

# Effects of thermal treatment on the physical properties of *Buchenavia* sp. (branquilha) wood

*Efeitos do tratamento térmico nas propriedades físicas da madeira de Buchenavia sp. (branquilha)*

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## Abstract

This work aimed to evaluate the effect of heat treatment on the physical properties of wood from *Buchenavia* sp. The heat treatments were carried out at temperatures of 180 °C and 200 °C for 2 h. Apparent density (AD), basic density (BD), porosity ( $\Phi$ ), mass loss, longitudinal (LS), radial (RS), tangential (TS) and volumetric (VS) shrinkages and anisotropic factor (AF) were determined. The lowest values of basic density (0.67 g cm<sup>-3</sup>), apparent density (0.77 g cm<sup>-3</sup>), and porosity (43.3%) were observed for the wood treated at a temperature of 200 °C. Mass losses increased with increasing temperature and the highest values were observed under the condition of 200 °C (9.3%). The LS and AF was not affected by heat treatments. The mean values for RS (3.1%), TS (5.1%), and VS (9.1%) were reduced after the performance of heat treatments at temperatures of 180 °C and 200 °C, which did not differ from each other. The thermal treatments were able to reduce the dimensional instability of *Buchenavia* sp. Thermal treatments enhance the use of less prestigious Amazonian woods in the civil construction market.

**Keywords:** Hygroscopicity of wood. Tropical wood. Wood density. Wood shrinkage.

## Resumo

*Objetivou-se avaliar o efeito do tratamento térmico nas propriedades físicas da madeira de Buchenavia sp. Os tratamentos térmicos foram feitos em temperaturas de 180 °C e 200 °C durante 2 h. Avaliou-se a densidade aparente (AD), densidade básica (BD), porosidade ( $\Phi$ ), perda de massa, contração longitudinal (LS), radial (RS), tangencial (TS) e volumétrica (VS) e fator anisotrópico (AF). Os menores valores de densidade básica (0,67 g cm<sup>-3</sup>), densidade aparente (0,77 g cm<sup>-3</sup>) e porosidade (43,3%) foram observados para a madeira tratada em temperatura de 200 °C. As perdas de massa foram crescentes com o aumento da temperatura e os maiores valores foram observados na condição de 200 °C (9,3%). A LS e o AF não foram afetados pelos tratamentos térmicos. Os valores médios para RS (3,1%), TS (5,1%) e VS (9,1%) foram reduzidos após a realização dos tratamentos térmicos nas temperaturas de 180 °C e 200 °C, que não diferiram entre si. Os tratamentos térmicos foram capazes de diminuir a instabilidade dimensional da madeira de Buchenavia sp. Os tratamentos térmicos potencializam o uso de madeiras da Amazônia de menor prestígio no mercado no contexto da construção civil.*

**Palavras-chave:** Densidade da madeira. Higroscopicidade da madeira. Madeira tropical. Retratibilidade da madeira.

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## Introduction

Wood is by far one of the materials more used by mankind from pre-historical times to the present day, mainly due to its excellent and versatile technological properties, which permit its application in several forms, such as: civil construction, flooring, furniture uses, watercraft, musical instruments, pulp and paper, source of chemicals and firewood, among other uses (FIGUEROA; MORAES, 2009; RAMAGE *et al.*, 2017). The anisotropic character of wood can raise some problems along variations in the moisture content, for instance, reflected negatively as twisting, cracking, splitting, bowing and also changes in shape and size of sawn pieces from the green to dry condition (SARGENT, 2019; MASCARENHAS; GHILARDI; MELO, 2020).

Therefore, in order to prevent or even eliminate the occurrence of defects during wood processing and drying, and also to avoid decay during its utilization, some techniques have been successfully developed with more or less efficiency on reducing the hygroscopicity of wood and the gain and loss of moisture with ambient conditions.

Among the processes employed on wood modification, the thermal treatment stands out since it can improve wood properties such as dimensional stability, water resistance and also durability, especially without addition of any type of chemicals (HILL, 2007; JIROUŠ-RAJKOVIĆ; MIKLEČIĆ, 2019). According to Silva *et al.* (2015), the benefits of heat treatments are majorly associated to the degradation of hemicelluloses, which are responsible for a significant role on sorption and desorption of water in the wood cell wall. This way, temperatures for heat treatment are usually in the range of 160 a 260 °C and the higher the temperature is greater will be the losses in mechanical strength of the wood, what can sometimes severely restrain its use for structural applications (ESTEVEZ; PEREIRA, 2009; SILVA *et al.*, 2015; PERCIN; PEKER; ATILGAN, 2016; SANDBERG; KUTNAR, 2016).

The contributions of heat-treated wood are also decisive to a low-carbon economy as presented by kutnar, Sandberg and Haller (2015), who highlighted that new modification processes of the material, such as thermal treatment, are important strategies to offer to the wood some technological applications without changing its eco-friendly characteristics and additionally broadening its fields of use. Other characteristics to be considered when thermal treatment is applied to the wood is the improvement of the color of the heartwood in lighter-colored woods, turning them into a higher-value-added species (FREITAS; GONÇALVEZ; DEL MENEZZI, 2016). However, most of the information on the application of thermal treatment to improve wood quality and value is available for non-Brazilian species.

Within the rationale exposed above, there is a lack in the literature of research works dealing with the use of thermal treatment to improve the quality of low-rated Amazonian wood species. There are so many useful and noble species in the Amazon rainforest that several of them, although having medium or high density and good characteristics for woodworking, only because of one or another physical property such as dimensional stability, for example, or yet for not having good aesthetical characteristics, are left behind at the time of harvesting in sustainable management plans. Within this context, the species *Buchenavia* sp. (Combretaceae), commonly known as “branquilha” (INSTITUTO BRASILEIRO..., 2021; RONDÔNIA, 2021) may be included. Its wood does not have any consolidated market compared to other Amazonian species, despite presenting acceptable physical-mechanical properties to be employed in civil construction, tools handles, and veneering (REIS *et al.*, 2019; INSTITUTO DE PESQUISAS..., 2021). The main limitation of wood of this species is its dimensional instability, which promotes the occurrence of warping and cracking during drying and its use in external applications. Moreover, its light color, within the Brazilian market, is associated to low quality woods. Because of this, it does not have prestige for more noble uses as wood sheeting and furniture, the interior finishing of homes, and frames and sheets for coating engineered wood panels.”

The presented context meets the aspects associated with the technology of the built environment, such as sustainability, the need for technological development in civil construction, and rationalization of costs. The understanding of techniques, such as thermo-rectification, to enhance the use of little-known Amazonian woods, whose aesthetic and technological characteristics are undesirable for the market, can contribute to reduce the overexploitation of species and reduce costs with wood, allowing its application in buildings for uses for which it would not be considered previously. Thus, the objective of the present work was to assess the effects of thermal treatment on the physical properties of the *Buchenavia* sp. wood.

## Material and methods

### Obtaining the samples

In order to obtain the test specimens, in a sawmill located at the municipality of Rolim de Moura (Rondônia State, Brazil), two 0.6 m diameter logs were quarter-sawn by using a band saw and from each log, three radial boards with final dimensions of 2 m length x 0.2 m width x 0.025 m thickness were obtained. Next, the boards underwent resawing to remove sapwood and pith, and as well wood defects such as knots, cracks, and grain slopes.

From each board, 60 test specimens with final dimensions of 0.1 m length x 0.025 m width x 0.025 m thickness were cut, according to procedures described in the standard D143-14 (AMERICAN..., 2014). The test specimens were accurately cut to expose the longitudinal, tangential and radial wood sections.

### Conducting thermal treatment

The samples were conditioned at 20 °C and 65% relative humidity until reaching the hygroscopic moisture content (~12%). This initial condition was established before the heat treatment. After, the test specimens were randomly divided into three groups. Two of them were thermally treated at 180 °C (T1) and 200 °C (T2) for 2 h. The third group of wood samples was maintained untreated and used as a reference. Before starting the thermal treatment, all test specimens were oven-dried for 24 h at  $105 \pm 2$  °C. At this time, the dry mass was measured to calculate the mass loss after thermal treatment.

Treatments T1 and T2 were applied to the test specimens right after the oven-drying. To reach the final temperatures of the respective thermal treatments, a heating rate of 20 °C/5 min was carried out. After 2 h in the respective final temperatures, the oven was switched off and left to cool until reaching 30 °C. After this step, the thermal-treated test specimens were taken to conditioning until reaching constant weight. A microprocessor-controlled oven with electric heating was employed both for drying and heat treatment. All tests were carried out without any gas injection, relying only on atmospheric air inside the equipment, according to the methodology reported by Delucis *et al.* (2014) and Modes, Santini and Haselein (2017).

### Calculation of analyzed variables

The basic density of the wood was determined by following the procedures described in the standard NBR 7190 (ABNT, 1997), and is defined as the ratio between the wood dry mass and the saturated volume of the sample. Saturated volume was determined from the radial, tangential, and longitudinal linear measures. For all samples, the basic density was determined, and for those submitted to thermal treatment that property was evaluated after the experimental treatment.

Following the aforementioned standard, the apparent density of the wood was obtained by the ratio between the mass and the volume of the wood specimen with moisture content equal to 12%. To reach this target moisture content, the wood specimens were conditioned at 65% of relative humidity and temperature of 22 °C in a climatic chamber until reaching equilibrium. The dry masses of the samples were recorded before and after the heat treatments to allow the calculation of the mass loss caused by the heat treatment, as pointed out above.

For radial and tangential faces, in each face, three measures were taken, one in the center and two others in each far end of the specimen with a precision of 0.01 mm, obtaining, this way, the average measures for each face. For the longitudinal face, the average measure of the four faces along the length direction was also taken with a precision of 0.01 mm.

### Statistical analysis

The experiment was set as in an entirely randomized design with three treatments, two temperatures of thermal treatment, and a control witness treatment, respectively, with 60 replicates (test specimens) per experimental treatment. Experimental data were submitted to analysis of variance and when the significant statistical difference was detected, the Scott-Knott test at 95% of probability was applied.

## Results and discussion

As experimentally observed, there were no statistical differences between the values of basic and apparent densities and, also, between the porosity for the wood treated at 180 °C and the control treatment (Table 1). However, the standard deviation for the porosity of the thermally-treated wood was slightly higher when compared to the control.

As pointed out by Percin, Peker and Atilgan (2016), when the wood is heated at a high temperature, it becomes more brittle and its mechanical strength decreases depending on the level and duration of the thermal treatment which is followed by a concomitant decrease in the wood density. So, more likely it occurred in the assessed material, despite no differences in density was observed after the thermal treatment, even though the heat promotes degradation of the wood cell leaving it susceptible to mechanical fatigue (FIGUEROA; MORAES, 2009).

In Table 2, the experimental results for wood mass loss were brought about by the thermal treatment. As observed, there was no statistical difference of mass loss for the wood treated at 180 °C compared to the control. Regarding the mass loss, Delucis *et al.* (2014) discussed that usually, temperatures up to 180 °C are not enough to promote significant mass losses and as well volume decrease of the wood as determined in the present work.

On the other hand, thermal treatment at 200 °C resulted in a concomitant decrease in basic and apparent densities, porosity and mass loss. Within this context, Poubel *et al.* (2013) and Cademartori *et al.* (2015) reported that such a pattern of decrease in these physical properties of the wood is mainly associated with the degradation of the hemicelluloses and extractives, which is followed by a significant decrease in the wood hygroscopicity.

Those components are the most sensitive to temperature and thermal degradation and their both structural and chemical modification are irreversible since the hydroxyl groups are removed by volatilization, and this is the reason why the wood hygroscopicity decreases (BORREGA; KÄRENLAMPI, 2008). Moreover, as temperatures of thermal treatment rise higher is the mass loss, as found by Conte *et al.* (2014) who worked with *Pinus elliottii* wood and determined a mass loss of 6.67% at 210 °C of temperature. The mass losses observed for these species were 4.5 times when compared to their original wood.

As shown in Table 3, the longitudinal shrinkage was not significantly influenced by thermal treatment. Such sort of result is expected since in the longitudinal direction the dimensional variations are negligible around 0.1 and 0.3%, depending on the type of wood, basic density, and either amount and type of extractives.

As observed, a reduction in the radial and tangential shrinkage occurred when compared to the control. Korkut and Guller (2008) pointed out that thermal treatment brings about a decrease in the water sorption capacity of the wood cell walls as a result of the decrease in the number of hydroxyl groups and consequently both radial and tangential shrinkage decrease as well.

Table 1 - Means of basic (BD) and apparent (AD) densities and porosity ( $\Phi$ ) for the of wood *Buchenavia* sp. (branquilha) before and after thermal treatment at 180 °C and 200 °C

Treatments	BD (g cm <sup>-3</sup> )	AD (g cm <sup>-3</sup> )	$\Phi$ (%)
Control	0.70 ( $\pm$ 0.04) a	0.82 ( $\pm$ 0.05) a	45.26 ( $\pm$ 2.84) a
180 °C	0.72 ( $\pm$ 0.05) a	0.83 ( $\pm$ 0.06) a	47.00 ( $\pm$ 3.23) a
200 °C	0.67 ( $\pm$ 0.05) b	0.77 ( $\pm$ 0.06) b	43.31 ( $\pm$ 3.24) b

Note: numbers between brackets are standard deviations; and means followed by different letters are statistically dissimilar by the Scott-Knott test at 95% of probability.

Table 2 - Means of mass loss for the of wood *Buchenavia* sp. (branquilha) before and after thermal treatment at 180 °C and 200 °C

Treatments	Mass Loss (%)
Control	0.0 a
180 °C	2.56 ( $\pm$ 0.99) a
200 °C	9.32 ( $\pm$ 3.95) b

Note: numbers between brackets are standard deviations; and means followed by different letters are statistically dissimilar by the Scott-Knott test at 95% of probability.

**Table 3 - Means of longitudinal (LS), radial (RS), and tangential shrinkage (TS) Means of mass loss for the of wood *Buchenavia* sp. (branquilha) before and after thermal treatment at 180 and 200 °C before and after thermal treatment at 180 °C and 200 °C**

Treatments	LS	RS	TS
	(%)		
Control	0.28 (± 0.25) a	4.60 (± 1.76) a	7.54 (± 1.68) a
180 °C	0.22 (± 0.16) a	3.30 (± 1.04) b	5.59 (± 1.50) b
200 °C	0.25 (± 0.14) a	2.90 (± 0.95) b	4.61 (± 2.37) b

**Note:** numbers between brackets are standard deviations; and means followed by different letters are statistically dissimilar by the Scott-Knott test at 95% of probability.

Usually, the tangential shrinkage is the most affected property when the wood is submitted to thermal treatment and such behavior was observed in the present work where the tangential wood movement decreased in 71% and 63% at temperatures of 180 °C and 200 °C, respectively, when compared to the original wood. The wood radial is commonly twice as less than the tangential one. In this research study, thermal treatment was able to reduce the radial movement by about 74% and 61% for the temperatures of 180 °C and 200 °C.

Since, for the pristine wood of the forest species assessed here, the mean radial and tangential shrinkage are higher than 4% and 7%, respectively, the stability can be classified as medium. After thermal treatment application, the values were reduced to the range of 2.90% to 3.30% for the radial movement and 4.61% to 5.59% for the tangential shrinkage, which led the stability of the wood to be classified as high dimensional (RUFFINATTO; CRIVELLARO; WIEDENHOEFT, 2015).

Bearing in mind the patterns discussed above, for a practical application, it is preferable to employ the thermal treatment at 180 °C because, besides improving dimensional stability of the *Buchenavia* sp. wood, it also caused a smaller mass loss and no alteration on the wood density. On the other hand, as shown in Figure 1, the thermal treatment at 200 °C promoted a higher darkening of the wood. Such a darker color can make some sorts of wood more attractive to the final consumers, depending on the market preferences, as pointed out by Freitas, Gonçalves and Del Menezzi (2016).

In Table 4, the results obtained for the volumetric shrinkage and the anisotropy factor are presented. The values of volumetric shrinkage are statistically different when compared to the control with the decrease in this parameter. However, there were no differences between the two thermal treatments. Once again, as mentioned before concerning the linear shrinkages, the thermal treatment at 180 °C is recommended since it brings about low mass loss.

Additionally, as volumetric shrinkage (VS) is an unwelcome characteristic for many kinds of wood uses, the results accomplished by applying the thermal treatments on the *Buchenavia* sp. wood turned it from medium dimensional stability with VS of 13.81% in the control to high stability with 8.32% and 9.81% of VS for thermal treatment at 180 °C and 200 °C, respectively, results explained by the significant reduction in the combined tangential and radial shrinkages. Nevertheless, no statistical differences were observed in the anisotropy factor (AF) between the control and the thermal treatments, which probably can be due to a proportional decrease in both tangential and radial shrinkages, whose ratio was kept constant.

This way, by comparing the values, the AFs can be considered normal-wood-like since they are in the range of 1.50 and 2.00. As discussed by Melo *et al.* (2013) and Mascarenhas *et al.* (2021a, 2021b), the AF cannot be solely considered as a parameter to define the dimensional stability of wood, because it is not exactly a limiting parameter for its use, since by using proper conditions of drying and woodworking woods with high AF can be normally used without any problems.

Within a general context, the experimental results found in this work showed that 2 h duration thermal treatments at 180 °C and 200 °C can satisfactorily increase the dimensional stability of the *Buchenavia* sp. wood without significant mass losses and alteration on its basic density. The improvement in dimensional stability acquired by thermal treatment enables the wood of the species to be indicated to nobler end uses such as fine furniture, window and door frames, wood sheeting for walls, which typically require more expensive and less widely available woods.

Figure 1 - Color differences among the of wood *Buchenavia* sp. (branquilha) of control (a), before and after thermal treatment at 180 °C (b) and 200 °C (c)

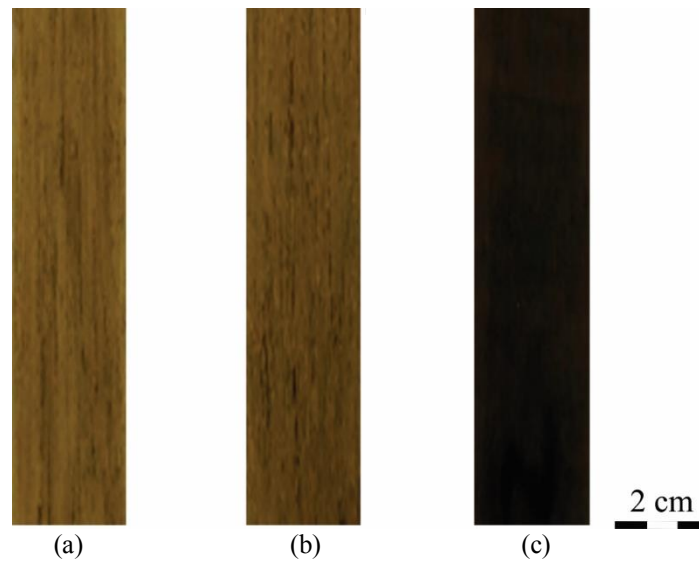


Table 4 - Means of volumetric shrinkage (VS) and anisotropy factor (AF) for the of wood *Buchenavia* sp. (branquilha) before and after thermal treatment at 180 °C and 200 °C

Treatments	VS (%)	AF
Control	13.81 ( $\pm$ 3.55) a	1.86 ( $\pm$ 0.78) a
180 °C	9.81 ( $\pm$ 2.23) b	1.87 ( $\pm$ 0.87) a
200 °C	8.32 ( $\pm$ 3.24) b	1.68 ( $\pm$ 0.85) a

**Note:** numbers between brackets are standard deviations; and means followed by different letters are statistically dissimilar by the Scott-Knott test at 95% of probability.

As observed, the heat treatment contributed to the increase in the dimensional stability of the *Buchenavia* sp. wood to ranges similar to those reported for high-dimensional-stability woods, especially the values presented by Pereira (2013) for the radial, tangential, and volumetric shrinkages. Moreover, there was a color alteration of the wood becoming darker, which can make it more attractive for uses such as siding or fine finishing. Therefore, woods commonly employed for those uses such as cumaru (*Dipteryx odorata*) and ipê (*Tabebuia impetiginosa*) may be substituted by the forest species assessed after thermal treatment in this work. More likely, these new possibilities of use can contribute to decrease the overexploitation of small groups of tropical forest species (REIS *et al.*, 2019; MASCARENHAS *et al.*, 2021c), since now an unconventional species, when properly heat-treated, can present similar characteristics to those traditionally marketed. These aspects are in context with the technology from the built environment, given that they are based on sustainability, the need for technological development in the production of civil construction, and the rationalization of costs.

## Conclusions

Thermal treatments with 2 h of duration at 180 °C and 200 °C increased significantly the dimensional stability of *Buchenavia* sp. wood with the decrease of basic density and concomitant mass loss as temperature increased. The longitudinal shrinkage was not significantly influenced by thermal treatment. The application of thermal treatment at 180 °C is recommended when the objective is to obtain improvements in dimensional stability with negligible mass loss and minimum alterations in the basic density.

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