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ABRASION RESISTANCE OF PINUS WOOD SUBJECTED TO THERMOMECHANICAL TREATMENS

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Abstract:

The study aimed at analising the effect of the thermomechanical treatment on the abrasion resistance of pine wood. Samples measuring 100mm (width) by 100mm (length) by 10mm (thickness) were used for the tests. Six thermomechanical treatments were studied and were compared with wood kept untreated. Two distinct temperatures were chosen for the thermomechanical treatment (160ºC and 190ºC), applying different times, one with pressure (20 minutes) and other without pressure (10 minutes). The densification rates were calculated considering the parameters of thickness (CR) and density (DR). The mass loss was also acessed. The abrasion test was performed in accordance to the ASTM D4060-95 standard, the amount of material lost during the abrasion test was determined by the abrasion rate (AR). It was observed that the higher the temperature the higher de densification rate and the mass loss. The mass loss varied between 11% and 13%, while DRt from 47 to 71%. The highest AR value was observed on the untreated material (0.035%), whereas the lowest on the thermomechanical treatment applied at 190ºC followed by the post-treatment (0.021%). In conclusion, the thermomechanical treatment improved the abrasion resistance of wood from Pinus sp.

Key words: *densification rate; abrasion test; pinus wood.*

INTRODUCTION

The wood from pine is known for presenting low biological resistance, and low resistance to the weathering, therefore, this species usually needs treatments to improve its resistance (Santos et al. 2012). The growing concern with the production quality is justified by the market demands, with customers who are attentive to the products they consume. This forces the industries, and consequently, the suppliers of raw material to improve the quality of the products, in order to attend needs and demands (Vasconcelos and Del Menezzi 2013).

Therefore, the wood densification, associated to elevated temperatures (thermomechanical treatment) is a good alternative, because it improves the physical and mechanical proprieties and also improves the biological resistance and reduces dimensional instability. This kind of treatment improves density and degrades the hemicellulose. During the treatment, the wood losses mass, which might be attributed to the drying and to the partial degradation of their polymers (Santos et al. 2012).

The thermomechanical treatment is an opportunity to make the soft and porous wood denser and turn them useful in situations where greater resistance is needed (Arruda and Del Menezzi 2013). Besides the physical and mechanical proprieties, it is possible to evaluate the resistance of the woods treated thermomechanically regarding the abrasion. The abrasion test consists on simulating real conditions in which the wood will be used. In this case, it consists on trampling of high heels, with small areas of pressure, on dragging and dropping objects, in other words, resisting to the abrasion consists on the friction caused by the displacement of people over the wood (Martins 2008). The resistance to the abrasion is evaluated by measuring the mass variation of a material or the extension of the damage, after submitting it to the abrasive load, during continuous cycles. Due its simplicity, reproducibility and versatility, the Taber equipment is the most used in the world to measure the resistance to abrasion for several materials (Lopes 2012). Recently, Aytin et al. (2015) used this method to evaluate the abrasion resistance of thermally modified wood.

OBJECTIVE

This research aimed to analyze the effect of the thermomechanical treatments on the abrasion behavior of wood from Pinus sp.

MATERIAL, METHOD, EQUIPMENT

Wood Material

This research was performed at the Sector of Wood Engineering and Physics, at Forest Products Laboratory which belongs to the Brazilian Forest Service (LPF/SFB) and at Laboratory of Engineering and Technology of Forest Products, University of Brasília. Pine wood boards from plantation trees were obtained from the local market and the material was cut into smaller pieces measuring 140mm (width) by 22mm (thickness) by 320mm (length). From this material, samples measuring 100mm (width) by 100mm (length) by 100mm (thickness) were made.

After the visual analysis, the samples that did not present knots, fungus stains or pith were selected, summing 89 samples. Then, the samples were put air-conditining room (20±3ºC; 65±1% RH) up to reach 12% moisture content approximately. Besides, the width, length and thickness of the samples were measured using the digital caliper Mitutoyo Digimatic. Samples were graded according to the density values and divided into seven groups (treatment) with similar initial density: 469-474kg/m^3.

Thermomechanical Treatments

After conditioning, the boards were thermomechanically treated using an automatically controlled single-opening hot press at two temperatures levels: 160ºC and 190ºC. The pressure (25MPa) was applied for 20 minutes (TUP) and was the value corresponding to 50% of perpendicular compression strength. In this step the densification of the sample took place, imparting mass loss and thickiness reduction. After this time, the sample was immediately removed from the hot-press (T1, T3, T4 and T6) while for T2 and T5 the pressure was fully realesed but the sample was kept into the hot-press for further 10 minutes (TWP). However, samples treated under T3 and T6 were treated again one week later again as a post-treatement (PT), as done by Del Menezzi et al. (2006) and Del Menezzi et al. (2009). TWP and PT were considered strategies to reduce springback of the treated wood. The post-treatment consisted on heating the treated samples, at 160ºC/190ºC, for 20 minutes. The same effect was tested for T2 and T5. This way, six different hot-pressing schedules based on the temperature (160ºC/190º), time without pressure (TWP) during compression stage (0´/10´) and time of thermal post-treatment (PT) were evaluated (0´/10´), as can be seen in Table 1. Further detalis about the treatments can be found in our previous paper (Del Menezzi et al. 2015). Table 1 shows the schedules tested.

Table 1

Description of the treatments tested.

Treatments	Temperature [°C]	TUP [min]	TWP [min]	PT [min]
T1	160	20	-	-
T2	160	20	10	-
T3	160	20	-	10
T4	190	20	-	-
T5	190	20	10	
T6	190	20	-	10
Control	-	-	-	-

After performing the treatment and post-treatment, the the compaction rate (CR) was calculated considering the thickness of the samples (Equation 1), while the densification rate according to (Equation 2). Mass loss was calculated according to Equation 3.

$$CR(\%) = (1 - \frac{t_A}{t_B}) \times 100 \qquad (1)$$

$$DR(\%) = (\frac{\rho_A}{\rho_B} - 1) \times 100 \qquad (2)$$

$$ML(\%) = (\frac{m_B - m_A}{m_B} - 1) \times 100 \qquad (3)$$

where:
t_A, t_B: thickness after and before treatment (mm);
ρ_A, ρ_B: density after and before treatment (g/cm³);
m_A, m_B: massa after and before treatment (g);

Abrasion Test

The abrasion test was performed at Sector of Wood Engineering and Physics, at Forest Products Laboratory (LPF/SFB). For the abrasion test, the ASTM D4060-95 standard was followed, which is similar to the NBR 14535:2000. The samples abrasiveness was tested using the Taber (Fig. 1) equipment, with two H18 grinding wheels, at the controlled speed of 60 RPM, a load of 1000 grams was applied in each grinding wheel, with 600 cycles. Aiming to avoid the excessive accumulation of abrasion waste, the grinding wheels were cleaned every 300 cycles. The amount of material lost due the abrasion was determined by the wear rate (WR) as seen on Equation 4.

Fig. 1.
Taber equipment used for the abrasion test.

$$WR(\%) = (1 - \frac{t_A}{t_B}) \times 100 \qquad (4)$$

where:
WD: wear rate (%);
A: sample's initial mass (g);
B= sample's final mass (g);
C= number of cycles used on the test.

Firstly, the abrasion test was performed on the samples that did not suffer thermomechanical treatment nor post-treatment, it was denominated test-treatment. The control treatment was a parameter to compare the abrasion tests applied on the densified samples. In this step, five samples from each one of the six treatments were chosen. The ones that presented the most regular surface were selected for the abrasion test. Then, eight of the eleven samples from treatment 7 that passed by the abrasion test were submitted to the thermomechanical treatment, with the temperature at 160ºC and pressing time of 20 minutes. Aiming to observe the densification effect on these samples, the abrasion test was repeated.

Experiment Analysis

Initially an analysis of variance (ANOVA) was run followed by the Dunnett mean test, to compare WR values between control and treated material pair to pair. The isolated effect of temperature (160ºC vs. 190ºC) was evaluated by simple F-test. The same procedure was used to evaluate the effect of time without pressure (TWP=T1 x T2, T4 x T5), post-treatment (PT=T1 x T3, T4 x T6) and to compare strategies (TWP/PT= T2 x T3, T5 x T6), as can be seen in Table 2

Table 2

Experiment design to analyse the effect of TWP, PT, strategy and temperature

Effect	Treatment Comparison
TWP	T1 x T2 (160ºC); T4 x T5 (190ºC)
PT	T1 x T3 (160ºC); T4 x T6 (190ºC)
Strategy	T2 x T3 (160ºC); T5 x T6 (190ºC)
Temperature	T1 x T4 (TWP); T2 x T5 (TUP); T3 X T6 (PT)

RESULTS AND DISCUSSION

Variables of the Thermomechanical Treatments

The internal temperature variations for each treatment and for the post-treatment measured by the thermocouple. The curves corresponding to the temperatures 160ºC and 190ºC represent the averages of each treatment. During the initial two minutes of each curve, the temperature gain was quicker. The presence of moisture on the samples enabled the internal heat exchange, providing the accelerated heating on this phase. It is noted in the graphic that the first internal stabilization occurs at 70ºC, highlighting that on the samples submitted to the post-treatment, such stabilization occurred at 130ºC. The total stabilization of the internal temperature occurred on different moments on the three curves observed. The temperature of 160ºC occurred at after 18 minutes from the beginning of the plates heating. As for the time to reach 190ºC was quicker, probably, due the fact that the plates had been heated, previously. During the post-treatment, the 170ºC temperature was reached quickly, at 5 minutes.

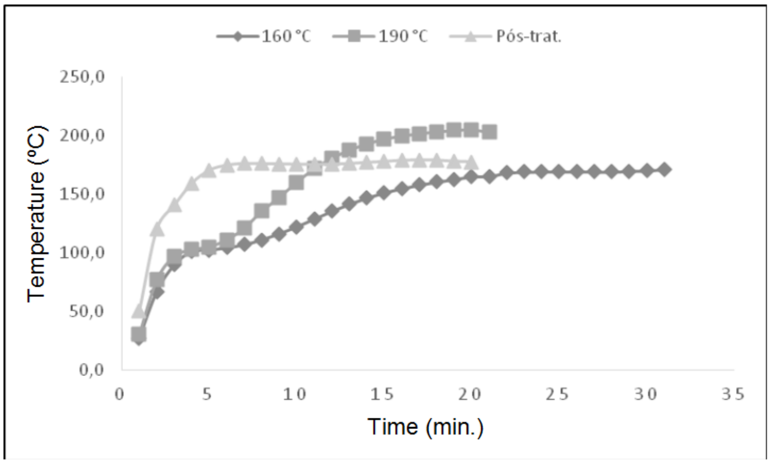

Fig. 2.
Taber equipment used for the abrasion test.

The main effect of the wood compression is the reduction of the spaces between the cells and the cell lumen. Due the heat effect over the wood viscoelastic polymers, the damage on the cell wall occurs without fractures, the vases flatten and the radius get curved (Kutnar et al. 2009). The compaction rates for wood thickness (CR) were higher on T5 (50.6%). The same results could be verified on the wood densification rates regarding density (DR). Again, T5 presented the highest value: 71.2%. Therefore, the use of elevated temperatures reduced the thickness and increased the density. The mass loss varied between 10.9 and 12.8%, being the higher levels verified on treatments with higher temperatures (190ºC). The loss of wood is one of the main characteristics of the thermomechanical treatments, it is attributed to the drying and partial damage of the wood (Vasconcelos and Del Menezzi 2013).

Table 3

Compaction, densification rate and mass loss of the boards subjected to different thermomechanical treatments

Treatment	CR [%]	DR [%]	ML [%]
T1	45.1	57.3	11.0
T2	45.4	57.3	11.2
T3	41.8	49.6	10.9
T4	49.1	67.7	11.8
T5	50.6	71.2	12.6
T6	49.6	64.5	12.8

According to Del Menezzi et al. (2015) during the heating-compression (TUP) step the hot-press was set to keep the pressure constant. Nevertheless, when the wood is heated the lignin loses stiffness, and passes from a glassy to a rubbery stage. This way, the pressure required to keep the wood deformation goes down (relaxation phenomenon) and thus the hot-press adjusted automatically to the pressure set and further wood densification happened. Fig. 2 shows the appearance of the wood board after the thermomechanical treatments. It is clear the reduction of the thickness which improved the density of the board. Some distortion can be also seen.

Fig. 2.
View of the thickness and the shape of the board after the thermomechanical treatments.

Abrasion Behavior

The averages wear rates of the abrasion test are represented on Fig. 3. The highest AR value was observed on the control boards (0.036%), while on T6 (190ºC, TWP+PT) the abrasion was significamtly lower (0.021%). However, AR values were not significantly differents when control boards were compared with any other thermomechanical treatment. Aytin et al. (2015) evaluated the abrasion resistance of the wood from wild cherry treated in accordance with ThemoWood process. They assessed the abrasion resistance in terms of weight loss (WL) and thickness reduction (TR) and observed more abrasion in the heated treated boards (tangential) than in the untreated samples.

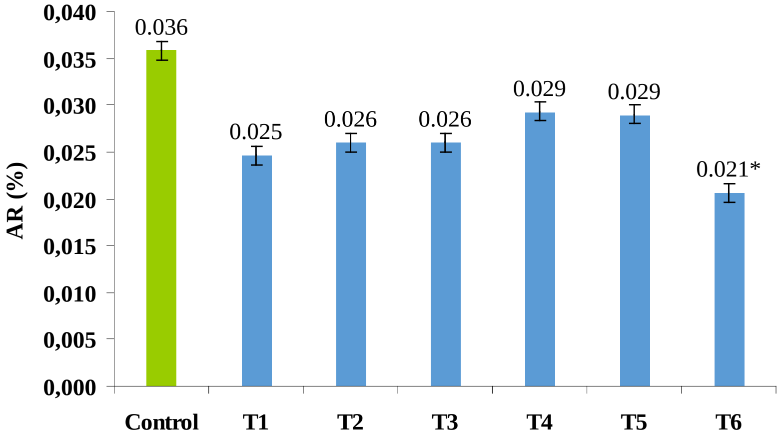

Fig. 3.
Abrasion resistance of pinus wood subjected to different thermomechanical treatments.

Fig. 4.
Apperance of the samples after the abrasion test.

Fig. 4 shows the appearance of the treated boards after the abrasion test. Visually there are not so many differences. According to the ANOVA results (Table 3), for both temperatures keeping the boards into the press or removed imediately led to no differences for AR values (*p*-value 20.6% and 96.8%). When the PT was employed the difference was statistically significantly only for 190ºC (*p*-value 0.008) which means that post treatment one week later was effective to improve the abrasion resistance: 0.021 (T6) x 0.029 (T4). On the other hand, for 160ºC the difference was not significant (*p*-value 0.659). The strategy did not affect the AR values for both temperature tested (*p*-values 0.725 and 0.066). The effect of the temperature was not observed as well (*p*-values 0.133, 0.746 and 0.059). It is unsual results since it is usually known that temperature is the most important factor for any kind of the thermal treatment. In our previous study (Del Menezzi et al. 2015) using the same treatments used here, it was observed that boards treated at 190ºC presented lower equilibrium moisture contente and higher dimensional stability in comparison with those treated at 160ºC.

Table 4

Results of the treatment comparison to evaluate the effect of TWP, TUP, strategy and temperature

Effect	Treatment Comparison	*p*-value
TWP	T1 x T2 (160ºC);	0.206
	T4 x T5 (190ºC)	0.968
PT	T1 x T3 (160ºC);	0.659
	T4 x T6 (190ºC)	0.008
Strategy	T2 x T3 (160ºC);	0.725
	T5 x T6 (190ºC)	0.066
Temperature	T1 x T4 (TWP);	0.133
	T2 x T5 (TUP);	0.746
	T3 X T6 (PT)	0.059

CONCLUSIONS

The thermomechanical treatment improved slighlty the proprieties of the Pinus sp. wood regarding the wear rates caused by the abrasion test. The best treatment observed was at 190ºC and post-treatment. The treatments tested reduced significantly the thickness of the samples, increasing the density.

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REFERENCES

Arruda LM, Del Menezzi CHS (2013) Effect of thermomechanical treatment on physical properties of wood veneers. International Journal of Wood and Wood Products 4(4):217-224.

Aytin A, Korkut S, As N, Ünsal Ö, Gündüz G (2015) Effect of heat treatment of wild cherry Wood on abrasion resistance and withdrawal capacity of screws. Drvna Industrija 66(4):297-303.

Bustos C, Escobar W, Cloutier A, Fang C, Carrasco P (2011) Densification of wood veneers combined with oil-heat treatment. Part III: Cell wall mechanical properties determined by nanoindentation. BioResources 7(2):1525-1532.

Del Menezzi C, Santos P, Ulian M (2015) Hot-pressing schedules for thermomechanical modification of wood. Proceedings of the 8th European Conference on Wood Modification, Helsinki, Finland, pp. 1-6.

Del Menezzi CHS, Tomaselli I, Okino EYA, Teixeira DE, Santana MAE (2009) Thermal modification of consolidated oriented strandboards: effects on dimensional stability, mechanical properties, chemical composition and surface color. European Journal of Wood and Wood Products 67(4):383-396.

Del Menezzi CHS, Tomaselli I (2006) Contact thermal post-treatment of oriented strandboard to improve dimensional stability: A preliminary study. Holz als Roh- und Werkstoff 67(3):212-217.

Kutnar A, Kamke F, Sernek M (2009) Density Profile and Morphology of Viscoelastic Thermal Compressed Wood. Wood Science and Technology 43(1-2):57-68.

Lopes MDM (2012) Resistência à Abrasão de 11 Espécies Tropicais, Departamento de Engenharia Florestal. Universidade de Brasília, Brasília-DF, pp. 48.

Martins M (2008) Ensaios de simulação de uso em pisos de *Eucalyptus cloeziana* F. Muell, *Eucalyptus microcorys* F. Muell e *Corymbia maculata* Hook, Lavras: UFLA 48p. il.

Santos C, Del Menezzi C, Souza M (2012) Properties of thermo-mechanically treated wood from Pinus caribaea var. hondurensis. BioResources 7(2):1850-1865.

Vasconcelos RG, Del Menezzi CHS (2013) Utilization of a three-step thermo-mechanical treatment to modify wood properties. Proceedings of the 19th International Conference on Composite Materials, Quebec, Canada, pp. 7692-7699.