Floresta e Ambiente 2014 jan./mar.; 21(1):108-113
http://dx.doi.org/10.4322/floram.2014.004
ISSN 1415-0980 (impresso)
ISSN 2179-8087 (online)

Original Article

Effect of Thermal Modification on the Physical Properties of Juvenile and Mature Woods of *Eucalyptus grandis*

Fred Willians Calonego[1], Elias Taylor Durgante Severo[1], João Vicente de Figueiredo Latorraca[2]

[1]Departamento de Ciência Florestal, Universidade Estadual Paulista – UNESP, Botucatu/SP, Brasil
[2]Departamento de Produtos Florestais, Universidade Federal Rural do Rio de Janeiro – UFRRJ, Seropédica/RJ, Brasil

ABSTRACT

This study aimed to evaluate the effect of thermal treatment on the physical properties of juvenile and mature woods of *Eucalyptus grandis*. Boards were taken from 30-year-old *E. grandis* trees. The boards were thermally modified at 180 °C in the Laboratory of Wood Drying and Preservation at UNESP, Botucatu, Sao Paulo state, Brazil. The results showed that thermal modification caused: (1) decrease of 6.8% in the density at 0% equilibrium moisture content of mature wood; (2) significant decreases of 14.7% and 35.6% in the maximum volumetric swellings of juvenile and mature woods, respectively; (3) significant decreases of 13.7% and 21.3% in the equilibrium moisture content of juvenile and mature woods, respectively. The influence of thermal modification in juvenile wood was lower than in mature wood and caused greater uniformity in the physical variations between these types of wood in *E. grandis*.

Keywords: thermally-modified wood, eucalyptus, maximum swellings, wood density.

Efeito da Termorretificação nas Propriedades Físicas dos Lenhos Juvenil e Adulto de *Eucalyptus grandis*

RESUMO

Este estudo teve como objetivo avaliar o efeito do tratamento de modificação térmica nas propriedades físicas dos lenhos juvenil e adulto da madeira de *Eucalyptus grandis*. Para tanto, tábuas centrais foram obtidas de árvores de *E. grandis* com 30 anos de idade. Esse material foi modificado termicamente a 180 °C no Laboratório de Secagem e Preservação de Madeiras da UNESP, Botucatu-SP, Brasil. Os resultados mostraram que o tratamento de modificação térmica ocasionou: (1) decréscimo de 6,8% na densidade a 0% de umidade no lenho adulto; (2) redução significativa de 14,7% e 35,6% nos inchamentos volumétricos máximos dos lenhos juvenil e adulto, respectivamente; (3) diminuição significativa de 13,7% e 21,3% no teor de umidade de equilíbrio dos lenhos juvenil e adulto, respectivamente. A influência da modificação térmica no lenho juvenil foi menor do que no lenho adulto e ocasionou uma maior uniformização nas propriedades físicas entre esses dois tipos de lenho da madeira de *E. grandis*.

Palavras-chave: madeira modificada termicamente, eucalipto, inchamentos máximos, densidade da madeira.

1. INTRODUCTION

The heterogeneity of wood generally causes much inconvenience to manufacturing and processing industries. Material physical discontinuity occurs owing to several factors: species, silviculture, and mainly, wood anatomy. Juvenile wood can be defined as being close to the pith and it differs technologically from mature wood on account of several properties (Bao et al., 2001; Calonego et al., 2005; Ferreira et al., 2011; Zobel & Van Buijtenen, 1989).

Specific gravity values of 0.807 g/cm³ and 0.893 g/cm³ were found for juvenile and mature wood of *Eucalyptus citriodora*. The values of tangential and radial shrinkage in the juvenile wood of this species were 10.06% and 7.39%, whereas the mature wood showed values of 10.61% and 8.70%, respectively (Bao et al., 2001).

The density at 0% moisture content of 5.9-year-old *Eucalyptus citriodora* was 0.477 g/cm³, whereas the volumetric, tangential and radial swellings of this wood were 14.12%, 9.42% and 3.93%, respectively (Calonego et al., 2012).

However, thermal treatment with high temperatures causes degradation in the hemicelluloses and in the amorphous region of cellulose, thereby contributing to the increase in the degree of crystallinity of this polymer. In addition, a cross-linkage between lignin and polymers occurs owing to the thermal degradation of wood, which is responsible for decreased hygroscopicity and improved dimensional stability (Bächle et al., 2010; Bhuiyan et al., 2000, 2001; Calonego et al., 2010, 2012; Metsä-Kortelainen et al., 2005; Severo et al., 2012; Vernois, 2001; Wikberg & Maunu, 2004).

Brito et al. (2008) showed that the thermal treatment of *Eucalyptus saligna* at 180 °C caused a decrease of up to 53.2%, 62.8%, 33.8%, and 35.1% in the contents of arabinose, galactose, mannose, and xylose, respectively. There was a proportional increase of up to 32.5% in the lignin content of wood because of degradation in the hemicelluloses.

According to Vernois (2001), wood that is thermally modified at 200 °C presents smaller hygroscopicity than that of untreated wood, and stabilizes at approximately 4% to 5% equilibrium moisture content, as opposed to 10% to 12% in untreated wood.

Arnold (2010) showed that the thermal treatment of *Picea abies* at 180-220 °C caused a decrease of 60% in the equilibrium moisture content. According to the author, the thermal treatment caused a reduction of 5% in the density at 0% moisture content.

On the other hand, wood of *Eucalyptus globulus* thermally modified at 190-210 °C presented weight loss and improvement in equilibrium moisture content and dimensional stability of 14.5%, 61.0%, and 90.0%, respectively (Esteves et al., 2007). Brito et al. (2006) verified that the thermal treatment of *Eucalyptus grandis* at 200 °C caused a decrease of 25% in the volumetric shrinkage.

Wood of *Eucalyptus grandis* thermally modified at 220 °C presented improvement in the equilibrium moisture content and in the volumetric, tangential, radial and axial swellings of up to 49.3%, 53.3%, 57.0%, 39.7%, and 77.4%, respectively (Calonego et al., 2012).

However, compared with mature wood, juvenile wood is characterized by high lignin content, which presents an adverse effect on its chemical modification (Severo et al., 2012). Regarding *Pinus sylvestris,* the influence of acetylation on the weight loss of juvenile wood was approximately 50% lower than on that of mature wood (Papadopoulos, 2006).

The aim of this study was to evaluate the effects of thermal treatment on the physical properties of juvenile and mature wood of *Eucalyptus grandis*, considering that there is little information on the subject in the literature.

2. MATERIAL AND METHODS

This study utilized wood from 30-year-old *E. grandis* trees from the Forestry Institute of Sao Paulo located in the municipality of Manduri, Sao Paulo state, Brazil. Four trees were felled and sectioned into 2.9 m-long logs. The first log from each tree with diameters between 30 and 35 cm were cut into flat sawn boards. The boards that contained the pith were cut into 28-mm-thick pieces for this study. Subsequently, all the boards were dried up to 10.0% moisture content in a dry kiln with capacity of approximately 2.5 m³ of wood.

2.1. Thermal treatment of boards

The four dried boards were planed to 24-mm thickness and cut into smaller pieces measuring 0.60 m in length. Regions with cracks and knots were discarded. One of these smaller pieces was kept in its original condition (untreated wood), and the other pieces were reserved for the thermal treatment (thermally modified wood).

The material was placed in an electric oven with a programmable controller. The treatment proceeded in steps from an initial temperature of 100 °C, and then to 180 °C for 2.5 h, according to the application of patent developed by Severo & Calonego (2009). At the end of the thermal treatment, the oven was turned off and the wood pieces were kept inside. The pieces were allowed to cool naturally until they reached 30 °C.

Subsequently, specimens were removed from all the boards (untreated and thermally modified woods) according to the standards presented in ABNT NBR-7190 (1997) for the physical characterization of juvenile and mature woods. The juvenile and mature wood regions were defined according to Oliveira et al. (1997). The anatomical characterization of the wood used in this study showed that juvenile wood is confined at approximately up to 80 mm from the pith.

2.2. Physical property test of wood

The untreated and thermally modified wood specimens were placed in an oven at 103±2 °C and were maintained under this condition until they reached 0% moisture content.

The specimens were then placed in a climatic chamber in the Laboratory of Wood Drying and Preservation in the Department of Natural Resources/ Forest Sciences, (FCA – UNESP), Botucatu, Sao Paulo state Brazil. The climatic chamber was adjusted to 21 °C and 65% relative humidity (RH) until the specimens reached equilibrium moisture content.

After that, the specimens were submerged in water until the cell walls were completely saturated. After each hygroscopic phase, the samples were weighed and their dimensions were measured using a 0.01-g accuracy balance and a 0.01-mm accuracy micrometer.

For the evaluation of physical properties (density at 0% moisture content, equilibrium moisture content, and maximum swellings), analysis of variance with 95% probability was performed taking into account the type of wood and thermal treatment.

3. RESULTS AND DISCUSSION

The density at 0% moisture contents of juvenile and mature wood of untreated *Eucalyptus grandis* were 0.585 and 0.778 g/cm^3, respectively (Table 1). These results are similar to those reported by Bao et al. (2001), Brito et al. (2006), and Calonego et al. (2012).

The equilibrium moisture contents of untreated and thermally modified (180 °C) juvenile wood, when acclimatized at 21 °C and 65% RH, were 9.5% and 8.2%, respectively. In mature wood, the respective moisture contents were 9.4% and 7.4%.

It was possible to verify that the equilibrium moisture contents of untreated juvenile and mature woods of *Eucalyptus grandis* were statistically equal. Therefore, according to Bao et al. (2001), Calonego et al. (2005), Severo et al. (2012), and Zobel & Van Buijtenen (1989), this result can be explained as follows: mature wood presents a higher number of hydroxyl groups available to adsorb moisture and juvenile wood presents thinner cell wall fibers, which facilitates the diffusion of moisture in wood.

It was also possible to note that the equilibrium moisture content of untreated woods was only between 9.4 and 9.5% because of a phenomenon known as hysteresis. However, as it can be seen in Table 1, thermal treatment at 180 °C promoted significant reductions of 13.7% and 21.3% in the equilibrium moisture content of juvenile and mature woods. The greatest weight loss in mature wood of *Eucalyptus grandis* due to thermal modification can explain the reduction in its equilibrium moisture content after thermal treatment. Similar improvements were reported by Vernois (2001), Esteves et al. (2007), Metsä-Kortelainen et al. (2005), Arnold (2010), and Calonego et al. (2012) for other types thermally modified wood.

It can be verified in Table 1 that the volumetric, tangential, radial, and axial swellings in untreated juvenile wood of *E. grandis* were 20.90%, 11.84%, 7.79%, and 0.269%, respectively; in untreated mature

Table 1. Physical properties of thermally modified juvenile and mature wood of *Eucalyptus grandis*.

Wood	Density at 0% Moisture Content (g/cm³)					Equilibrium Moisture Content at 21 °C and 65% RH (%)				
	N	U	N	TM	Reduction or (Increase) %	N	U	N	TM	Reduction %
Juvenile	10	0.585	16	0.586	**(0.2)**NS	10	9.5	16	8.2	**13.7***
Mature	18	0.778	20	0.725	**6.8**NS	18	9.4	20	7.4	**21.3***
Reduction or (Increase) %		**(33.0)***		**(23.7)***			**1.1**NS		**9.8***	

Wood	Maximum Volumetric Swelling (%)					Maximum Axial Swelling (%)				
	N	U	N	TM	Reduction %	N	U	N	TM	Reduction %
Juvenile	10	20.90	16	17.82	**14.7***	10	0.269	16	0.163	**39.4***
Mature	18	29.04	20	18.70	**35.6***	18	0.298	20	0.129	**56.7***
Reduction or (Increase) %		**(38.9)***		**(8.7)**NS			**(10.8)***		**20.9***	

Wood	Maximum Tangential Swelling (%)					Maximum Radial Swelling (%)				
	N	U	N	TM	Reduction %	N	U	N	TM	Reduction %
Juvenile	10	11.84	16	10.25	**13.4**NS	10	7.79	16	6.68	**14.2***
Mature	18	17.23	20	10.52	**38.9***	18	9.74	20	7.26	**25.5***
Reduction or (Increase) %		**(45.5)***		**(2.6)**NS			**(25.0)***		**(8.7)**NS	

Where: N - repeated number of samples; U - untreated wood; TM - thermally modified wood; * - significantly different by the F test at 95% probability; NS - non-significantly different.

wood of *E. grandis*, the respective swellings were 29.04%, 17.23%, 9.74%, and 0.298%. These results are consistent with those obtained by Bao et al. (2001), and are similar to those reported by Brito et al. (2006) and Calonego et al. (2012) for *E. grandis* wood.

In addition, the effect of thermal treatment on the dimensional instability of *E. grandis* wood is shown in detail in Table 1.

The current study demonstrates that the thermally modified juvenile wood of *E. grandis* showed reductions of up to 14.7%, 13.4%, 14.2%, and 39.4% in the volumetric, tangential, radial, and axial linear swellings, respectively, compared with the values found for untreated wood. Mature wood, when thermally modified, presented reductions of up to 35.6%, 38.9%, 25.5%, and 56.7% in those respective swellings.

Similar results were presented by Brito et al. (2006), who found that the thermal treatment of *E. grandis* at 200 °C caused a decrease of 25% in volumetric shrinkage, and by Calonego et al. (2012), who concluded that wood of *E. grandis* thermally modified at 220 °C presented improvement in the volumetric, tangential, radial and axial swellings of 53.3%, 57.0%, 39.7%, and 77.4%, respectively.

However, these improvements were slightly lower than those found by Esteves et al. (2007), because in that study the author applied treatments with steam as an inert fluid. Thus, this variation is consistent with that reported by Bhuiyan et al. (2000) and Arnold (2010), who found an increase in the degradation of the hemicelluloses by acid hydrolysis under high humidity.

Table 1 shows that the influence of thermal treatment on juvenile wood was lower than on mature wood and that thermal modification caused a greater uniformity in the physical properties of juvenile and mature wood. Similar results were reported by Papadopoulos (2006) and Severo et al. (2012) for thermally treated *Pinus* wood. According to the authors, juvenile wood presents an adverse effect on the modification because of its chemical composition.

However, the improvement of dimensional stability in thermally modified wood was explained by Bhuiyan et al. (2000, 2001) and Bächle et al. (2010) as resulting from increases in the degree of crystallinity and the width of crystallites of cellulose, and by Arnold (2010), Bächle et al. (2010), Brito et al. (2008), Calonego et al. (2010), Esteves et al. (2007), Metsä-Kortelainen et al. (2005), Severo et al. (2012), Vernois (2001), and Wikberg & Maunu (2004) as owing to degradation in the hemicelluloses of the free hydroxyl groups in the amorphous region of cellulose and the cross-linkage of wood polymers during thermal treatment.

In verifying the effects of thermal treatment on the physical properties of *E. grandis* wood, it was found that temperatures up to 180 °C promoted improvement of dimensional stability without losses of material by internal cracks. These results are similar to those reported by Bhuiyan et al. (2001), Calonego et al. (2012), Metsä-Kortelainen et al. (2005), Severo et al. (2012), Vernois (2001), and Wikberg & Maunu (2004) for thermally modified wood of other species.

4. CONCLUSIONS

Thermal treatment produced the following effects on the physical properties of *E. grandis*: (1) decrease of 6.8% in the density at 0% equilibrium moisture content of mature wood; (2) significant decreases of 14.7% and 35.6% in the maximum volumetric swellings of juvenile and mature wood, respectively; (3) significant decreases of 13.7% and 21.3% in the equilibrium moisture content of juvenile and mature wood, respectively. It was demonstrated that the influence of thermal modification on juvenile wood was smaller than on mature wood. Finally, thermal modification reduced the physical variations between these types of wood and caused a greater uniformity of lumber.

ACKNOWLEDGEMENTS

The authors are grateful to the Coordination for the Improvement of Higher Education Personnel (CAPES), Brazil, for the financial support (grant number PNPD-02405/09-1).

SUBMISSION STATUS

Received: 06/20/2013
Accepted: 12/03/2013
Published: 02/31/2014

CORRESPONDENCE TO

Fred Willians Calonego
Departamento de Ciência Florestal,
Universidade Estadual Paulista – UNESP,
CEP 18610-307, Botucatu, SP, Brasil
e-mail: fwcalonego@ig.com.br

REFERENCES

Arnold M. Effect of moisture on the bending properties of thermally modified beech and spruce. *Journal of Material Science* 2010; 45: 669-680. http://dx.doi.org/10.1007/s10853-009-3984-8

Associação Brasileira de Normas Técnicas. *ABNT NBR 7190*: Ações nas estruturas, propriedades da madeira e dimensionamento nos estados limites de utilização. Rio de Janeiro; 1997.

Bächle H, Zimmer B, Windeisen E, Wegener G. Evaluation of thermally modified beech and spruce wood and their properties by FT-NIR spectroscopy. *Wood Science and Technology* 2010; 44: 421-433. http://dx.doi.org/10.1007/s00226-010-0361-3

Bao FC, Jiang ZH, Jiang XM, Lu XX, Luo XQ, Zhang SY. Differences in wood properties between juvenile wood and mature wood in 10 species grown in China. *Wood Science and Technology* 2001; 35: 363-375. http://dx.doi.org/10.1007/s002260100099

Bhuiyan TR, Hirai N, Sobue N. Changes of crystallinity in wood cellulose by heat treatment under dried and moist conditions. *Journal of Wood Science* 2000; 46: 431-436. http://dx.doi.org/10.1007/BF00765800

Bhuiyan TR, Hirai N, Sobue N. Effect of intermittent heat treatment on crystallinity in wood cellulose. *Journal of Wood Science* 2001; 47: 336-341. http://dx.doi.org/10.1007/BF00766782

Brito JO, Garcia JN, Bortoletto G Jr, Pessoa AMC, Silva PHM. Densidade básica e retratibilidade da madeira de *Eucalyptus grandis*, submetida a diferentes temperaturas de termorretificação. *Cerne* 2006; 12(2): 182-188.

Brito JO, Silva FG, Leão MM, Almeida G. Chemical composition changes in eucalyptus and pinus woods submitted to heat treatment. *Bioresource Technology* 2008; 99: 8545-8548. http://dx.doi.org/10.1016/j.biortech.2008.03.069

Calonego FW, Severo ETD, Assi PP. Mensuração do comprimento das fibras para a determinação da madeira juvenil em *Eucalyptus citriodora*. *Scientia Forestalis* 2005; (68): 113-121.

Calonego FW, Severo ETD, Ballarin AW. Physical and mechanical properties of thermally modified wood from *E. grandis*. *European Journal of Wood and Wood Products / Holz als Roh- und Werkstoff* 2012; 70(4): 453-460. http://dx.doi.org/10.1007/s00107-011-0568-5

Calonego FW, Severo ETD, Furtado EL. Decay resistance of thermally-modified *Eucalyptus grandis* wood at 140°C, 160°C, 180°C, 200°C and 220°C. *Bioresource Technology* 2010; 101(23): 9391-9394. http://dx.doi.org/10.1016/j.biortech.2010.06.119

Esteves B, Marques AV, Domingos I, Pereira H. Influence of steam heating on the properties of pine (*Pinus pinaster*) and eucalypt (*Eucalyptus globulos*) wood. *Wood Science and Technology* 2007; 41: 193-207. http://dx.doi.org/10.1007/s00226-006-0099-0

Ferreira AL, Severo ETD, Calonego FW. Determination of fiber length and juvenile and mature wood zones from *Hevea brasiliensis* trees grown in Brazil. *European Journal of Wood and Wood Products / Holz als Roh- und Werkstoff* 2011; 69: 659-662. http://dx.doi.org/10.1007/s00107-010-0510-2

Metsä-Kortelainen S, Anitikainen T, Viitaniemi P. The water absorption of sapwood and heartwood of Scots pines and Norway spruce heat-treated at 170°C, 190°C, 210°C and 230°C. *European Journal of Wood and Wood Products/Holz als Roh- und Werkstoff* 2005; 64: 192-197. http://dx.doi.org/10.1007/s00107-005-0063-y

Oliveira JTS. *Caracterização da madeira de eucalipto para a construção civil* [tese]. São Paulo: Escola Politécnica, Universidade de São Paulo; 1997.

Papadopoulos AN. Pyridine-catalyst acetylation of pine wood: influence of mature sapwood vs juvenile wood. *European Journal of Wood and Wood Products/Holz als Roh- und Werkstoff* 2006; 64: 134-136. http://dx.doi.org/10.1007/s00107-005-0056-x

Severo ETD, Calonego FW. *Processo de modificação térmica, por irradiação de calor, para a melhora da estabilidade dimensional e da durabilidade biológica de madeira sólida*. BR PI 0902/38-8A2, 2009 junho 24.

Severo ETD, Calonego FW, Sansígolo CA. Physical and chemical changes in juvenile and mature woods of *Pinus elliottii* var. *elliottii* by thermal modification. *European Journal of Wood and Wood Products / Holz als Roh- und Werkstoff* 2012; 70(5): 741-747. http://dx.doi.org/10.1007/s00107-012-0611-1

Vernois M. Heat treatment of wood in France: state of the art. In: *Special Seminar*: Environmental Optimisation of Wood Protection; 2001. Antibes: COST ACTION E 22; 2001. p. 39-46

Wikberg H, Maunu SL. Characterization of thermally-modified hard- and softwoods by 13C CPMAS NMR. *Carbohydrate Polymers* 2004; 58: 461-466. http://dx.doi.org/10.1016/j.carbpol.2004.08.008

Zobel BJ, Van Buijtenen JP. *Wood variation: its causes and control*. New York: Springer-Verlag; 1989. http://dx.doi.org/10.1007/978-3-642-74069-5