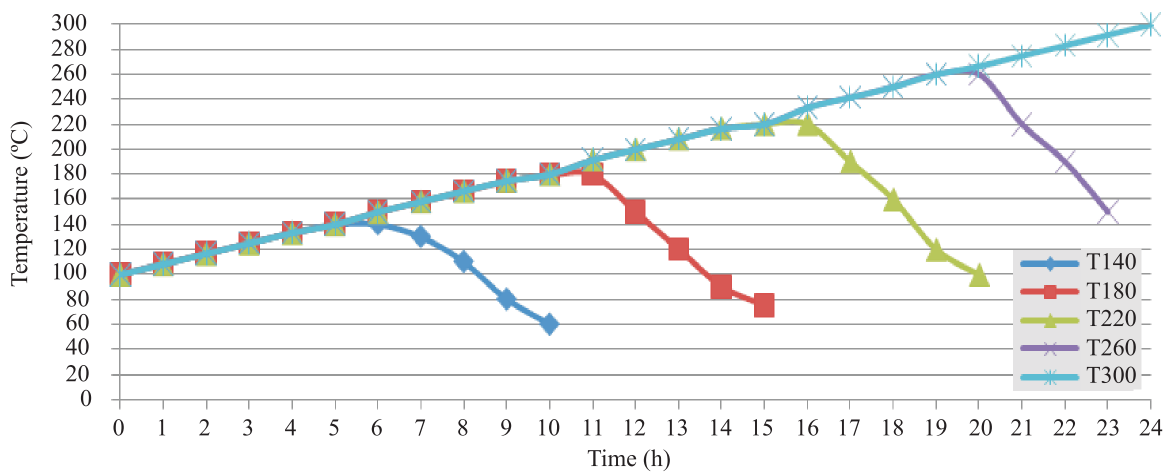


Figure 2 – Diagram representing rising temperatures (ºC) as a function of time (h).

***Figura 2 –** Diagrama representando a elevação de temperatura em (ºC) em função do tempo em (h).*

thermal treatment. A free span of 150 mm was adopted using an EMIC testing machine, DL/300 kN model, at a speed of 1 mm/min.

2.2.5 Charpy impact test

To perform this test, specimens 30 cm (long) x 2 cm (wide) x 2 cm (thick) in nominal size were used, with a free span of 24 cm and an energy of 10 kgf.m. The bamboo strips being less than 2 cm in thickness, however, a section was thus required comprising two strips, glued with PVA, under pressure. This test was performed at the Wood Division of the Technological Research Institute (IPT).

2.2.6 Scanning electron microscopy (MEV)

This test was performed at the National Laboratory of Synchrotron Light (LNLS). Each duly prepared sample was analyzed in order to detect any structural changes to bamboo resulting from the thermal treatment.

3 RESULTS AND DISCUSSION

3.1 Mass loss after the thermal treatment

The mass loss in bamboo strips was more intensified for the treatment at 300 °C, around 50% in relation to the original mass, denoting drastic changes in the bamboo structure as a result of temperature (Figure 3).

3.2 Effects of thermal treatment on density, velocity and dynamic modulus

In treatments performed at higher temperatures, the properties of thermally treated bamboo (BTR) dropped dramatically (Table 1). Density decreased as a result of mass loss being more intensified than volume contraction; the dynamic modulus of elasticity Ed (Figure 4) and VPU (Figure 5) increased because the moisture content in the BTR decreased. At 300 °C, however, a marked reduction was noted in such values, indicating the presence of major structural flaws in the BTR.

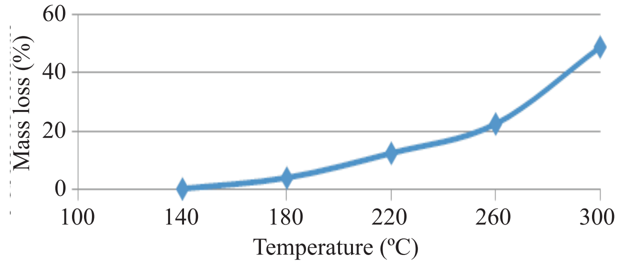


Figure 3 – Mass loss (%) in thermally treated bamboo (BTR) as a function of temperature.

Figura 3 *– Perda de massa (%) do Bambu Termorretificado (BTR) em função da temperatura.*

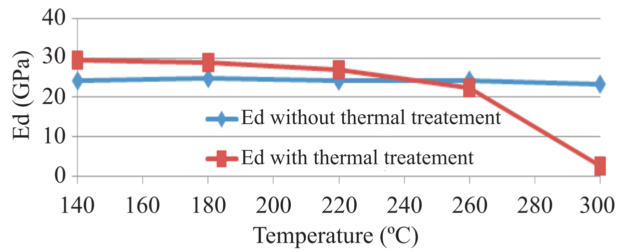


Figure 4 – Dynamic modulus of elasticity (Ed), in GPa.

Figura 4 *– Módulo de elasticidade dinâmico (E_d), em GPa.*

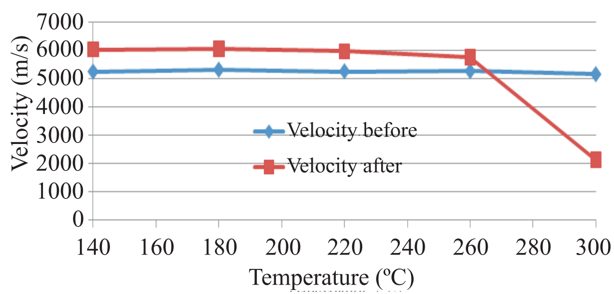


Figure 5 – Ultrasonic pulse velocity (VPU), in ms^{-1}.

Figura 5 *– Velocidade do pulso ultrassônico (VPU), em ms^{-1}.*

Table 1 – Properties of thermally treated bamboo (BTR) as a function of treatment temperature.

Tabela 1 *– Propriedades do Bambu Termorretificado (BTR) em função da temperatura de tratamento.*

Temperature	30 ºC	140 ºC	180 ºC	220 ºC	260 ºC	300 ºC
Density ($g.cm^{-3}$)	0.87^{a*}	0.81^{ab}	0.79^{bc}	0.75^{c}	0.67^{d}	0.54^{e}
VPU ($m.s^{-1}$)	4354^{d}	6041^{a}	6055^{a}	5973^{b}	5774^{c}	2147^{e}
E_d (GPa)	16.56^{d}	29.42^{a}	28.92^{a}	26.95^{b}	22.47^{c}	2.47^{e}
MOR (MPa)	194^{b}	232^{a}	157^{c}	123^{d}	79^{e}	12^{f}

(* Different letters in the same row indicate a significant difference between means at the 95% probability level by the Tukey test). VPU – ultrasonic pulse velocity; E_d – dynamic modulus of elasticity; MOR – modulus of rupture

3.3 Effect of thermal treatment on the modulus of rupture (MOR)

MOR dropped rapidly with increasing temperatures, proving to be more sensitive to the effect of temperature than VPU or E_d (Figure 6).

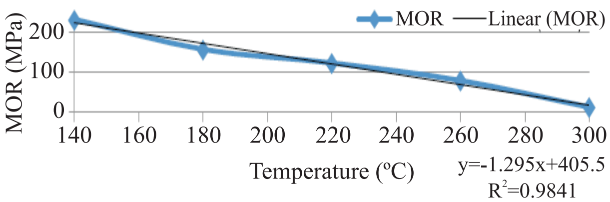


Figure 6 – Modulus of rupture (MOR, in MPa) of thermally treated bamboo (BTR) as a function of temperature, in °C.

Figura 6 – *Módulo de ruptura (MOR, em MPa) do Bambu Termorretificado (BTR), em função da temperatura, em °C.*

3.4 Effect of thermal treatment on swelling

Swelling after 24 hours was found insignificant in the axial direction (0.12% to 0.18%), except for the treatment at 300 °C (1.60%), indicating once again, in this case, an important anatomical change occurring in the bamboo. Swelling was greater in the radial direction than in the tangential direction (opposite pattern to normal wood). At 220 °C, a tendency was noted toward stabilization (2%) in both anatomical directions (Figure 7). At higher temperatures, samples were found to become frailer, with a tendency to twist and crack.

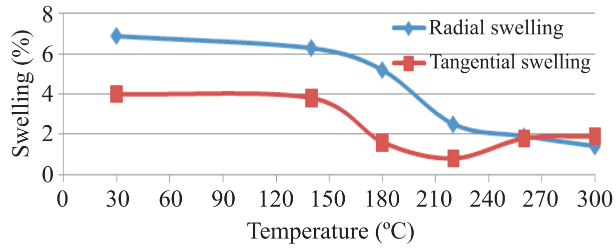


Figure 7 – Swelling of thermally treated bamboo (BTR) as a function of anatomical direction.

Figura 7 – *Inchamento do Bambu Termorretificado (BTR) de acordo com a direção anatômica.*

3.5 Impact strength of BTR relative to other woods

Figure 8 provides Charpy test results for impact strength in bamboo. It should be noted that, for the bamboo treated at 140 °C, the maximum value of the energy scale was adopted (10 kgf.m), since strips being tested simply would not break. For temperatures between 180 °C and 220 °C an abrupt drop in impact strength was noted, yet the value found was well above the value found for woods rated as good quality, again illustrated in Figure 8.

3.6 Effect of thermal treatment on anatomical structure

Figures 9a to 9h provide imagery by scanning electron microscopy, for bamboo at room temperature and after thermal treatment. A large quantity of starch is clearly noted, with its typical globular shape and almost filling out

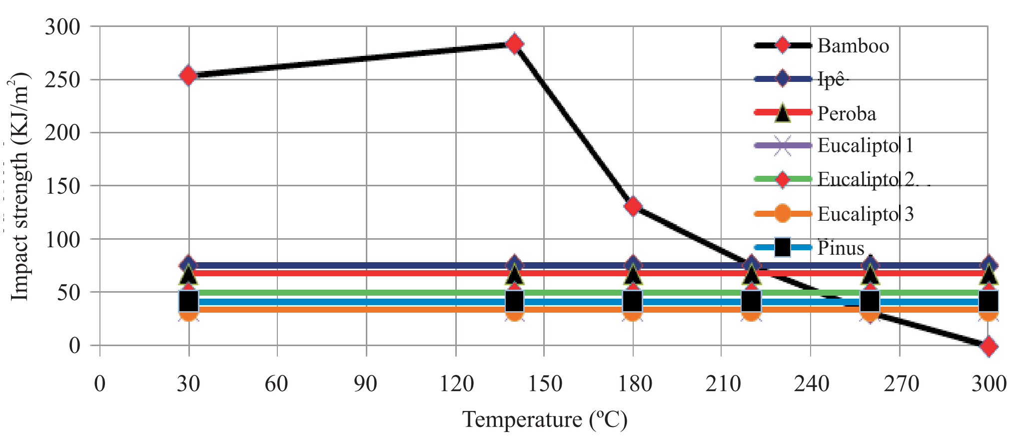
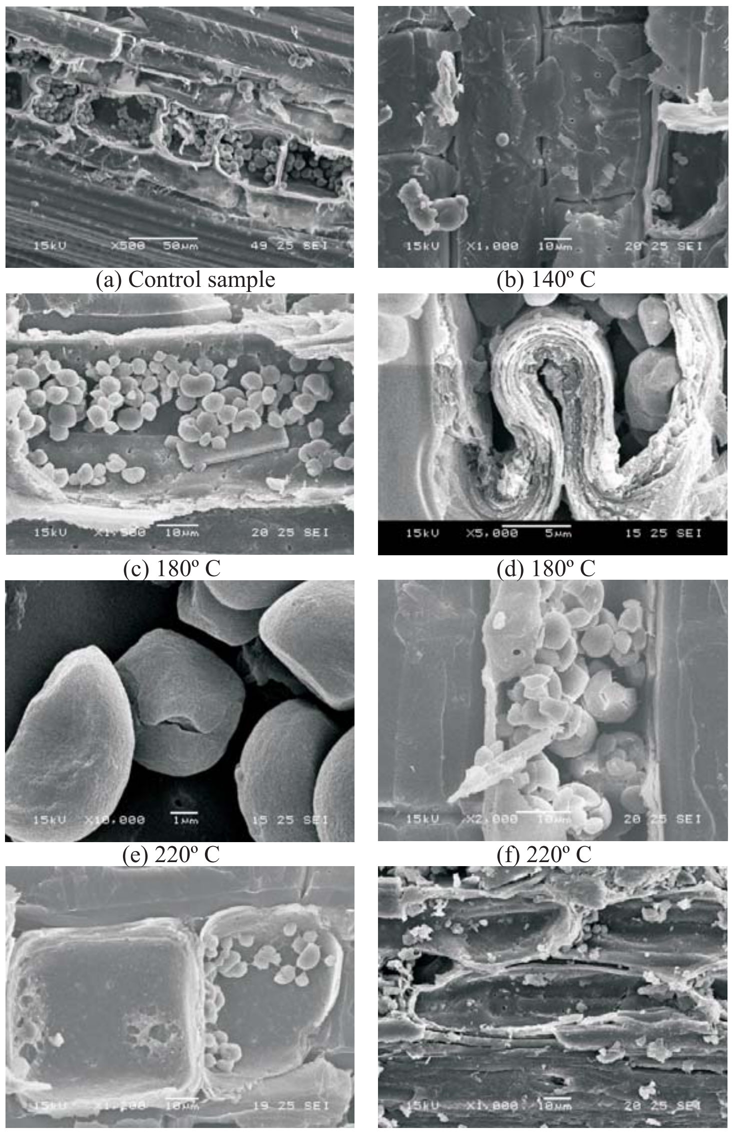


Figure 8 – Comparative graph between bamboo and other woods.
Other wood data were provided by the Technological Research Institute (IPT).

Figura 8 – *Gráfico comparativo entre o bambu e diversas madeiras.*
Os dados referentes às madeiras foram fornecidos pelo Instituto de Pesquisas Tecnológica (IPT).

the parenchyma cells (Figure 9a). Bamboo fiber bundles appear on the top and bottom portions of the picture. At 140 °C, starch and cells are still almost unchanged in structure (Figure 9b). Some laceration is yet noted in the parenchyma walls due to cutting being done with an instrument other than a microtome. At 180 °C, structural changes are found to be more drastic (Figure 9c). Parenchyma cells are severely contracted (Figure 9d), noting some fissured starch grains (Figure 9e) about to burst. At 220 ºC, starch grains start to burst (Figure 9f). The degradation process continues in the parenchyma wall, in Figure 9g, observing a totally degraded starch (incorporated) on the left-hand parenchyma cell, while on the right-hand cell the starch is completely fragmented, with some parts starting to fuse. At 300 °C (Figure 9h), the structure of the material resembles charcoal, with totally degraded starch grains, with distorted and detached cell walls, denoting absence of a basic support structure for the material.



(a) Control sample (b) 140º C

(c) 180º C (d) 180º C

(e) 220º C (f) 220º C

(g) 260º C (h) 300º C

Figure 9 – Images obtained by scanning electron microscopy (MEV).

Figura 9 – *Imagens obtidas por microscopia eletrônica de varredura (MEV).*

4 CONCLUSIONS

Thermally treated bamboo (BTR) was found to have potential for various applications as a function of temperatures being adopted. At 180 °C, the bamboo underwent major changes in structure. Temperatures above 260 °C caused considerable damage to the bamboo structure, suggesting that it may be unsuitable, in particular, for furniture making.

An optimum temperature range was noted to exist, between 140 °C and 220 °C, which could be further refined in order optimize the process.

Overall, the thermally treated bamboo was found to have greater dimensional stability than the reference bamboo. Structural changes caused by temperature led to a drastic reduction in the mechanical properties of bamboo. Detected by ultrasound, these changes were more noticeable in impact strength and static bending tests.

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