ISSN impresa 0717-3644
ISSN online 0718-221X
Maderas. Ciencia y tecnología 20(3): 489 - 498, 2018
DOI: 10.4067/S0718-221X2018005031801

NATURAL DURABILITY ASSESSMENT OF THERMO-MODIFIED YOUNG WOOD OF *Eucalyptus*

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In memoriam of Dr. Thomas C. MANNES

ABSTRACT

This study focuses on the effect on wood strength and natural durability of *Eucalyptus globulus* and *Eucalyptus botryoides* when subjected to heat treatments with low energy consumption. The objective was to improve the wood durability, without negatively impacting the strength properties. Six-year-old trees from *Eucalyptus globulus* and *Eucalyptus botryoides* were used.

The samples were heat treated for 4 h conditioned to very low oxygen availability. A field test for assessing the resistance to termites and fungal degradation was conducted according to EN 252:1989/ AC1:1989 Inspections were made every six months for 3 years. All the samples of *Eucalyptus globulus* showed signs of termite and microorganisms attack, most showing extensive galleries. *Eucalyptus botryoides* wood showed no sign of termite attack and only few traces of microrganisms presence. The wood bending strength was smaller upon thermal treatment for both species, decreasing 3.8% and 4.8% for *Eucalyptus globulus* and *Eucalyptus botryoides*, respectively. Overall the results are promising regarding some common utilizations, mainly floor coverings, decks, doors and door and window frames, fences (only for *Eucalyptus botryoides*), decorative arbors and pergolas (only for *Eucalyptus botryoides*) but excluding structural beams for building roofs or bridges due to the fragility of the wood treated thermally towards impacts.

Keywords: *Eucalyptus botryoides, Eucalyptus globulus,* mechanical properties, shrinkage, termites, wood degradation.

INTRODUCTION

Wood is a biological material vulnerable to several biotic agents such as fungal degradation and termite attacks that are a major threat to the service-life of wood. Wood durability depends on species, heartwood and sapwood distribution, chemical composition e.g. extractives and lignin content and composition, density, moisture content, and conditions of use (Panshin and de Zeew 1980). The service-life of wood products depends primarily on the specific wood durability (Kollmann and Côté 1984). However, the determination of characteristic strong timbers or the utilization of additive treated wood segments are affected by cost and end-utilize prerequisites (e.g. measurements).

Termites are one of the most successful groups of insects that feed on dead plant material and cellulose, generally in the form of wood, leaf litter, soil, or animal dung (Cruz *et al.* 2015). Various woods differ in their susceptibility to termite attack; the differences are attributed to factors such as moisture content, hardness, and resin and lignin content (Cruz *et al.* 2015). Important biological

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Received: 19.07.2017 Accepted: 08.03.2018

attacks that may strongly impact wood in-use performance result from termites. When feeding on wood, termites compromise the mechanical and physical properties. The durability of various tropical timbers feeding termite attacks was assessed in several studies (Arango *et al.* 2006, Peralta *et al.* 2004, Takamura 2001, Tsunoda 1990). A positive relationship was found between specimen dimension and natural resistance (Antwi-Boasiako and Allotey 2010), and wood resistance in ground contact was proportional to its thickness (Trada 1984).

Several treatments have been investigated to increase the wood resistance against termites. For example, application of waxes and paraffin impregnation (Esteves *et al.* 2014, Lesar and Humar 2010, Scholz *et al.* 2010), and wood smoking (Hadi *et al.* 2010) showed dependence of termite resistance on the type and intensity of treatments e.g. wood smoking had no effect on resistance. A recent study on termite resistance of pine wood treated with zinc- and copper-based nanocompounds showed a strong inhibition of termite feeding (Mantanis *et al.* 2014). Acetylated radiata pine and furfurylated Southern yellow pine were tested against Mediterranean termites and these two wood modification processes were considered as alternative preventive treatments (Gascón-Garrido *et al.* 2013).

The thermal treatment is also a wood modification method that improves dimensional stability, decreases hygroscopicity, and enhances durability except when in direct contact with the soil (Esteves *et al.* 2007, Nguyen *et al.* 2012).

Heat treatment of wood changes its chemical composition by altering cell wall compounds and extractives leading to mass loss, and also affects the anatomical structure of wood and its physical properties (Esteves *et al.* 2008, Esteves *et al.* 2007). Wood colour is also altered by darkening and becomes uniform throughout the thickness of wood (Esteves *et al.* 2008, Guller 2012). Research on wood thermal modifications is quite active and several wood species and treatment conditions have been studied (Araújo *et al.* 2016, Doi *et al.* 1999, Esteves and Pereira 2009, Manabendra *et al.* 2002).

The thermal treatment of wood has been successfully applied by the wood industry (Zhang *et al.* 2013), and Guller (2012) reports that there are 30 companies operating across Europe, mainly in Finland (40%), Germany (13%), Netherlands (12%) and Estonia (8%). The thermally treated wood is applied for exterior uses such as decks, fences, garden furniture, doors and windows and for interior uses like kitchen furniture, parquet and panels (Esteves *et al.* 2007).

Eucalypt species have been increasingly considered for thermal treatments aiming at their use for high quality solid wood products because they have high mechanical performances, few knots and are suitable for glued joints. e.g. *E. grandis* (Bal *et al.* 2013), *E. globulus* (Esteves *et al.* 2007, Santos 2000). *E. globulus* presents a slow and difficult drying process with low dimensional stability (Santos 2000) and the heat treatment allowed improvements regarding a decreased moisture equilibrium and surface wettability, and an increased dimensional stability (Esteves *et al.* 2007). Thermally treated wood of *E. botryoides* also showed an increase in dimensional stability (Delucis *et al.* 2014) as well as several tropical species (Araújo *et al.* 2016).

This study analyses the effect on wood natural durability and strength of *Eucalyptus globulus* and *Eucalyptus botryoides*, when subjected to heat treatments with low energy consumption.
The objective is to improve the wood quality of these two eucalypt species regarding durability, but without negatively impacting the strength properties.

MATERIALS AND METHODS

For this study, 6-year-old trees from *E. globulus* (heartwood and sapwood) and *E. botryoides* were used. The trees were grown in rows with 3mx3m spacing (without fertilization) on an experimental site located in the campus fields of the School of Agriculture, University of Lisbon (ULisboa), at Tapada da Ajuda, Lisboa, Portugal (38°42´N; 09°10´W). The trees were cut into small logs (0,5 m length) of which samples were taken according to standard demands.
The wood samples were air-dried by conventional methods until below 13% moisture content.

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Wood boards were cut to 30 mm thickness, 200 mm width and 400 mm length. The samples were introduced in a metallic box that was filled with wood pieces of other dimensions in order to obtain an almost full space occupation, and the remaining space filled with an inert material (fine sand) (Santos *et al.* 2016) assuring a maximum of 2 % oxygen content. The box was closed by an appropriate cover and introduced in the laboratorial oven provided with internal ventilation. The treatment was done at 210 ºC during 4 h in a closed atmosphere (with the temperature inside the box rising previously at a rate of approximately 50 ºC per h), conditioned to very low oxygen availability (Santos *et al.* 2016). For wood to not combust, it is necessary to condition the surrounding environment, preventing the arrival of oxygen, which is achieved in this invention by immersing the wood in a medium consisting of solid particles, very fine sand, mixed or not with reducing agents which preferentially consume the available oxygen.

The thermally treated and the non-treated board samples (containing only sapwood) were cut to the specific dimensions required by the physical and mechanical tests (modulus of elasticity, bending strength, tangential and radial shrinkage, and density) according to BS 373, EN 408, EN 1910, and IPQ-NP 616-1973 and the natural durability assessment tests following the "Field test method for determining the relative protective effectiveness of a wood preservative in ground contact" (EN 252). The field (Figure 1) was located in the campus of the School of Agriculture; the region is under the influence of a meso-thermal humid climate, with a dry season in the summer extending from June to August, and registering above 10°C in the coldest month and below or equal to 22°C in the hottest month, and the soil is a Vertisol characterized by a fine, or medium to fine, texture, derived from tuffs or basalts, frequently with limestone on the inferior horizons, or from calcareous rock (in much less extension). No studies were made to establish the species of termites present in the field. The wood stakes, with 500±1 mm x 80±0,3 mm x 25±0,3 mm (axial, tangential, radial), were inserted vertically to half their length in the soil (Figure 1). The distribution of the wood samples per species was made randomly.

Figure 1. Field test for wood durability: preparation of the samples (left); samples placed in the ground according to EN 252:1989/AC1:1989 specifications.

Inspections were made every six months, and the results in this paper contemplate inspections made at 6, 12, 18 and 36 months. On each inspection, the stakes were removed from the ground, cleaned, and a visual classification was conducted with images of the wood stakes recorded to register signs of termite and microorganisms attack. Table 1 displays the standard rating system. After examination, the stakes were re-installed in the ground taking in the same positions.

Table 1. Rating system for the visual classification inspection (EN 252).

Class	Class Designation	Features
0	No attack	No signs
1	Mild attack	Superficial signs of attack
2	Medium attack	Attack signs to 2 to 5 mm depth
3	Severe attack	Attack signs with 4 to 10 mm depth with interior galleries
4	Rupture	Total penetration or destruction

Mechanical testing was made using a Shimadzu AG-I universal machine type 250, with a 250 kN force sensor. The bending strength and modulus of elasticity were determined in agreement with the standard IPQ-NP 619-1973.

RESULTS AND DISCUSSION

Table 2 presents the results on wood properties of untreated and thermally treated *E. globulus* and *E. botryoides* bending modulus of elasticity (MOE), modulus of rupture (MOR), radial and tangential shrinkage, and density. Density decreased in the thermally treated samples by 9% for *E. globulus* and 7% for *E. botryoides*. The heat-treated wood showed a decrease of radial and tangential shrinkage, for both species but the difference was higher for *E. botryoides*, especially for the tangential shrinkage. MOE and MOR were affected by the thermal treatment. This behaviour is consistent with former results obtained for *E. globulus* (Esteves *et al.* 2007).

Table 2. Wood properties of untreated and thermally treated *E. globulus* and *E. botryoides*.

	Eucalyptus globulus		*Eucalyptus botryoides*	
	Natural	Thermally treated	Natural	Thermally treated
Tangential shrinkage (%)	16,7	12,4	13,0	4,7
Radial shrinkage (%)	7,5	6,2	6,4	2,6
MOE (MPa)	13 909	13 379	11 021	10 488
MOR (MPa)	111	102	100	82
Density (kg.m^{-3})	732	664	821	765

Overall MOE was less affected by the heat treatment than MOR, which is in accordance with Bengtsson *et al.* (2002) and Esteves *et al.* (2007). *E. globulus* showed a MOE decrease of 4%. Studies with *E. globulus* found that MOE decreased 5% until 8% mass loss and 15% for a 13% mass loss (Esteves *et al.* 2007), and similar results were found for *E. saligna* (Vital *et al.* 1983). Contrary to these results *E. botryoides* showed an increase of 4%, a tendency supported by Santos (2000) who reported an increase in MOE using *E. globulus*.

The wood bending strength was smaller upon thermal treatment for both species, decreasing 3,8% and 4,8% for *E. globulus* and *E. botryoides*, respectively. These values are in accordance with studies for *E. globulus* (Esteves *et al.* 2007).

Figure 2 and Figure 3 display images of the samples after 36 months of ground contact. The termite damage was characterized by the occurrence of channels excavated inside the wood stakes, whereas the attack by microorganisms was shown by the presence of spots and stains (white or green). The decay was confirmed visually.

All the samples of *E. globulus* showed signs of termite and microorganisms attack, some with extensive galleries (Figure 2). After 36 months exposure, 10 % of *E. globulus* stakes showed severe attack and 90% were totally destroyed (Table 3). Hence, *E. globulus* stakes were classified as susceptible to termites or microorganisms (severe attack and rupture according to the rating system for the visual classification inspection for termite attack displayed on Table 1). On the other hand, *E. botryoides* showed no sign of termite attack and only few traces of microorganisms' presence (Figure 3). Hence, *E. botryoides* stakes were classified as not susceptible to termites or microorganisms (no attack and rupture according to the rating system for the visual classification inspection for termite attack displayed on Table 1).

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Figure 2. *E. globulus* wood: images of the samples after ground contact.

Figure 3. *E.botryoides* wood: images of the samples after ground contact.

The results for *E. globulus* were similar to the ones obtained with *E. grandis* also showing grooving channels inside the wood (Ncube *et al.* 2012) with the classification of slightly durable that lead the authors to advise the impregnation of *E. grandis* wood with preservatives. Other studies with *E. grandis* showed a low to moderate natural durability on thermally treated wood (Batista *et al.* 2016, Pessoa *et al.* 2006, Silva *et al.* 2006).

Table 3. Comparative results (% of samples in different classes) of termite and microorganisms attack in field test, after 6, 12, 18 and 36 months exposure.

	Time in field test	Sound	Slight attack	Moderate attack	Severe attack	Rupture
Termites attack						
Eucalyptus globulus (natural)	6 months	45%	55%	0%	0%	0%
	12 months	20%	70%	10%	0%	0%
	18 months	0%	0%	35%	55%	10%
	36 months	0%	0%	0%	0%	100%
Eucalyptus globulus (thermally treated)	6 months	88%	12%	0%	0%	0%
	12 months	38%	63%	0%	0%	0%
	18 months	25%	25%	0%	25%	25%
	36 months	0%	0%	0%	10%	90%
Eucalyptus botryoides (natural)	6 months	100%	0%	0%	0%	0%
	12 months	100%	0%	0%	0%	0%
	18 months	100%	0%	0%	0%	0%
	36 months	100%	0%	0%	0%	0%
Eucalyptus botryoides (thermally treated)	6 months	100%	0%	0%	0%	0%
	12 months	100%	0%	0%	0%	0%
	18 months	100%	0%	0%	0%	0%
	36 months	100%	0%	0%	0%	0%
Microorganisms attack						
Eucalyptus globulus (natural)	6 months	90%	10%	0%	0%	0%
	12 months	60%	30%	10%	0%	0%
	18 months	0%	80%	20%	0%	0%
	36 months	0%	0%	80%	20%	0%
Eucalyptus globulus (thermally treated)	6 months	100%	0%	0%	0%	0%
	12 months	50%	50%	0%	0%	0%
	18 months	0%	75%	25%	0%	0%
	36 months	0%	0%	80%	20%	0%
Eucalyptus botryoides (natural)	6 months	95%	5%	0%	0%	0%
	12 months	90%	10%	0%	0%	0%
	18 months	55%	45%	0%	0%	0%
	36 months	50%	40%	5%	0%	0%
Eucalyptus botryoides (thermally treated)	6 months	100%	0%	0%	0%	0%
	12 months	100%	0%	0%	0%	0%
	18 months	60%	40%	0%	0%	0%
	36 months	60%	40%	0%	0%	0%

A study on natural durability against basidiomycetes and the wood-boring insect using *E. grandis* and *Eucalyptus x trabutii* (according to EN335-1), showed promising results for the latest (Palanti *et al.* 2010). A study on the termite resistance of wood species grown in Hawaii showed that *E. microcorys* was very resistant, *E. robusta* slightly resistant and *E. deglupta* very susceptible (Grace *et al.* 1996).

Comparative studies on the in-ground and above-ground durability of European oak heartwood were made using also EN 252 (Brischke *et al.* 2009). *Quercus robur* ranged from slightly durable to non-durable and *Quercus petraea* was classified as non-durable.

Overall the results of this study indicate a need to increase the duration of the treatment since the difference in values for physical properties is not as significant as in other species subjected to the same treatment.

CONCLUSIONS

The main conclusion is that, in general, the thermal treatments administrated in this study are not an effective process for increasing natural durability of wood when in direct contact to the ground.

Nevertheless, the values for the studied properties of thermally treated wood of *E. Globulus* and *E. botryoides* point towards potential promising utilizations mainly for floor coverings, decks, doors and door and window frames. Additionally, the use of thermally treated *E. botryoides* wood can also be considered for outdoor and in-ground contact uses such as fences and decorative arbors and pergolas.

However, it is not advisable to apply this wood for structural purposes due to the fragility of the thermally treated wood towards impacts.

The high durability of *E. botryoides* towards termite attack is probably due to its chemical composition, something that should be addressed in a future study.

ACKNOWLEDGMENTS

This study was funded by project EucPlus - New processes and uses for eucalypt woods (PTDC/AGR-CFL/119752/2010) by FCT (Fundação para a Ciência e a Tecnologia, Portugal). Centro de Estudos Florestais is a research unit supported by the national funding of FCT (UID/AGR/00239/2013). Funding from FCT is acknowledged by the first author with a post-doctoral grant (SFRH/BPD/76101/2011).

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