INFLUENCE OF THERMAL TREATMENT ON DIMENSIONAL STABILITY AND WOOD DURABILITY OF *Trattinnickia burseraefolia*

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Recebido em 05.09.2013 e aceito em 15.11.2014.
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ABSTRACT: The thermal treatment may be utilized as an alternative to increase the wood natural durability and improve its dimensional stability. This technique utilizes temperatures between 100°C and 250°C, which promote chemical alterations in cellulose, hemicellulose and lignin polymers, capable to increase the wood biological strength and reduce its hygroscopicity. This study aimed to evaluate the thermal treatment influence on dimensional stability and strength to amescla wood deterioration (*Trattinnickia burseraefolia* Mart.). The treatments were performed in an incubator with air forced circulation. 200°C and 245°C temperatures were assessed on dimensional stability and wood natural durability. The thermal treatments utilized were effective to improve the dimensional stability and the amescla wood durability. The best results were observed for treated wood at 245°C.

Key words: Thermal-rectification, Natural durability, Swelling.

INFLUÊNCIA DO TRATAMENTO TÉRMICO NA ESTABILIDADE DIMENSIONAL E DURABILIDADE DA MADEIRA DE *Trattinnickia burseraefolia*

RESUMO: O tratamento térmico pode ser utilizado como uma alternativa para elevar a durabilidade natural de madeiras e melhorar sua estabilidade dimensional. Esta técnica utiliza-se de temperaturas entre 100°C e 250°C, que promovem alterações químicas nos polímeros celulose, hemicelulose e lignina, capazes de aumentar a resistência biológica da madeira além de reduzir sua higroscopicidade. O presente trabalho teve como objetivo avaliar a influência do tratamento térmico na estabilidade dimensional e resistência à deterioração da madeira de amescla (*Trattinnickia burseraefolia* Mart.). Os tratamentos foram realizados em estufa com circulação forçada de ar. Foi avaliado o uso das temperaturas 200 e 245°C sobre a estabilidade dimensional e sobre a durabilidade natural da madeira. Os tratamentos térmicos utilizados mostraram-se eficientes para melhorar a estabilidade dimensional e durabilidade da madeira de amescla. Os melhores resultados foram observados para as madeiras tratadas com a temperatura de 245°C.

Palavras chave: Termorretificação, durabilidade natural, retratibilidade.

INTRODUCTION

The wood products market is increasingly demanding on the used material quality. Thus, the studies on processes that eliminate and/or minimize aspects which limit the wood utilization as material are required. Among these, it is highlighted the natural durability and wood hygroscopicity.

Regarding to durability, all woods are subject to deterioration natural processes due the biotic and abiotic agents' action over time, which alter the structural properties, yield, use period and the material security grade. Among the woods deteriorative biological agents, the fungi and termites are responsible by the major damage (Melo et al., 2010).

The hygroscopicity is the sorption and desorption phenomenon of the wood water content, being related to environmental conditions in which it operates, as well as the wood physical and chemical properties. This phenomenon causes dimensional variations in the wood, that swelled when absorbs moisture (increases its volume) and retracts when it lose moisture (reduces its volume). This dimensional variation is called Swelling and is considered one of the main limiting factors to wood utilization. This variations knowledge is essential as it may limit the use of parts requiring specific technical processing and utilization (Brito et al., 2006; Trevisan et al., 2008).

The thermal treatment may be utilized as an alternative to increase the wood natural durability and improve its dimensional stability. Many species, although available on a commercial scale, are subjected to restrictions regarding its use, by the inadequacy of one or more properties for a particular purpose. This process may enable the use of wood considered as problematic from a technological point of view, diversifying them for other uses, and enlarging its economic potential (Del Menezzi & Tomaselli, 2006). This technique consist to submit the wood to temperatures action between 100°C and 250°C, which promote degradation and chemical alteration in the hemicellulose, which present hydroxyl sites that attract water molecules and thus cause the dimensional variation and biological deterioration problems. The thermal treatment method had improved largely in terms of trade in recent years, mainly due to its low cost technique, easy application and any chemical product (Modes et al., 2013)

The amescla wood has potential use in Northern Region of Mato Grosso State, since it is a quite logged timber and its use is almost exclusively aimed at rolling. In this sense, this study aimed to evaluate the thermal treatment influence on the dimensional stability and natural durability of amescla wood (*Trattinnickia burseraefolia* Mart.).

MATERIALS AND METHODS

Obtaining Test Bodies

The wood was obtained in timber located at Sinop city - MT. Five boards of *Trattinnickia burseraefolia* (amescla) were randomly selected for test-bodies preparation. The boards were flattened with a smoothing plane and one-side thickness planing machine, and then the test-bodies were produced with a table circular saw. The test-bodies produced were intended to determine the physical properties (specific weight and Swelling) and field deterioration tests. The samples were produced at 2.0 x 2.0 x 10.0 cm nominal dimensions (radial, tangential and longitudinal) and 2.0 x 2.0 x 30.0 cm (radial, tangential and longitudinal), for physical and bio deterioration tests, respectively.

Experimental Design

Three different treatments were evaluated in the study: i) wood without thermal treatment (control); ii) timber submitted to thermal treatment at 200°C; and iii) wood submitted to thermal treatment at 245°C. The temperatures utilized were determined on preliminary studies performed by Del Menezzi & Tomaselli (2006). Twenty-four (24) and twenty (20) samples of each treatment were utilized for physical properties and natural resistance evaluation to field deterioration, respectively. Fifteen (15) samples of each treatment for each environment were used for field deterioration tests (open field and forest).

Test-bodies thermal-rectification

All samples were dried in an oven (100°C) for dry weight determination, before starting the thermal treatment. Then, the control samples (without thermal treatment) were placed in a laboratory to cooling. In other cases, thermal treatment at 200°C and 245°C was performed. Each of these treatments was in the oven for 2h in determined thermal-rectification temperature. After reached the temperature, the oven was turned off to cooling the samples. Then, as control samples, they were placed in a laboratory to cooling.

After thermal treatment, the test-bodies were immediately weighted and measured in three directions, after removed from the oven. These data were used to evaluate the weight loss and volume reduction caused by the treatment.

Physical Properties Characterization

Samples linear retraction in longitudinal, radial and tangential directions (Equation 1) and the volumetric Swelling (Equation 2) were determined for each sample tested, as standardized by the NBR 7190 standard of the Brazilian Association of Technical Standards (Associação Brasileira de Normas Técnicas – ABNT) (1997). The basic and apparent specific weight samples were determined by obtaining dry weight and saturated volume values (Equation 3 and 4). Information regarding to anisotropy factor (Equation 5) and the moisture content on wet basis (Equation 6) was additionally utilized to assist in the results analysis.

$$R_{(L,R,T)} = \frac{D_v - D_s}{D_v} * 100 \quad (1)$$

$$R_{(V)} = \frac{V_v - V_s}{V_v} * 100 \quad (2)$$

$$ME_b = \frac{M_o}{V_v} \quad (3)$$

$$ME_b = \frac{M_{(t)}}{V_{t(saturado)}} \quad (4)$$

$$F_A = \frac{R_T}{R_R} \quad (5)$$

$$TU = \frac{Mu - M_0}{Mu} \quad (6)$$

Where: $R_{(L,R,T)}$ = longitudinal, radial or tangential linear Swelling, in %; $R_{(V)}$ = volumetric Swelling, in %; D_v and D_s = linear dimensions in saturated volume and dry condition, in cm; V_v and V_s = saturated volume and dry condition, in cm^3. ME_b = basic specific weight, in $g.cm^{-3}$; F_A = anisotropy factor; TU = moisture content, in %; M_0 and Mu = dry (0%) and saturated weight, in g;

The controls swelling (treatment at 0°C) was calculated in dry condition at 0% moisture for saturated condition and 200°C and 24°C treatments refers to the swelling caused by the test-bodies saturation after passing through the thermal treatment process. A digital caliper rule with 0.01mm precision was utilized for test-bodies dimensions and an analytical balance with 0.01g precision for obtaining weight.

Field Deterioration Test Installation

The field deterioration test was performed in two environments (open field and forest). The test-bodies distribution, in each area, was defined by randomized block, with fifteen test-bodies per block (Figure 1). The test-bodies were buried up to the half of its length, i.e., 15 cm.

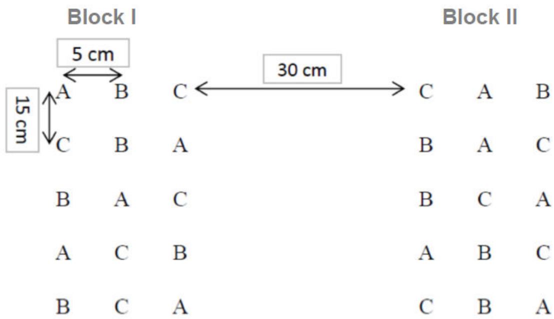

Figure 1. Disposition of samples. (A - 200°C; B - 245°C; C – Control).

Natural Durability Characterization

The durability tests were performed according to the methodology suggested by Melo et al (2010). Therefore, different thermal treatments samples were submitted in field deterioration test for three months, in Sinop *Campus* – UFMT (Federal University of Mato Grosso). After removal, the test-bodies were cleaned with a brush to remove the adhering soil, and dried in forced air circulation oven at 100°C until obtaining constant weight. The weight loss determination of each test-body was performed by the difference between the initial and final weight (Equation 7).

$$PM = \frac{Mi - Mf}{Mi} * 100$$

Where: PM= weight loss (%); Mi= initial weight (g); Mf= final weight (g).

Additionally, samples visual analysis was performed according to Lepage (1970) recommendations. In this study, a different nomenclature was utilized to the index suggested by the author, denominated as

"Sanity Index - IS" instead of "Deterioration Index - ID" (Table 1). The index was assigned by four evaluators, considering the parts deterioration level.

Table 1. Wood deterioration index rating.

Description	Sanity Index
Sanity, no attack	100
Light or superficial fungus and termites	90
Clear attack, but moderate fungi and termites	70
Intense rotting or intense attack of termites	40
Break, almost complete loss of strength	0

Results Analysis

A completely randomized design (CRD) was used for physical properties analysis, with 24 repetitions per treatment. A randomized block design (RBD) was used for deterioration resistance with factorial arrangement, where the following factors were evaluated: thermal treatment (three levels - control, 200°C and 245°C), deteriorating environment (two levels - open field and forest) and the interaction between the factors. Each block was composed by fifteen repetitions.

The treatments effects were evaluated with variance analysis (ANOVA). Observing significant differences, the means were compared with Tukey test at 5% error probability.

RESULTS AND DISCUSSION

Weight loss and Volume Reduction

A weight loss increase was observed as increasing the thermo rectification temperature (Table 2). As for volumetric reduction, the 245°C treatment caused more wood constituents degradation and consequently higher volumetric retraction. For Poncsák et al. (2006), the hemicelluloses degraded first (between 160°C and 260°C) due to its low molecular weight, and according to Araújo (2010) the lignin content starts to decrease only when the temperature exceeds 200°C, which may explain the weight loss increase for temperature increase.

According to Figueroa & Moraes (2009), the lignin is more thermal resistant than other carbohydrates that comprise the timber. Its thermal degradation is situated between 225°C and 450°C. The cellulose thermal degradation occurs at temperatures between 200ºC and 280ºC with a gradual deterioration which includes depolymerization and dehydration. Thus, the thermal-rectification at 245°C caused more cellulose and lignin polymers degradation than treatment at 200°C.

Table 2. Weight loss and volume reduction caused by thermal treatment.

Treatment	Weight Loss (%)	Volume Reduction (%)
Control	-	-
200°C	4,70 a	3,34 a
245°C	7,55 b	8,45 b

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

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Silva (2011) observed similar results evaluating the behavior of bracatinga wood (*Mimosa scabrella*) thermal-rectified at 220°C, 250°C and 270°C for 90 minutes, with increased weight loss of 9.03%, 21.11% and 23.47%, respectively. Poubel (2011) analyzing the thermal-rectification effect in *Pinus caribea* Morelet technological properties observed weight loss of 9.94% and 21.03% for temperatures at 200°C and 220°C, respectively. Brito et al (2006) evaluating the basic specific weight and *Eucalyptus grandis* wood Swelling, submitted to different thermal-rectification temperatures (120°C, 140°C, 160°C, 180°C and 200°C), observed an increase in weight loss with increasing temperature.

Density

The Density values show a 7.46% and 7.35% reduction for treatment at 200°C and 250°C, respectively. An increased of 0.52% for treatment at 200°C and 5.51% for treatment at 245°C was observed for basic specific weight, as shown in Figure 2. Percentage values in relation to controls. Despite variations, there are non-significant differences. This result may be related to samples volume reduction in the same proportion of weight reduction, according to data mentioned before in Table 2.

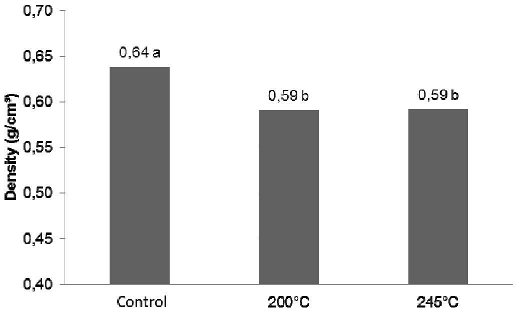

Figure 2. Density of wood samples after thermal treatment.

The wood polymers degradation is reflected in the wood specific weight reduction. The similar values of this variable between both treatments may be explained by the fact that the cellulose and lignin start its degradation at temperatures higher than 200°C. In treatment at 245°C, the short period in which the pieces were maintained at this temperature may justify the non-differentiation between the treatments.

Esteves & Pereira (2009) believe that the hemicellulose degradation in volatiles products and the extractives evaporation are the reason for wood specific weight reduction after thermal treatment.

Silva (2012), assessing the *Corymbia citriodora* and *Pinus tarda* structural parts behavior, thermally treated, observed reductions in specific weight for both species evaluated. Araújo (2010), studying thermo rectification woods properties, observed a small increase in specific weight for peroba mica (*Aspidosperma populifolium*) species, but reported specific weight slight reduction for Cumaru (*Dipteryx odorata*) and *Eucalyptus grandis* species. The specific weight is greatly influenced by the wood heterogeneity, considering that many variables influence the specific weight calculation.

Brito et al. (2006), studying the *Eucalyptus grandis* basic specific weight and Swelling at thermal treatment different temperatures, observed that with increasing temperature, the thermo rectification woods specific weight does not differ statistically. For the authors, the heat action increase was not enough to cause weight loss in the same proportion of woods volume reduction.

Moisture content

The thermal treatment provided a significant reduction in the moisture (Table 3), demonstrating effectiveness in reducing the wood hygroscopicity, since the moisture wet basis expresses the ratio between the product water mass and the total mass. This result is in accordance with other authors (Shi et al., 2007; Fengel & Wegener, 1989; Quirino & Vale, 2002; Borges & Quirino, 2004), who states that the thermal treatment process acts initially degrading the hemicellulose, which are known as the less resistant wood component to the temperature increase. Among the wood components, the hemicellulose show the highest hygroscopic, hence its degradation influences significantly the moisture content which may be reached by wooden parts.

Table 3. Moisture content for the different thermal treatments.

Treatment	Moisture Content (%)
Control	52,38 a
200 °C	45,71 b
245 °C	40,82 c

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

Swelling

The swelling for control samples (treatment at 0°C) is due the water molecules inclusion in spaces between the wood constituent cells and in its amorphous regions, moving them away and causing wood swelling. According to Table 4, the higher the temperature the lower the wood swelling, but the treatment at 245°C caused higher degradation and consequently lower swelling compared to the other treatments.

Table 4. Linear and volumetric swellings for the different thermal treatments.

Treat ment	αL (%)	αT (%)	αR (%)	αV (%)	FAα
Control	1,00 a	10,16 a	8,41 a	20,74 a	1,32 a
200 °C	0,81 a	6,13 b	5,29 b	11,94 b	1,25 a
245 °C	0,01 b	3,69 c	3,23 c	7,75 c	1,19 a

αL = longitudinal swelling, αT = tangential swelling, αR = radial swelling, αV = volumetric swelling e FAα = anisotropy factor. Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

The volumetric swells showed a reduction of 42% and 62% for treatments at

200°C and 245°C respectively, when compared to the original value, but the thermal treatment makes the wood more dimensionally stable when compared to the controls. The lower the volumetric retraction, better is the wood, since there will be lower dimensional movement. The maximum swelling reduction followed the weight loss pattern in thermal modification (Table 2), in which the highest weight loss resulted in large swelling reduction.

Nunes (2009), assessing the thermal treatment effect on *Corymbia citriodora* wood, under two temperature conditions (200°C and 220°C) observed an improvement in the thermal-rectified wood dimensional stability, with significant reductions in the linear and volumetric swells and in the volumetric Swelling.

Araújo (2010), studying the bracatinga (*Mimosa scabrella* Bentham), cumaru (*Dipteryx odorata*), eucalyptus (*Eucalyptus grandis*) and peroba mica (*Aspidosperma populifolium*) woods properties, observed that the volumetric retraction and the anisotropy coefficient did not follow a trend relative to the temperature increase, however, all values were lower than the control. The volumetric Swelling showed significant differences between the treatments, reducing with the temperature increase, making the material more stable, which may be evidenced by the anisotropic factor, which was lower for the treatment at 245°C.

Natural Resistance to Field Deterioration Tests

The weight loss was higher in the controls, followed by treatment at 200°C and lower in the treatment at 245°C as expected in the interaction between weight loss and thermal treatment (Table 5). Non-significant statistical difference was observed between treatments for weight loss. However, it shall be highlighted that the relatively short period for parts exposure (three months) to biodeterioration was not enough for xylophagous organisms to cause significant deterioration.

Table 5. Weight loss according the thermal treatments.

Treatment	Weight Loss (%)
Control	2,76 a
200 °C	2,43 a
245 °C	1,30 a

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

According to Moura et al (2008); Poncsak et al (2006) and Homan et al (2000), the thermal treatment provides the volatilization and/or replacement of wood polysaccharides OH groups by other with hydrophobic character, reducing its hygroscopicity. These alterations reduce the wood balance moisture and the fungi attack potential, because the main xylophagous fungi (staining, molding and decay) attack mainly materials with high moisture content.

Silva (2011) also observed that common bracatinga samples (*Mimosa scabrella*) thermal-rectified at 250°C per 30 to 60 minutes (wrapped in aluminum foil) had not showed weight loss, i.e. they did not suffer xylophagous' fungi attack, being a great indicative that these conditions would be the most suitable for thermal treatment of this wood type.

As shown in Table 6, the weight loss showed significant differences being large in the field compared to the forest. The field tests were carried out between December 2012 and March 2013, rainy season in the northern region of Mato Grosso, which may have caused a flooding (soil saturation) in forest environment, becoming anaerobic the environment where the parts were installed, avoiding xylophagous organisms action. Opposite results to those found by Trevisan et al (2008), which attributed higher existing moisture in forest environment and higher stability in environmental conditions (temperature and moisture) of that place as favorable factors to higher incidence of termites and coleopterans, when compared to open field test.

Table 6. Weight loss according the evaluated environments.

Environment	Weight Loss (%)
Field	3,21 a
Forest	1,12 b

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

The higher field deterioration (Table 7) may be explained by a higher sun exposure in field environment which causes more abrupt drying and wetting processes, and provides the appearance of drying tensions that may cause cracks in the wood. The openings produced by cracking may accumulate moisture, thereby creating a region of greater weakness to fungi attack, and the termites in sequence (MELO et al, 2010).

Table 7. Weight loss according thermal treatment for each evaluated environment.

Treatment	Field (%)	Forest (%)
Control	3,77 a	1,75 ab
200 °C	3,74 a	1,13 ab
245 °C	2,10 ab	0,49 b

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

Moreschi (2011) states that the ideal condition for fungi species development are variable. Thus, the wood may be installed and deteriorated in an environments variety by different fungi species. Thus, the occurrence of one or more species of fungi in the wood is a function, among other aspects, of favorable conditions found in this material.

Ribeiro (2011), evaluating the environmental factors influence in the *Cariniana micrantha* Ducke wood natural durability in field tests, observed weight loss of 6.19% for field environment and 2.57% for forest environment, after 90 days, both performed during the rainy season, where soil waterlogged was verified in the forest.

Within the environment the temperature increase produced a significant reduction in weight loss due to biological deterioration. Table 8 shows that the treatment at 245°C presented the lowest weight loss both in field and forest.

Melo et al. (2010) highlights that the same wood behavior may be different in different environments, since they present characteristics as, insulation, aeration, temperature and xylophagous organisms presence.

Regarding to soil moisture, due to pluviometric high precipitation period, Dionísio (1994) identified a great reduction in the fungi amount in higher pluviometric precipitation periods, when studying permanently soil covered with vegetation.

Ribeiro (2011) highlights that the soil along with climate conditions, such as air temperature, pluviometric precipitation, moisture; pH, organic matter availability and soil aeration, at appropriate levels are important deterioration intermediates. In the rainy season the open field environment is more propitious to decay agents' performance and in the dry season, the forest environment is the most favorable.

Sanity Index

Considering the forest and field environments, it is observed a significant difference existence between them. In open field were observed the weight loss highest percentage, as well as smaller sanity index (Table 8).

Table 8. Sanity Index according the evaluated environments.

Enviroment	Sanity Index
Field	72,75 a
Forest	88,08 b

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

The significant differences between the deterioration environments shows that this variable is sensitive to characterize the natural resistance, similar behavior to that observed when the weight loss was the criterion used.

The mean test for deterioration index (Table 9) for thermal treatment factor demonstrates significant differences between the control treatments and treatments at 250°C, proving to be more sensitive than the weight loss assessment to evaluate the natural wood durability, since when the evaluation criterion was the weight loss (Table 6) the thermal treatments were not significant.

Table 9. Sanity Index according the thermal treatments.

Treatment	Sanity Index
Control	74,12 a
200 °C	82,12 ab
245 °C	85,00 b

Averages followed by the same letter in vertical position not differ statistically (Tukey at 5% probability).

Relations between Weight Loss and Sanity Index

The regression analysis showed a significant adjust between the analyzed variables, with a determination coefficient (R^2) of 0.69 approximately (Figure 3). According to Melo et al (2010), the subjective analysis assigned by notes is the main parameter for assessing the wood durability in decay field test. This methodology is used in tests performed with large dimensions samples, in which visual assessments are carried out periodically, with further reintroduction in the test environment.

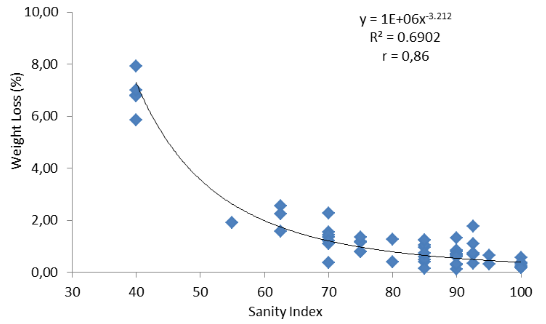

Figure 2. Correlation between weight loss and sanity index.

Lopez & Milano (1986) report that diverse researchers utilizes, besides the visual assessment as sanity index, a second parameter, as mechanical test or weight loss, to better characterize the wood natural durability in field test.

CONCLUSION

The wood dimensional stability improved with thermal treatment. The treatment at 245°C was the most efficient for dimensional stability improving of this species, since it provided the lowest volumetric swelling.

Among the thermal treatment temperatures applied, 245°C was the temperature which produced highest weight loss and volumetric reductions due to wood constituents' degradation.

The thermal treatment provided highest resistance to amescla wood deterioration submitted to different environments. The highest deterioration was observed for samples submitted to open field environment conditions.

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