BIOLOGICAL RESISTANCE OF THERMALLY TREATED *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S. Johnson E *Pinus taeda* L. WOODS AGAINST XYLOPHAGOUS TERMITES[1]

Juarez Benigno Paes[2*], Pedro Gutemberg de Alcântara Segundinho[2], Allan Ewerton Rezende Euflosino[3], Márcio Rogério da Silva[4], Carlito Calil Junior[5] and André Luis Christoforo[6]

[1] Received on 08.12.2014 accepted for publication on 29.10.2015.
[2] Universidade Federal do Espírito Santo, Departamento de Ciências Florestais e da Madeira, Jerônimo Monteiro, ES - Brasil. E-mails: <jbp2@uol.com.br> and <p_gutemberg2001@yahoo.com.br>.
[3] Universidade Federal do Espírito Santo, Programa de Pós Graduação em Ciências Florestais, Jerônimo Monteiro, ES - Brasil. E-mail: <allan_ewerton@hotmail.com>.
[4] Universidade de São Paulo, Programa de Pós-Graduação em Ciências e Engenharia de Materiais, São Carlos, SP - Brasil. E-mail: <marciomr@sc.usp.br>.
[5] Universidade de São Paulo, Departamento de Estruturas, São Carlos, SP - Brasil. E-mail: <calil@sc.usp.br>.
[6] Universidade Federal de São Carlos, Departamento de Engenharia Civil, São Carlos, SP - Brasil. E-mail: <christoforoal@yahoo.com.br>.
*Corresponding author.

ABSTRACT – This research aimed to evaluate the effect of the thermal-treated temperature to improvement of *Corymbia citriodora* and *Pinus taeda* wood resistance to the xylophagous termite *Nasutitermes corniger*, into forced feeding assay. The wood thermally treated was performed at temperatures of 160, 180, 200, 220, 240°C. For *Pinus taeda*, the temperature of 260°C was also used. Three boards of 6 × 16 × 56 cm (thickness × width x length) were used for each temperature. After being thermally treated, the boards were transformed into samples of 2.54 × 2.54 × 0.64 cm (longitudinal × radial × tangential). The experiment was kept in a climatized room (25 ± 2°C and 65 ± 5% of relative humidity), for 28 days. For *Corymbia citriodora*, the thermal treatment at 220 and 240°C improved the resistance to the termite. For *Pinus taeda*, the resistance improvement occurred at 240 and 260°C. The temperature of 160°C caused a decrease in the natural durability of both species.

Keywords: Thermal treatment; Natural resistance; No chose feeding assays.

RESISTÊNCIA BIOLOGICA DAS MADEIRAS DE Corymbia citriodora (Hook.) K.D. Hill & L.A.S. Johnson E Pinus taeda L. TRATADAS TERMICAMENTE CONTRA CUPINS XILOFAGOS

RESUMO – Esta pesquisa teve como objetivo avaliar o efeito do tratamento térmico nas madeiras de ***Corymbia citriodora*** *e de* ***Pinus taeda*** *visando sua melhorar a resistência ao cupim xilofagos* ***Nasutitermes corniger****, por meio de ensaios de alimentação forçada. As temperaturas utilizadas nos tratamentos térmico das madeiras foram 160, 180, 200, 220 e 240 °C. Para o* ***Pinus taeda*** *também foi empregada a temperatura de 260 °C. Três pranchas de 6 × 16 × 56 cm (espessura × largura × comprimento) foram confeccionadas para avaliar os efeitos de cada temperatura investigada. Depois de tratadas, as pranchas forma transformadas em amostras de dimensões 2,54 × 2,54 × 0,64 centímetros (longitudinal ×radial × tangencial radial). O experimento foi mantidos numa sala climatizada (25 ± 2 °C e 65 ± 5% de umidade relativa) durante 28 dias. Para a madeira de* ***Corymbia citriodora****, o tratamento térmico de 220 e 240 °C aumentou a resistência ao ataque do cupim. Para as madeiras de* ***Pinus taeda****, a melhoria da resistência ocorreu a 240 e 260 °C. A temperatura de 160 °C provocou um decréscimo na resistência natural de ambas as espécies.*

Palavras-chave: Tratamento térmico; Resistência natural; Ensaios de alimentação forçada.

1. INTRODUCTION

The biological resistance of the wood is interpreted as its ability of resisting deteriorating actions of biological organisms (GOMES; FERREIRA, 2002). The same authors define classes as high, medium or low wood resistance to these organisms.

In order to use the wood as building material, the biological durability is one of the priorities of greatest importance (OLIVEIRA, 1998). Knowing about the natural resistance of the wood is very important to recommend the most appropriate use for the material, avoiding unnecessary expenses with maintenance or substitution of deteriorated pieces (PAES et al., 2004).

Usually, toxic substances are impregnated inside the wood to increase its biological durability. Although the emission of active ingredients is low during the fixation of chemical products to the wood, this technique is not usually seen as friendly. Therefore, the increase in the wood durability due to thermal modification or thermal treated is usually more acceptable (HOMAN et al., 2000).

Thermal modification can be defined as a pre-carbonization process, which is developed at the endothermic phase of the wood. Under these temperature conditions, some wood compounds are degraded, especially hemicellulose, as they are more sensitive to high temperatures. Acetic acid and phenolic fractions are also degraded under these conditions (RENDEIRO et al., 2008).

Thus, thermally treated wood is obtained through a thermal degradation process, in which wood constituents are usually degraded with no oxygen or lack of air, possibly characterizing it as controlled pyrolisys that is interrupted before reaching the level of an exothermic reaction (which begins at approximately 280°C), when spontaneous combustion of the wood takes place (BORGES; QUIRINO, 2004).

The desired changes caused by the thermal treatment of the wood begin at approximately 150°C and go on as the temperature goes up (GUNDUZ et al., 2009). However, according to Esteves; Pereira (2008), the temperature, at which degradation begins, depends on the molecular mass and crystallinity of the wood constituents.

The alterations are followed by many desirable changes on the physical properties, including the contraction and swelling reduction, decrease in the moisture balance content, improvement in the weathering resistance, dark decorative color and higher resistance to decomposition (BORGES; QUIRINO, 2004; KORKUT; BEKTAS, 2008).

During the process of wood thermal modification, cracks might be observed and the cell wall structure might be partially degraded, therefore, individual optimizations of these parameters can be separately conducted for each type of wood and even the same type of wood can be treated in different conditions, possibly leading to significant differences in cell structure and, thus, requiring different treatment conditions (PONCSÁK et al., 2006).

Among the uses of thermally treated wood, flooring, installation of sound proof walls, floors, terraces, garden furniture, door and window casings and house furniture can be mentioned (DUCHEZ; GUYONNET, 2002). Under these use conditions, the wood is susceptible to the action of subterranean termites. In order to supply the growing demand for more resistant wood when it comes to xylophagous organisms and to reduce the pressure on native forests, an appealing option is the use of thermal modification for species that are planted and grow fast.

As a result, thermal treatment comes as an alternative to improve the use of wood that is considered to bring problems regarding technology, diversifying the use of such woods and broadening its economical potential, issues that concern the use of wood from *Pinus* and *Eucalyptus* (*Corymbia*), which although they are available in commercial scale, they are limited when it comes to their use, as one or more of their properties is not suitable for specific purposes.

This study aimed to verify the effect of temperature on thermal modification in order to improve the resistance of *Corymbia citriodora* and *Pinus taeda* to the xylophagous termite *Nasutitermes corniger* into force feeding assay.

2. MATERIAL AND METHODS

2.1. Origin and thermal modification of the woods

The *Pinus taeda* trees were originally from Jaguariaiva region, Paraná State, Brazil. The *Corymbia citriodora* were originally from Brotas region, São Paulo State, Brazil. For both species, trees from 18 to 20 years old were used.

Older trees were used with the objective of decreasing the problems resulted from internal tensions, present in younger individuals, avoiding excessive cracks during the process of wood thermal modification.

The thermal modification process was performed at the Laboratory of Chemistry, Cellulose and Energy, of the Agriculture School "Luiz de Queiroz", University of São Paulo, in Piracicaba, São Paulo, Brazil.

The heat rate used in this study was 0.033 °C min^{-1}, based on the experiments with broadleaved conifers by Pincelli et al. (2002). This heat rate was adopted with the objective of avoiding cracks and on the wood of the studied species.

The thermal treatment began at environmental temperature (30 °C) and, the time to increase the temperature was 40 min, being necessary different temperatures for the beginning of the ramp, due to the different species and the different temperature ranges that were adopted (Table 1).

The initial moisture of the wood samples for the thermal treatment was 12 ± 2%. The time the samples were kept in the oven after reaching the final temperature of the ramp was called final plateau, with a variation of more or less 2 °C min^{-1}. After the end of the thermal treatment process, only the air circulation of the oven was left on, until the temperature of 30°C was reached. The wood thermal modification process was performed at five or six temperature ranges (Table 1). For each range the thermal treatment was performed with three repetitions.

In order to perform the thermal modification process, seven wooden boards of 6 × 16 × 56 cm (thickness x width x length) were used, being placed in a metal box with a lid and separated by iron bars of 1 cm in diameter. This procedure was performed in order to allow gases to circulate around all the sides of the wood. Besides that, nitrogen gas was injected in the box with the objective of avoiding the wood oxidation.

Aiming at keeping the homogeneity of the thermal treatment in the thermal modification box, the temperature inside the boards was monitored by five temperature sensors, placed on the first and sixth boards out of the seven, from top to bottom, being called upper board and lower board. Five K type thermocouple sensors were connected to the data acquisition system Agilent. The depth the temperature sensors were installed was of 3 cm; two of them were placed at 3 cm from the extremities and the other one in the center, all of them at 8 cm widthwise (Figure 1).

Three temperature sensors were used for the upper board and two for the lower one. However, the positions of the temperature sensors were defined as front upper board, when placed near the box lid; central upper board, when placed on the center of the board; back upper board, when placed on the back of the thermal modification box; front upper board, when placed near the box lid; and central lower board, when placed on the center of the board.

2.2. Assays with subterranean xylophagous termites at laboratory

The experiment was conducted at the Wood Biodeterioration Laboratory of the Department of Forest

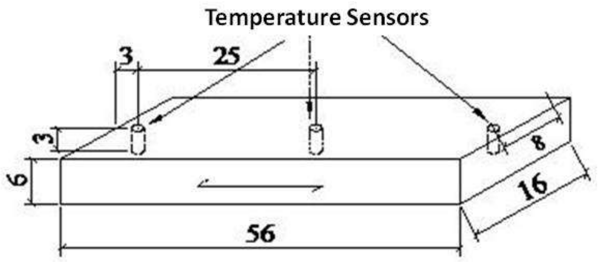

Figure 1 – Position of temperature sensors on the wooden boards (dimensions in cm).
Figura 1 – *Posição dos sensores de temperatura nas Planchas de madeira (dimensões em cm).*

Table 1 – Initial and final temperatures of the ramp for each thermal modification temperature range and wood species.
Tabela 1 – *Temperaturas inicial e final para cada faixa de temperatura de modificação térmica e espécies de madeira.*

Species	Temperature	Temperatures and Final Plateaus (ºC)					
		160	180	200	220	240	260
Corymbia citriodora	Initial	120	110	110	105	105	-
	Final	170	190	210	225	245	-
Pinus taeda	Initial	110	110	105	105	105	105
	Final	170	190	205	225	245	265

and Wood Science, Agricultural Science Center of the University of Espírito Santo, in the city of Jerônimo Monteiro, Espírito Santo State, Brazil.

In order to evaluate the biological resistance of the thermal treated wood to xylophagous termites, test samples of 2.54 x 0.64 x 2.54 cm (radial × tangential × longitudinal) were made. Aimed at simplifying the visual analysis of the termites attack, the samples were sanded to eliminate defects.

The assay was performed in accordance to the American Society for Testing and Materials - ASTM D - 3345 (2012), and to simplify the termites collection and the experiment establishment, some changes, suggested by Paes (1997), were adopted 600-mL bottles were filled with 200 g of sand, sterilized at 130 ± 2°C for 48 hours.

For the analysis of wood resistance to subterranean termites, the samples were dried in an oven at 103 ± 2°C for 48 hours. After they had cooled, they were weighed in order to find the anhydrous mass. The samples were then transferred to the bottles, adding and 37 mL of distilled water, so that the sand would reach 75% of its capacity to retain water, and 1 ± 0.05 g of the subterranean termite *Nasutitermes corniger*, which corresponds to ± 350 individuals, being 88% workers and 12% soldiers (same proportion of the colony).

After adding the termites, the bottles were slightly closed, aiming at allowing them to be aerated. A total 10 repetitions were performed for each wood species and thermal modification temperature. These samples were obtained from three randomly selected boards of each thermal treatment adopted. The bottles were kept in a climatized room (25 ± 2°C and 65 ± 5% of relative humidity), for 28 days.

In order to analyze the thermal modification efficiency regarding the wood resistance, the mass loss (%), the damage caused by the termites on the wood (Table 2) and the number of days for the termites to die were computed. The mass loss was corrected by submitting samples to the same conditions of the experiment, but with no termites.

In order to compare the wood resistances of *Corymbia citriodora* and *Pinus taeda* concerning thermal modification temperatures, submitted to the assay, a completely randomized design was used, with 10 replications for each wood and thermal modification temperature. To possibility the statistical analysis, as suggested by Stell and Torrie (1980), the data on percentage of mass loss, were transformed into arcsin [root (mass loss/100)], and the waste values (note) and the number of days till the termites death were transformed into root [(note or days) + 0.5]. Such transformations were needed to enable the data normality (Lilliefors test) and the homogeneity of variances (Cochran test). For the assays evaluation, the Tukey's test was used at 5% significance for the significant factors according to the F test. In the first stage of analysis the effect of treatment temperature was evaluated for each species separately, as for the pine wood was adopted a temperature more. In the second stage to allow comparison between species (factorial 2 x 6) was excluded from the very last temperature adopted for the pinewood.

Table 2 – Evaluation of the waste caused by the termites in test samples.
Tabela 2 – *Avaliação do desgaste causado pelo ataque dos cupins nas amostras testadas.*

Types of Waste	Rating (Note)
Sound, surface nibbles permitted	10
Light attack	9
Moderate attack, penetration	7
Heavy	4
Failure	0

3. RESULTS

For the thermal treated wood of *Corymbia citriodora*, the analysis of variance accused significance at 1% for the mass loss and termites' mortality and at 5% for the damage caused by these insects on the wood. As for the *Pinus taeda* wood, there was significant difference at 1% for all the studied variables. The mean values were compared by the Tukey's test (Table 3).

It is possible to observe on Table 3 that the lowest mass loss was obtained at the temperature of 240 °C. However, the damage caused by the termites at this temperature was higher than the observed at 100 °C (control). The number of days for the termites' mortality was similar to the obtained for the control (100 °C), except at the temperature of 160 °C.

It is possible to observe on Table 3 that the wood of *Pinus taeda* presented lower mass loss at the temperature of 260 °C, being 6.54 times lower than the mass loss of the control (100 °C).

Table 3 – Comparison of means for mass loss, waste and mortality caused by the termite *Nasutitermes corniger* in thermal treated wood of *Corymbia citriodora* and *Pinus taeda*.

Tabela 3 *– Comparação de médias para a perda de massa, desgaste e mortalidade causada pelo ataque do cupim* ***Nasutitermes corniger*** *nas madeiras de* ***Corymbia citriodora*** *e* ***Pinus taeda*** *tratadas termicamente.*

Thermal Treated Temperature (°C)	Mass Loss (%)	Waste (Note)	Mortality (Days)
100	2.24 ± 0.03 b	9.34 ± 0.37 a	14.40 ± 2.46 b
160	3.20 ± 0.02 a	8.86 ± 0.45 ab	20.10 ± 4.15 a
180	2.10 ± 0.03 b	8.84 ± 1.18 ab	13.40 ± 2.27 b
200	1.92 ± 0.02 b	8.82 ± 0.35 ab	15.30 ± 2.71 b
220	0.80 ± 0.01 c	8.40 ± 0.83 b	15.10 ± 1.37 b
240	0.41 ± 0.01 d	8.28 ± 0.65 b	14.90 ± 1.45 b

Pinus taeda

Thermal Treated Temperature (°C)	Mass Loss (%)	Waste (Note)	Mortality (Days)
100	3.86 ± 0.02 ab	9.26 ± 0.35 a	16.60 ± 2.17 a
160	5.31 ± 0.14 a	9.10 ± 0.44 a	14.90 ± 2.60 ab
180	3.88 ± 0.01 ab	8.82 ± 0.88 a	15.50 ± 2.17 ab
200	2.96 ± 0.01 ab	9.20 ± 0.31 a	13.00 ± 2.45 b
220	2.69 ± 0.01 ab	8.64 ± 0.43 a	15.60 ± 0.70 ab
240	2.12 ± 0.01 b	7.26 ± 0.73 b	15.30 ± 1.06 ab
260	0.59 ± 0.01 c	6.96 ± 0.78 b	14.20 ± 2.04 ab

Means followed by the same letter, in each section, do not differ one to another (Tukey; $p > 0.05$).

When comparing the species, *Pinus taeda* and *Corymbia citriodora*, at the thermal treated temperatures that are common to both, it is possible to observe that the isolated effect of temperature and species (mass loss) and the interactions between the species and the temperature (waste and mortality) were significant at 1%. The effect of the temperature and species and the implications of the interactions between species and temperature were analyzed by the Tukey's test at 5% significance (Table 4).

Table 4 – Comparison of means for mass loss, waste and mortality caused by the termite *Nasutitermes corniger* in thermal treated wood of *Corymbia citriodora* and *Pinus taeda*.

Tabela 4 *– Comparação das médias para a perda de massa, desgaste e mortalidade causada pelo cupim* ***Nasutitermes corniger*** *em madeiras de* ***Corymbia citriodora*** *e* ***Pinus taeda*** *tratadas termicamente.*

Thermal Treated	Mass Loss(%)	Mass Loss (%)	
Temperature(°C)		*Corimbya citriodora*	*Pinus taeda*
100	3.05 ab	1.78 B	3.47 A
160	4.26 a		
180	3.00 ab		
200	2.44 bc		
220	1.74 cd		
240	1.27 d		

Thermal Treated	*Corymbia citriodora*		*Pinus taeda*	
Temperature(°C)	Waste (Note)	Mortality (Days)	Waste (Note)	Mortality (Days)
100	0.36 Aa	14.40 Bb	9.26 Aa	16.60 Aa
160	8.86 Aab	20.10 Aa	9.10 Aa	14.90 Bb
180	8.84 Aab	13.40 Bc	8.82 Aa	15.50 Ab
200	8.82 Aab	15.30 Ab	9.20 Aa	13.00 Bc
220	8.40 Ab	15.10 Ab	8.64 Aa	15.60 Aab
240	8.28 Ab	14.90 Ab	7.26 Bb	15.30 Ab

Means followed by the same small letter vertically, or the same capital letter horizontally, in each parameter, do not differ one to another (Tukey; $p > 0.05$).

4. DISCUSSION

Regarding the wood from *Corymbia citriodora* (Table 3), the highest mass loss caused by termites attack was found at the temperature of 160 °C. This very temperature caused waste similar to the one found in the control, temperature at which the termites stay alive for a longer period of time. Gunduz et al. (2009) mentioned that the desirable changes on wood begin at 150 °C, which was not observed on this research regarding the attack of termites from *Nasutitermes* genus. Therefore, the temperature of 160 °C must not be recommended for wood thermal treated of *Corymbia citriodora* to improve its biological resistance to termites.

The subjectiveness of the data on waste (note), evaluated as recommended by ASTM D - 3345 (2012), might have led to some difficulties to evaluate due to internal cracks (cracks in honeycomb pattern) that occurred during the thermal modification process, as mentioned by Poncsák et al. (2006), and when termites attacked the borders of these cracks, there seemed to be a higher waste.

Based on the mass loss (Table 4), it can be inferred that the wood from *Pinus taeda* was less resistant than from *Corymbia citriodora*. The thermal modification temperature that had as a result a higher resistance to termites (lower mass loss) was 240 °C, which did not differ from 220 °C as in regard to mass loss of the samples. The explosion to the temperatures of 160 and 180 °C resulted in mass losses similar to the control (100 °C). At 200 °C, the woods responded by having an intermediate behavior compared to the ones exposed to 100, 180 and 220 °C.

As for the damage (Table 4), it was observed that only at 240 °C the species statistically differed, as the wood from *Pinus taeda* had a more severe attack of termites for this wood, the most severe termites attack was at 240 °C. The same happened at 220 and 240 °C for the wood from *Corymbia citriodora*. However, this wood when exposed to temperatures of 160, 180 and 200 °C responded by having an intermediate behavior, between the most and the least attacked woods, at 100 °C (control).

Concerning the number of days till the death of the termites (Table 4), explosion to 220 and 240 °C provided similar resistances to the woods from both species. At 160 and 220 °C, the wood resistance was higher for *Corymbia citriodora* than for *Pinus taeda*. However, at 100 (control) and 180 °C, the wood from *Pinus taeda* was more resistant.

Thus, it can be stated that the adopted thermal treated temperatures, except 160°C, provided an increase in the resistance of the woods to the xylophagous termites used in this study; such results agree with what was found by Homan et al. (2000), Borges; Quirino (2004), and Korkut; Mektas (2008), when it comes to the effect of thermal treated on the improvement of wood resistance to fungal degradation.

5. CONCLUSIONS

When wood from *Corymbia citriodora* was exposed to thermal treatment at 220 and 240 °C, the resistance to the termite *Nasutitermes corniger* increased, and when exposed to 160 °C, the wood resistance decreased.

As for wood from *Pinus taeda*, the thermal modification temperatures that provided a higher resistance to the used termite were 240 and 260°C and the temperature that caused the resistance to decrease was 160°C.

For thermal treated woods exposed to higher temperatures, there might have been cracks in honeycomb pattern inside the samples which, as the termites attacked the borders of such cracks, might have led to the false impression that those samples were more damaged due to the increased crack borders.

6. ACKNOWLEDGMENTS

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