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Influence of thermo-vacuum treatment on bending properties of poplar rotary-cut veneer

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The present paper investigates the influence of thermo-vacuum treatment at 170, 190 and 210 °C on the mechanical and physical properties of poplar wood rotary-cut veneers obtained from two different poplar clones ('I-214' and 'Lena'). The modulus of rupture in bending was determined according to a method derived from European Standard EN-310 and previously validated by the authors, while the density was determined on the basis of EN-323. With both clones no significant decrease was recorded either in bending strength or in density with treatment temperatures up to 190 °C. On the contrary, at 210 °C a highly significant decrease in modulus of rupture ('I-214': -18%; 'Lena': -15%) was recorded; the density showed a similar, though lower, trend ('I-214': -5 %; 'Lena': -8.5 %).

Keywords: ***Populus***, **Poplar Wood, Veneer, Thermal treatment, Bending Strength**

Introduction

Thermal treatment has been applied to wood since the beginning of the last century, when several studies demonstrated that exposing wood to high temperatures reduces its equilibrium moisture content and consequently its dimensional shrinkage (Bekhta & Niemz 2003, Esteves & Pereira 2008). High-temperature heat treatment is considered a suitable method to improve some wood characteristics. It allows to reduce the amount of toxic chemical applications normally required to increase wood durability and enhances dimensional stability by reducing its hygroscopicity (Pétrissans et al. 2003, Romagnoli et al. 2015). Nowadays, heat treatment (HT) is mainly applied to sawn timber, while limited information is yet available about the treatment of wood-based engineered materials, in particular poplar veneers and plywood. In this context, a few recent studies focused on these products: Goli et al. (2014) investigated the physical mechanical properties of poplar plywood heated in normal conditions of oxygen availability; Lovrić et al. (2014) studied the influence of thermal modification on the color of poplar veneers; Zdravković et al. (2013) assessed the dimensional stability of plywood made of thermally modified poplar veneers.

Several HT processes have been developed during the last years; among these, thermo-vacuum treatment is an innovative technology in which reduction of oxygen concentration, necessary to avoid wood combustion, is obtained by creating a vacuum inside the reactor. This method provides several advantages in terms of process efficiency and quality of the material treated (Allegretti et al. 2012). On the whole, the industrial and scientific interest in thermally treated wood is currently having new impetus due to the growing demand for environmental-friendly construction products (Sandberg et al. 2013, Todaro et al. 2015).

In this paper we report the results of a study on the bending properties of poplar rotary-cut veneers to which a thermo-vacuum process was applied at 170 °C, 190 °C and 210 °C. The aim was to determine which process parameters allow to achieve the maximum improvement of performance. In fact, it is well known that while some wood characteristics (*e.g.*, durability, dimensional stability) benefit from thermo-treatment, others (*e.g.*, the mechanical behavior) can be negatively influenced (Esteves & Pereira 2008, Kocaefe et al. 2008).

Materials and methods

In this experimental work, veneers of the clones 'I-214' (*Populus* × *canadensis* Moench) and 'Lena' (*Populus deltoides* W. Bartam. ex Marshall) were peeled by a plywood factory of established experience, according to its usual industrial practice. For each clone, 4 veneers were chosen among the sheets where growth rings and/or separation between sapwood and false heartwood were clearly visible, in order to evaluate the influence of these anatomical features on the properties of the wood material considered. Veneers were divided into different portions, which were subjected to heat treatment at 170 °C (T1), 190 °C (T2), 210 °C (T3); due to the limited amount of material available, treatment T2 was not performed on the veneers of the clone 'Lena'. Non-treated veneers (T0) were also collected and successively tested as control.

After treatment, all veneers, including non-treated ones, were photographed and a grid was drawn on their surface in order to locate all test pieces which were subsequently cut from the sheet and marked according to their original position. From each sheet portion a set of 36 test pieces was drawn.

As there are no international standards establishing mechanical test methods for veneers, the bending strength of the test pieces (2.5 mm thick, 20 mm wide and 80 mm long) was determined according to a

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Tab. 1 - Clone 'I-214': minimum and maximum values of MoR (N mm^{-2}) and density (in g cm^{-3}), together with standard deviation and mean values, of tested veneers.

Parameter	Statistics	T0 (non treated)	T1 (170 °C)	T2 (190 °C)	T3 (210 °C)
MoR (N mm^{-2})	Min.	48.39	47.73	49.95	35.21
	Max.	73.06	77.48	74.87	63.30
	St. dev.	6.64	6.25	6.35	7.17
	Mean value	62.14	62.75	62.82	50.97
Density (g cm^{-3})	Min.	0.290	0.299	0.297	0.281
	Max.	0.393	0.386	0.389	0.372
	St. dev.	0.345	0.022	0.021	0.023
	Mean value	0.345	0.340	0.342	0.329

Tab. 2 - Clone 'Lena': minimum and maximum values of MoR (N mm^{-2}) and density (in g cm^{-3}), together with standard deviation and mean values, of tested veneers.

Parameter	Statistics	T0 (non treated)	T1 (170 °C)	T3 (210 °C)
MoR (N mm^{-2})	Min.	45.83	48.46	26.15
	Max.	83.60	76.71	76.65
	St. dev.	9.84	7.08	11.52
	Mean value	61.05	62.28	51.99
Density (g cm^{-3})	Min.	0.304	0.314	0.292
	Max.	0.465	0.471	0.451
	St. dev.	0.041	0.038	0.046
	Mean value	0.398	0.386	0.364

method – based on EN-310 (1994) – already validated by one of the authors in a previous study (Castro et al. 2014). Due to the high correlation between modulus of elasticity (MoE) and modulus of rupture (MoR) demonstrated (Castro et al. 2014), and in consideration of the simplicity and convenience of determining the latter with the equipment available, only MoR was measured.

The test pieces were conditioned until constant mass was reached in a climatic cell at a temperature of 20 ± 2 °C in an atmosphere with 65 ± 5 % of relative humidity and then subjected to three-point static bending (with a span of 70 mm), to determine their longitudinal Modulus of Rupture (MoR). The tests were carried out using a tensometer particularly suitable for small-size test pieces when the strains to be measured are rather low, by means of a 100 daN load cell. The load was applied with a constant movement rate of the loading head of 5 mm min^{-1}, corresponding to a total time until rupture between 90 s and 120 s.

As for the determination of density, the tests were carried out in conformity with EN-323 (1994) standard. The dimensions of each test piece were measured using a digital caliper with an accuracy of ± 0.01 mm, while the weight was measured using a scale with an accuracy of ± 0.01 mm.

For both MoR and density, statistical differences among treatments To, T1, T2 and T3 were investigated through the analysis of variance (ANOVA) using a LSD *post-hoc* test.

Results and conclusions

Tab. 1 and Tab. 2 report minimum and maximum values, together with standard deviations and mean values, of the bending strength and density determined on test pieces of the clones 'I-214' and 'Lena' respectively, cut both from veneers subjected to all treatments and from non-treated ones.

According to previous researches (Castro et al. 2014), it can be easily seen that the bending strength varies significantly in the different zones of the growth ring. The values determined on early wood are considerably lower than those obtained on latewood: for instance, in the case of 'I-214' non-treated (To) veneers the minimum value (48.4 N mm^{-2}), recorded on early wood, is only 43% of the maximum value (73.1 N mm^{-2}) obtained on latewood. Similar differences were also found for all the treatments for both clones.

Either for MoR or density, no significant difference was found for both clones among non-treated veneers and veneers treated at 170 °C and 190 °C. Instead, statistically significant differences ($p < 0.01$ for MoR and $p < 0.05$ for density) were found between veneers treated at 210 °C and all the other treatments (Fig. 1 and Fig. 2). This behavior, showed both by 'I-214' and 'Lena' veneers, indicates that beyond 190 °C a relevant degradation of wood fibre structure occurs, determining an abrupt decrease of bending strength properties. Finally, a high and significant correlation was found by linear regression between density and MoR both for 'I-214' ($R^2 = 0.88$) and 'Lena' ($R^2 = 0.81$), confirming the well-known relation between these parameters.

In conclusion, the results obtained so far suggest that no significant modification in terms of modulus of rupture and density occurs to thermo-vacuum treated poplar

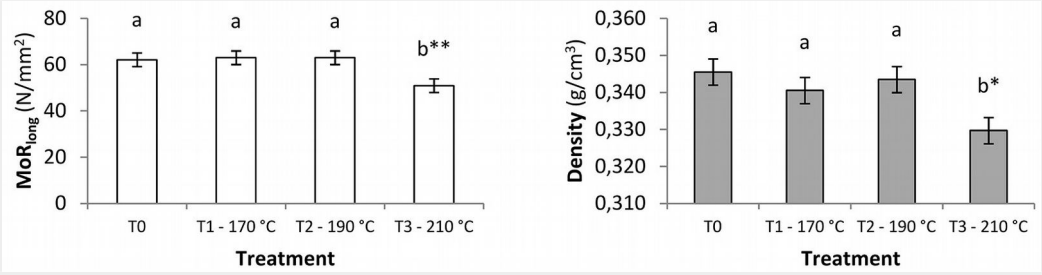

Fig. 1 - Clone 'I-214': mean values and statistical differences MoR (left) and density (right) determined on veneers subjected to HT To, T1, T2 and T3. Different letters indicate significant differences after LSD test. (*): $p < 0.05$; (**): $p < 0.01$.

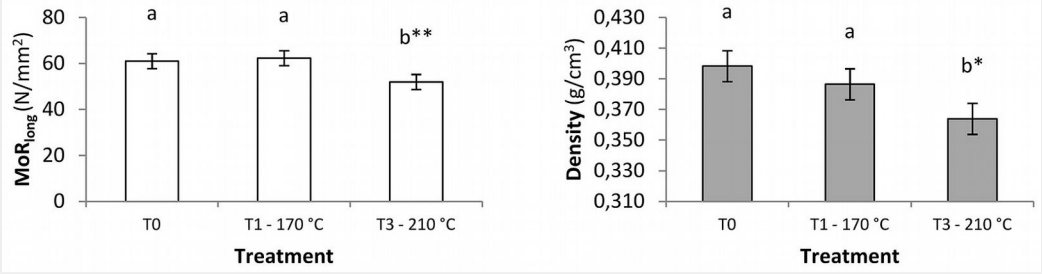

Fig. 2 - Clone 'Lena': mean values and statistical differences MoR (left) and density (right) determined on veneers subjected to HT To, T1 and T3. Different letters indicate significant differences after LSD test. (*): $p < 0.05$; (**): $p < 0.01$.

veneers up to 190 °C, while at 210 °C these properties decrease significantly. These findings, together with other data on treated veneers such as natural durability and dimensional stability, could allow to develop an effective thermo-vacuum treatment for poplar veneers and plywood. Such a product could be suitable for many applications in exterior environments, particularly as a replacement for panels made with some exotic wood species.

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