PROPERTIES OF THERMO-MECHANICALLY TREATED WOOD FROM *PINUS CARIBAEA* VAR. *HONDURENSIS*

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This study aimed at evaluating the effect of thermo-mechanical treatment on properties of *Pinus caribaea* var. *hondurensis* wood. Two pressure levels (25% and 50% of the compression strength perpendicular to grain) were evaluated. The treatment was applied in a laboratory hot press in one-step or two-step modes for 50 minutes. In the one-step treatment, the total pressure was applied after the temperature of the center of the wood reached 170°C. In the two-steps treatment, half of the pressure was applied after the center of the wood reached 100°C, and the final pressure was applied when it reached 170°C. The weight loss immediately after treatment was equivalent to the wood moisture content, indicating that degradation of wood polymers did not occur. However, the treatments showed decreasing values of the moisture content, which were reduced from 12.3% to 9.8%. A moderate improvement on surface roughness was achieved, while wood wettability was highly reduced in all treatments, as determined by contact angle measurement. On the other hand, the treatment applied did not improve the wood dimensional stability, but all mechanical properties presented a trend of improvement.

Keywords: Dimensional stability; Surface properties; Wettability; Thermal treatment

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INTRODUCTION

The wood from tropical *Pinus* species usually presents low strength, low biological resistance, and poor weatherability, thus often requiring treatments to improve these properties. According to Wang (2007) the thermo-chemical modification of wood is of great interest, since it can enhance the performance of wood by improving the dimensional stability and the resistance to wood decay organisms. During the thermo-mechanical treatment, the chemical reactions required to modify the wood properties happen at same time the wood is compressed. This approach has been studied since the 1940s (Forest Products Laboratory, 2010). It has been found that weight loss of wood occurs during treatment, and it can be attributed to the loss of free and hygroscopic water and to the partial degradation of wood.

The results of thermal treatments depend on a number of factors, such as: heating rate, final temperature, time of treatment, use of oxidizing or reducing atmosphere, pressure, and type of wood being treated (Borges and Quirino 2004). In recent years, thermal modification processes are the ones most evolved in commercial terms. This success is probably due to the low cost of thermal treatments when compared to other

wood modification processes that rely on the use of chemicals. The processes are usually divided into four stages: heating, thermal treatment, cooling, and stabilization (Esteves and Pereira 2009)

The mechanical properties of low density wood can be modified and improved by different combinations of compression, thermal treatments, and chemical treatments. The wood can be compressed transversally to grain (i.e. densified) under certain conditions that do not cause significant damage to the cell wall. Densified wood products thus have a higher degree of stiffness, strength, and hardness (Kutnar et al. 2008). The main objective in performing wood compression together with the presence of heat is to improve its physical and mechanical properties. This process can result in a new material, depending on the conditions employed during treatment (Unsal et al. 2009). In this way, improvements of physical and mechanical properties are mainly due to increased material density.

The utilization of low pressures during the treatment processes do not give the wood a high dimensional stability as occurs in high pressure compressed wood, while the use of very high pressures tends to cause a crushing of the boards and may reduce their mechanical properties (Seborg et al. 1945). The generation of residual stresses may occur during densification of the wood due to the structural change in the cell wall, which may affect the properties of the final product. In general, this phenomenon is more common in wet wood than in dry compressed wood. As the wood is exposed to moisture conditions, residual stresses are released, resulting in dimensional instability and warping. This residual mechanical stress increases as the compression rate increases (Gong et al. 2008). According to Kutnar and Kamke (2012) the fixation of compressive deformation is the main problem associated with wood densification. Some authors have reported the utilization of a cooling step (Kutnar and Kamke 2012; Rautkari et al. 2011), in which the material is cooled under pressure, thus helping to fixate its final shape. Other authors have studied methods without this step, and the material is cooled at room temperature after densification (Arruda et al. 2011).

In spite of these drawbacks, the thermo-mechanical treatments of wood products have been extensively studied, as can be seen in several works (Bekhta et al. 2012; Kutnar and Kamke 2012; Fang et al. 2012; Arruda et al. 2011; Candan et al. 2010; Navi 2010; Bekhta et al. 2009; Welzbacher et al. 2008). In general, the density and mechanical properties are improved. The main objective of this study was to evaluate the effect of thermal treatments associated with compression pressure levels on the properties of wood from *Pinus caribaea* var. *hondurensis*.

EXPERIMENTAL

Wood Material

23 year-old *Pinus caribaea* var. *hondurensis* trees grown in Planaltina, Distrito Federal (Brazil) were used in this study. The trees were felled in 2009 from an experimental provenance/species trial established by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) in partnership with Central America and Mexico Coniferous Resources Cooperative (CAMCORE). Thirty boards measuring 25 mm x 150 mm x 450

mm (thickness, width, length) were randomly cut from these trees. Further details about tree plantation conditions and silvicultural practices can be found in Embrapa Cerrados (2009). The obtained boards were kept in an air-conditioning room (20ºC; 65% RH) to reach constant weight (ca. 120 days). Afterward, a 25 mm x 30 mm x 30 mm (thickness, width, length) sample of each board was taken to determine the equilibrium moisture content (EMC_b, %) before the treatment.

Thermo-Mechanical Treatments

The thermo-mechanical treatments were performed using a laboratory hot-press (electrical resistance heating) with temperature and pressure control. The final temperature of the treatments was set to 170ºC. The pressure values were established using fractions of the average values of the compression strength perpendicular to grain ($f_{c,90}$), published by Embrapa Cerrados (2009): 25% and 50%, i.e. 1.35 N/mm^2 and 2.70 N/mm^2. The pressures were applied only after the center of the board reached 100°C and 170°C. Figure 1 describes the four treatments performed. Tests conducted previously showed that the internal temperature of boards achieved near 170ºC (assumed as glass transition temperature of dry wood, T_g) after about 30 minutes. According to our previous work (Del Menezzi et al. 2009) the duration of treatment between 12 and 20 minutes would be enough to promote polymer degradation.

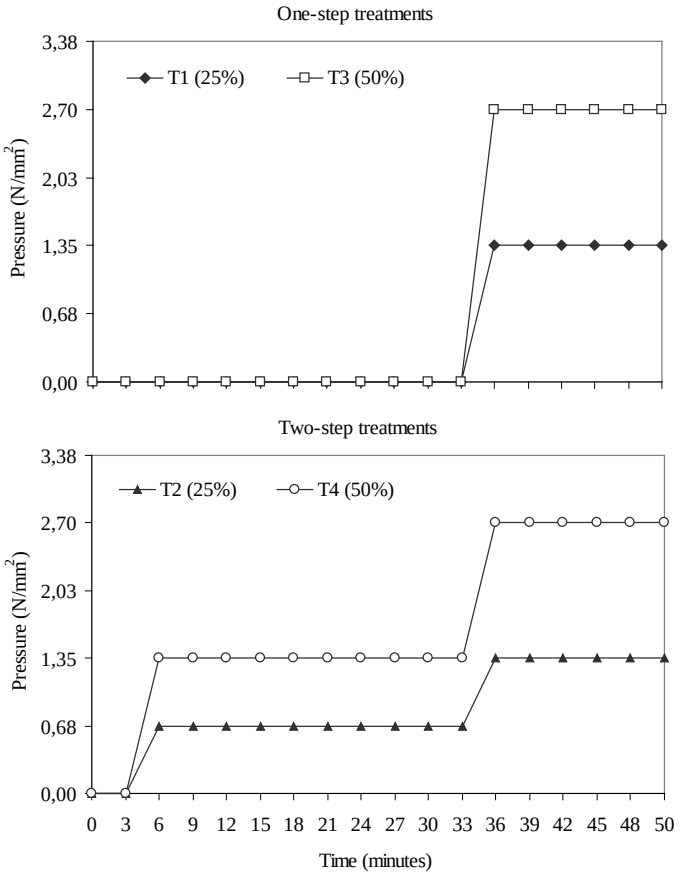

Fig. 1. Treatment schedule used in one- and two-step treatments showing mechanical pressure over time

This way, in treatments 1 and 3, the pressures were applied for 15 minutes after the board reached the inner temperature of 170°C (ca. 34 minutes). Treatments 2 and 4 were performed in two steps. The first step was the application of half the desired final pressure when temperature in the center of the board reached 100°C (ca. 3 min; assumed as T_g of wet wood); the second step applied the remaining desired pressure after the center of the wood reached 170°C (ca. 34 min), keeping the final pressure for another 15 minutes. In this way, all treatments lasted about 50 minutes in total, and afterwards the board was removed from the press and put to cooling down in an air-conditioned room (20ºC; 65% RH).

For each treatment, six boards were thermo-mechanically treated, while another six remained untreated as control samples. After the thermo-mechanical treatments both board thickness and weight were assessed. The densification rates (DR, %) of the boards were calculated, as the relation between the board thickness after treatment and conditioning, and the original board thickness. The weight loss (WL, %) and permanent weight loss (PWL, %) of the boards were determined as well. WL was calculated as the percentage of weight loss immediately after treatments compared to the original weight before treatments, whereas PWL was the percentage of weight loss after board reached equilibrium moisture content in an air-conditioned room (20ºC; 65% RH) compared to the original weight before treatments.

Physical and Mechanical Properties

Physical properties of the untreated and treated samples were assessed for density, dimensional stability, and equilibrium moisture content. The dimensional stability properties were determined according to NBR 7190 (1997) procedure, through wood shrinkage and swelling behavior. The shrinkage ($\varepsilon_{r,}$ %) and swelling ($\varepsilon_{i,}$ %) dimensional variations were determined for the longitudinal (Lg), radial (Rd) and tangential (T_g) directions. The equilibrium moisture content (EMC_t, %) was determined after 85 days of the thermo-mechanical treatments, in which the boards could reach constant weight in an air-conditioned room (20ºC; 65%RH). The following mechanical properties were determined according to ASTM D143 (2000) procedures: modulus of elasticity (E_M, N/mm^2), modulus of rupture (f_m, N/mm^2), parallel strength compression ($f_{c,0}$, N/mm^2), and Janka hardness ($f_{H,90}$, N). For each property the number of test specimens was 12. Due to thickness reduction of the boards, the specimens span in the static bending test was adjusted to 14 times of the thickness, as determined by the standard. The failure mode in static bending was also analyzed according to the ASTM D143 (2000) procedure. For the $f_{H,90}$ tests, the size of specimens was adjusted to 25 mm x 25 mm x 100 mm.

Surface Roughness and Wettability Measurement

The roughness of the boards was evaluated on the surface where the thermo-mechanical treatments were performed, always perpendicular to grain. A stylus profilomenter (Mitutoyo Surftest-SJ-301) roughness tester device connected to a computer was used. The measurements were performed according to the JIS 2001 procedure. The values were measured with the sensitivity of 0.5 μm, scanning length of 12.5 mm, and the cutoff of λ=2.5 mm. The following surface roughness parameters were

studied: R_a (mean roughness), R_z (mean peak-to-valley height), and R_t (maximum height of the profile). To evaluate the wettability of the wood surface, the contact angle (θ) of water was measured at room temperature (ca. 24ºC) using Krüss DSA30 goniometer and DSA3 software. Measurements were performed on the surfaces of eight samples of untreated wood and 32 thermo-mechanically treated samples (eight replicates per treatment) using the sessile drop method. The drop deposited on the surface of the material was 20 μL distilled water (surface tension 72.8 mN/m). The values of θ were measured every 2 seconds for 120 seconds.

Statistical Analysis

The results of the board properties were studied initially by the analysis of variance (ANOVA). As ANOVA was statistically significant, a Dunnett test at α=0.05 level was performed, comparing the properties between treated and untreated wood (control). This test compares means of the control and treated board, pairwise, instead of comparing entire treatments. Afterwards, a full factorial ANOVA was subsequently performed in order to determine the effect of pressure, step and pressure x step interaction on these properties.

RESULTS AND DISCUSSION

Physical, Mechanical and Wettabillity Properties

Table 1 shows the means and standard deviations of the average density of the wood boards before treatments and after treatments, as well as the densification rate (DR), which indicates the reduction in material thickness, weight loss immediately after treatments (WL), permanent weight loss after treatments, and acclimatization of the boards (PWL). The ANOVA did not indicate any statistical difference between densities of all treatments (T1, T2, T3, T4) and the density before treatment (control): ca. 0.55 g/cm^3. However, immediately after the thermo-mechanical treatments the density of treated materials decreased about 7.2% (0.55 to 0.51g/cm^3). This means that during the treat-ment, mass loss was more pronounced than volume shrinkage, leading to a reduction of density. In fact, WL (ca. 12%) values were higher than DR (ca. 6.0%) values. When the boards were put in an air conditioned room, they recovered to almost their original mass, but their thickness remained the same. Therefore, after conditioning, the density of the treated boards was improved at same intensity observed for densification ratio (DR). WL values were similar to the equilibrium moisture content calculated before treatments (EMC_b): 12.3%.

Therefore, the WL might have been exclusively due to the loss of water and volatile extractives, instead of polymer degradation, or even this last happened at low intensity. This result was surprising, since at 170ºC at least the thermal degradation of hemicelluloses would be expected, which would lead to more mass loss, as found by Del Menezzi et al. (2009). It also can be concluded that the initial reduction in the density of the treated materials was due to the decrease of moisture content (MC). After conditioning, the treated boards gained moisture, but they showed lower MC values than their MC values before treatments.

Table 1. Mean Values and Standard Deviation of Density, Wood Densification rate and Weight Loss Variables

Variable[b]	Control	Treatments[a]			
		T1	T2	T3	T4
ρ before (g/cm^3)	0.54 (0.10)	0.55 (0.11)	0.56 (0.12)	0.55 (0.11)	0.56 (0.12)
ρ after (g/cm^3)[c]		0.51 (0.10)	0.52 (0.11)	0.51 (0.11)	0.52 (0.12)
ρ after (g/cm^3)[d]		0.57 (0.12)	0.58 (0.13)	0.58 (0.12)	0.59 (0.13)
DR (%)		5.33 (0.56)	5.92 (1.02)	5.96 (1.05)	6.86 (1.44)
WL (%)		12.1 (0.17)	12.11 (0.64)	12.25 (0.43)	12.32 (0.61)
PWL (%)		4.79 (0.12)	5.12 (0.32)	5.39 (0.76)	5.97 (1.7)

Note: [a] T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%. b: DR: densification ratio; WL: weight loss; PWL: permanent weight loss; c: immediately after treatment; d: after treatment and air-conditioning;

The values of the moisture content after 85 days of treatments in air-conditioned room are shown in Fig. 2. Statistical analysis indicated that all treatments differed from control samples, with T3 showing the largest decrease in MC value (-20%). According to the results of the factorial ANOVA, it was not possible to specifically identify the source of variation (pressure, pressure x step interaction) of MC values. In this context, the utilization of the simplest schedule, 1 step and 25% (T1) pressure is recommended.

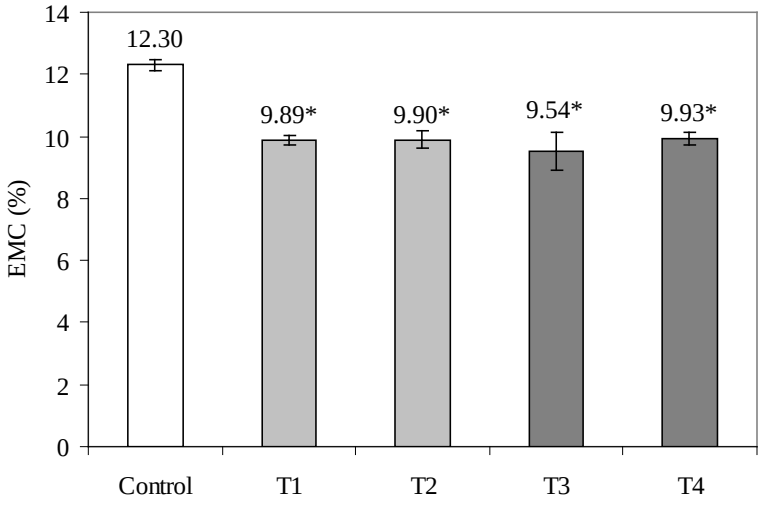

Fig. 2. Mean and standard deviation of the moisture content of untreated and thermo-mechanically treated wood (*statistically significant difference compared to the control using the Dunnett test at α = 0.05; Note: T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%)

As there was no degradation of polymers or it happened at low intensity as the treatments performed, the decreasing in wood MC can be explained by the migration of the resin contained in the *Pinus* wood to the surface of the boards. Thus, there was a sealing effect on the surfaces, which hindered the entry of water into the wood during conditioning. In this way, the resin coating acted as a water-repellent, reducing the rate of moisture uptake, as expected for any moisture-excluding treatments. This explains why MC values cannot be considered exactly as an equilibrium state for the treated material. According to Rowell and Banks (1985), these kinds of treatments do not significantly interfere with the water movements into wood (vapor-phase or bound-water), and treated wood will present the same swelling behavior as untreated material.

It should also be taken into account that moisture-proof treatments can take a long time to be effective, yet only last for short time, as presented by FPL (2010). Therefore, the values of MC of treated boards were obtained after 85 days of conditioning (20ºC; 65%RH), which should be enough for samples to reach the equilibrium moisture content, and they demonstrated higher numbers than any other moisture-proof treatments. In this context, the applied thermo-mechanical treatments might have endowed samples with further protection against water, promoting some inactivation of the surface of the treated board, and making it less hydrophilic. According to Christiansen (1990), the following mechanisms are involved in this phenomenon: migration of hydrophobic compounds, reactivity of compounds, surface oxidation, molecular reorientation of compounds, and closure of wood micropores.

The modification of the surface's hydrophilic nature can be better observed by analyzing the contact angle. Figure 3 illustrates the behavior of the water drop on the surface of untreated wood sample (a) and treated wood sample (b). The sequence of images shows the standard behavior of untreated and treated material immediately after deposition of the drop (ca. 2s) and after every 30s. The sequence of these images of untreated wood shows that volume of the water drop decreased over time, i.e. the water easily penetrated into the wood.

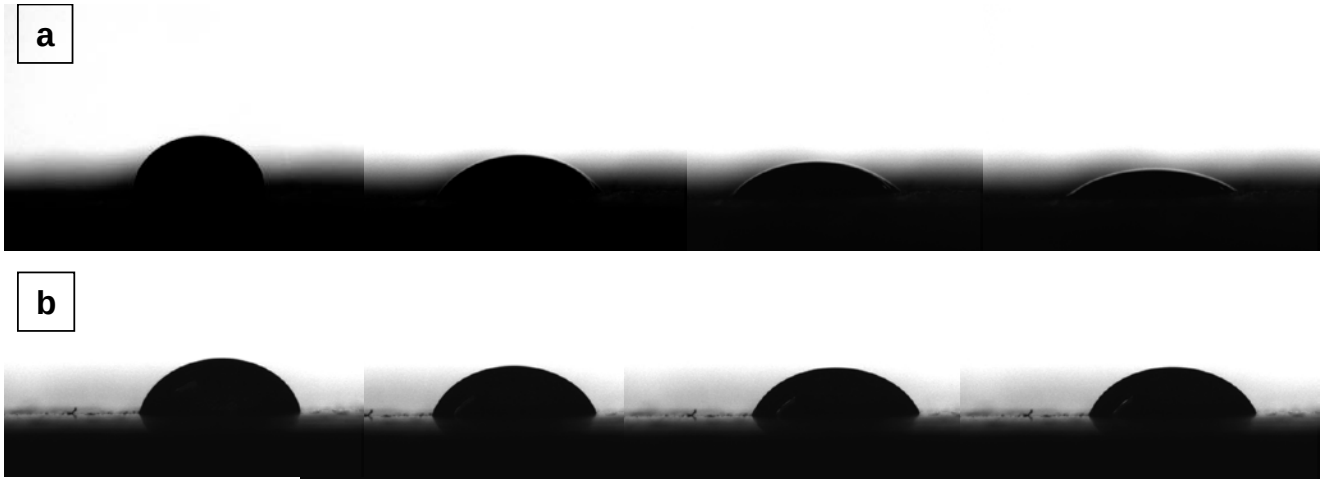

Fig. 3. Water drop profile on the surface of untreated (a) and thermo-mechanically treated (b) wood after deposition (ca. 2s), 30s, 60s and 90s.

At the beginning the θ value of the water drop to untreated wood was about 79.6º, and after 120s the value reached only 11.7º (Fig. 4). On treated wood, in turn, the drop remained almost intact on the surface, with a mean initial θ value about 95.8º. This value was only slightly reduced with time, reaching 88.9º after 120s. The results of contact angle measurements indicate that the surface of untreated board was more wettable than the surface of thermo-mechanically treated wood. The comparison between treated samples and controls shows that treated samples displayed higher θ values. As for the surface of untreated wood, θ values decreased asymptotically over time, indicating that part of the water was absorbed by the wood and part was spread over its surface. It is clearly indicated that thermo-mechanical treatments reduced the ability of wood to absorb water. In this context, the migration of resin to the surface of treated board made the wood surface more hydrophobic, which considerably reduced the ability of water to absorb and spread.

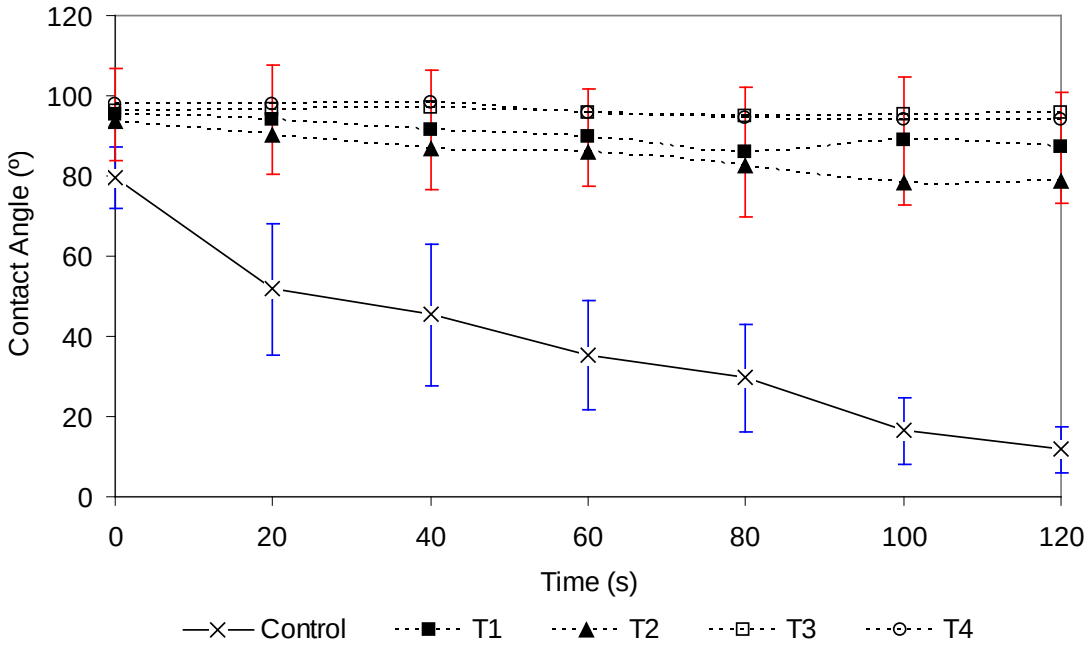

Fig. 4. Contact angle over time of untreated and thermo-mechanically treated wood. (Note: T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%)

Another hypothesis for the reduction of wood MC after thermo-mechanical treatments is the increase in cross-linking bonds, through which the hydroxyl groups (-OH) of the cell walls are joined together through methylene bridges (-CH_2-). The unavailability of hydroxyl groups hindered the water adsorption. However, along with increased cross-linkages, an improvement in dimensional stability was expected (Tjeerdsma et al. 1998). The increase in the degree of crystallinity of cellulose after thermal treatments has been reported by several authors (Kocaefe et al. 2008; Akgül et al. 2007), who indicated that this increase also contributes to the decrease of EMC, as it reduces the access of water molecules to hydroxyl groups. Therefore, according to our

results, the cross-linking mechanism might occur only at a superficial level, since dimensional stability was not achieved in this present work.

Table 2 shows the mean of the treated and untreated samples regarding the properties of dimensional stability (swelling and shrinkage rate). Statistically, through ANOVA, the thermo-mechanical treatments did not affect the dimensional stability of boards. The hypothesis that thermal treatments did not change dimensional stability properties is related to the fact that the weight loss of materials might have been exclusively due to the loss of water and soluble extractive. Thus, degradation of the chemical compositions of wood (hemicelluloses, cellulose, and lignin) did not occurred at a sufficient level to improve the dimensional stability.

Table 2. Mean Values and Standard Deviation of Swelling and Shrinking Values of Untreated and Thermo-Mechanically Treated Wood

Variable	Direction	Control	Treatments[a]			
			T1	T2	T3	T4
Swelling (%)	Tg	6.79 (1.41)	6.68 (1.29)	7.27 (1.05)	7.55 (1.28)	6.90 (1.73)
	Rd	4.33 (1.79)	5.24 (1.02)	4.67 (1.71)	4.80 (1.52)	3.88 (1.16)
	Lg	0.390 (0.93)	0.349 (0.12)	0.457 (0.24)	0.370 (0.16)	0.411 (0.21)
Shrinking (%)	Tg	6.34 (1.22)	6.33 (1.00)	6.77 (0.92)	7.03 (1.07)	6.44 (1.51)
	Rd	4.12 (1.65)	4.89 (0.93)	4.44 (1.56)	4.54 (1.39)	3.72 (1.07)
	Lg	0.388 (0.09)	0.347 (0.11)	0.454 (0.24)	0.369 (0.16)	0.408 (0.21)

Note: [a] T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%.

The improvement in the dimensional stability of wood obtained by several authors (Kocaefe et al. 2008, 2010; Welbzbacher et al. 2005; Tjeerdsma et al. 1998) is one of the main objectives of thermal treatments and was not achieved in the thermo-mechanical treatments proposed in this study. For the cleavage of cellulose and hemicelluloses molecules, thus reducing the wood hygroscopicity, a longer treatment time at higher temperature would be required. Additionally, thermo-mechanical treatments are often followed by a post-treatment to release the compression stresses, and thus improving considerably the dimensional stability, as reported by several authors (Fang et al. 2012; Diouf et al. 2011; Welzbacher et al. 2008). In this present work no post-treatment was applied.

The means and standard deviations of the mechanical properties are presented in Fig. 5. The graphs show that thermal treatments resulted in slight increase in the mechanical properties as compared to the properties of control sample. Although no treatment has been statistically differentiated for E_M, treatment T4 showed an average increase of 14.2% in this property. The increase in E_M has been found by other authors as

well (Fang et al. 2012; Del Menezzi et al. 2009; Shi et al. 2007; Welzbacher et al. 2005). Shi et al. (2007) reported an increase in E_M of 15% and 30% respectively in *Betula spp* and *Populus spp*. woods treated by the ThermoWood method at 200°C compared to the control samples (untreated wood). Welzbacher et al. (2005) obtained a 42% increase in this property in densified *Picea abies* wood thermally treated using an oil process, and 50% for those treated in industrial hot press.

The increase in $f_{H,90}$ values of the treated samples varied from 4.7% (T1) to 18.9% (T4), while f_m values of the treated samples showed an average increase of 13.9% compared to that value of the control samples, varying from 2.3% (T2) to 22.9% (T4). Fang et al. (2012) have reported that Brinell hardness of *Populus tremuloides* veneers was positively affected by the thermo-mechanical treatment employed. $f_{c,0}$ values, in turn, showed a mean increase of 10.5% in these four treatments, varying from 5.2% (T4) to 13.4% (T3).

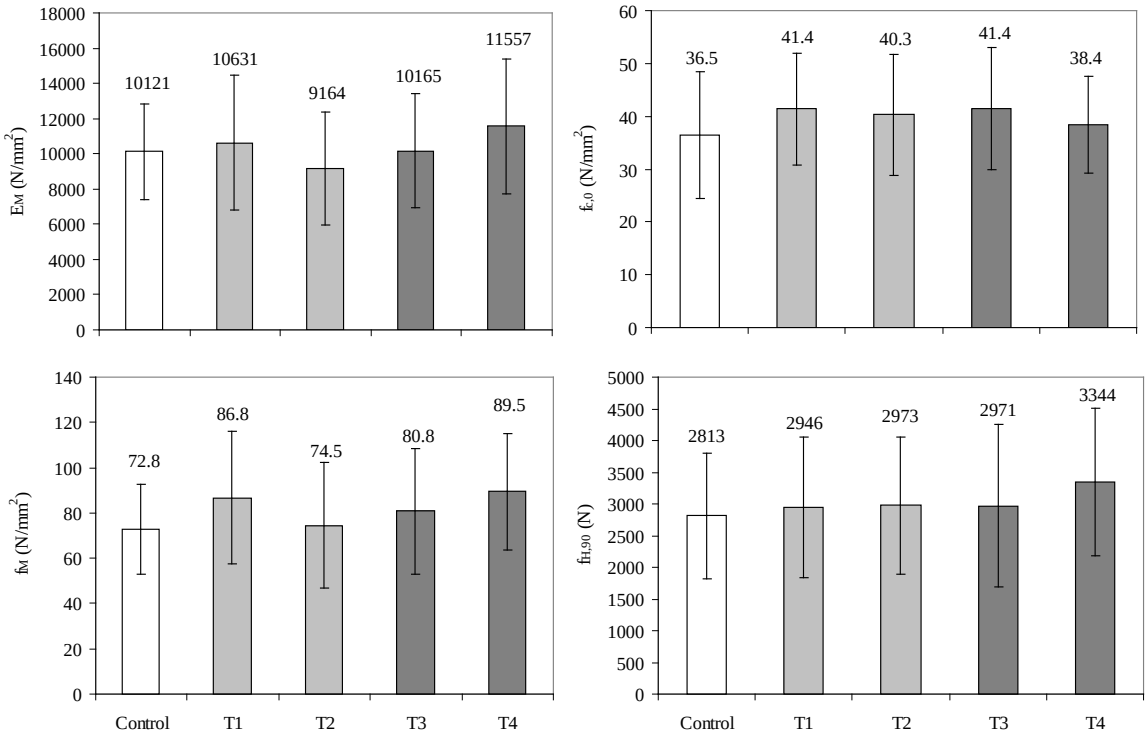

Fig. 5. Mean values and standard deviation of mechanical properties of untreated and thermo-mechanically treated wood (Note: [a] T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%)

Some authors have mentioned a relationship between losses of strength of heat treated wood and polymer degradation. According to Curling et al. (2002), bending property losses are highly associated with the kind of carbohydrate being degraded: f_m loss corresponds to hemicelluloses loss, whereas E_M to cellulose. Fang et al. (2012) also argued about the effect of hemicelluloses degradation on the bending strength. This way, by observing only under this point of view, according to the results it can be inferred that

polymer degradation did not happen at a level sufficient to impart negative effect on the flexural properties.

The results of the failure mode analysis of the wood samples subjected to the static bending test are shown in Table 3. It is clear that the thermo-mechanical treatments decreased the incidence of tension rupture and increased brittle rupture. The increase in failure by brittle rupture often indicates the presence of a defective molecular structure of the wood, while splintering rupture usually occurs in wood with low moisture content (Nicolas 2006), which leads one to infer that some polymer degradation happened at least on the surface of the board, where bending stresses are concentrated.

The conditions under which thermal treatments were conducted - low temperature, relatively short duration and low moisture content - did not cause severe wood polymer degradation and had no negative effects on mechanical properties. One explanation for the slight increase in mechanical properties, besides the decrease in MC, could be related to the density profile. Just as occurred in hot-pressed-boards (vertical density profile), higher densification of the wood boards may have occurred closer to the surface. When the material was subjected to static bending, the regions that received greater stresses (compression parallel to grain on the top and tension parallel to grain on the bottom) were precisely the places where the wood showed higher density. Thus, board density profile would have contributed positively to improving the properties of the thermo-mechanically treated materials, as reported by Rautari et al. (2011).

Table 3. Number of Specimens According to the Failure Mode in the Static Bending Test

Failure Mode	Untreated	Treatments[a]			
		T1	T2	T3	T4
Simple tension	9	4	2	2	1
Cross-grain		1	3	2	2
Splintering			2	2	1
Brittle	3	4	5	6	6
Non-identified		3			2

Note: [a] T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%

Surface Roughness

The standard roughness profiles of untreated and treated wood samples are presented in Fig. 6. It can be observed that in general the thermo-mechanical treatment yielded in a smoother sample surface. The results presented in Fig. 6 also suggest that thermo-mechanical treatments improved the roughness parameters of the sample surface. However, this improvement was statistically significant only for the mean arithmetic deviation of the profile - R_a parameter (mean reduction of 32%), according to the values showed in Table 4. These results can be used to additionally explain the reduction of the surface wettability of treated board, as discussed previously.

Korkut and Guller (2008) reported a 15.1% reduction in roughness of *Acer trautvetteri* wood, after 10 hours thermal treatment at 180°C. According to the authors, improved surface quality, i.e. smoother surfaces, is very important for various applica-

tions of solid wood, in addition to reducing material loss in finishing machines. Similar results of surface quality improvement through thermal treatment were obtained in *Betula pubescens* (Bekhta et al. 2012), *P. nigra* (Gündüz et al. 2008), and *E. camaldulensis* (Unsal and Ayrilmis 2005) woods.

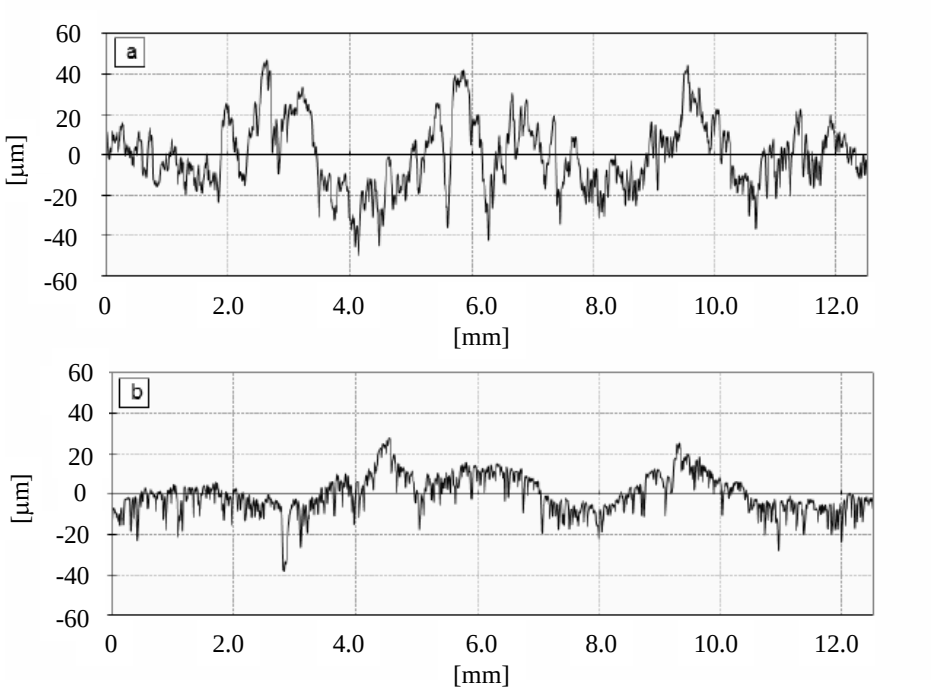

Fig. 6. Standard roughness profile of the surface of untreated (a) and thermo-mechanically treated (b) wood

Table 4. Mean Values and Standard Deviation of Surface Roughness Parameters of Untreated and Thermo-Mechanically Treated Wood

Variable	Control	Treatments[a]			
		T1	T2	T3	T4
R_a (µm)	6.99 (3.53)	4.53* (0.61)	5,08* (0.98)	4.43* (0.58)	4.98* (0.78)
R_z (µm)	44.2 (15.9)	35.8 (6.0)	39.6 (4.2)	34.5 (4.5)	38.6 (6.5)
R_t (µm)	59.1 (25.3)	59.8 (20.5)	63.6 (9.1)	51.6 (8.8)	65.3 (19,3)

Note: [a] T1: 1 step/25% final pressure; T2: 2/25%; T3: 1/50%; T4: 2/50%; *statistically significant difference compared to the control using the Dunnett test at α = 0.05

Del Menezzi et al. (2008) also reported reduction of the R_a parameter of thermally treated oriented strand boards. Recently, Diouf et al. (2011) observed that surface roughness of veneers from *Populus tremuloides* was significantly reduced when they were thermo-mechanically treated. The reduction in the surface roughness of thermally treated wood could be explained by the fact that surface inactivation occurred when wood was exposed to high temperatures, as a result of three main factors: exudation of extractives to

the surface, reorganization of its molecules, and reduction in cell wall pores (Christiansen 1990).

When factorial ANOVA was run to determine the factor responsible for the R_a parameter changing, it was concluded that the step was the only source of this variation. That is, regardless of the pressure used in the treatment (25 or 50%), the best value of R_a surface roughness parameter was obtained when a one-step schedule treatment was employed: 4.48 µm x 5.03 µm

CONCLUSIONS

1. The thermo-mechanical treatments changed some properties of *Pinus caribaea* var. *hondurensis* wood: moisture content was reduced, wettability was decreased, and surface quality (smoothness) was improved.
2. The thermo-mechanical treatments might have promoted surface inactivation and densification of board, which can explain these improvements.
3. The improvement of the dimensional stability could not be achieved as expected since the treatment conditions were considered not as harsh in comparison with other treatments and also because no post-treatment was applied.
4. All mechanical properties of thermo-mechanically treated boards showed a trend of improvement in comparison with untreated ones, but this effect was not statistically significant.

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