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# TORREFACTION OF LAMELLAR PANELS MADE OF OAK AND SPRUCE WOOD SPECIES

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## ABSTRACT

This paper is focused on the torrefaction of lamellar panels made of wooden species of spruce and beech, with a view to noticing the influences of the torrefaction on the physical and mechanical properties. The working method highlights the special character of the lamellar panel torrefaction as compared to other torrefied products. The obtained results emphasize that the mass losses increase with the severity of the thermal-treatment condition, where as the hygroscopicity and mechanical properties of the material simultaneously decrease. The analysis of the obtained results recommends the use of these panels in humid/moist environment.

KEYWORDS: Lamellar panels, oak, spruce, torrefaction.

## INTRODUCTION

Nowadays, the lamellar panels are a step forward in the use of many fabrication residues, and are afterwards usable, in their turn, in the industry of furniture and other wooden finished products. At a small scale, these panels are the predecessors of Glue Laminated Products (Glulam), so much used in civil engineering, in the last years. As compared to Glulam, which is made of light species only, the lamellar panels are made of easy and heavy species, due to their final use in furniture and other decorative products. The wood used in such lamellar panels as renewable biomass source (Lakó et al. 2008, Griu and Lunguleasa 2014, McKendry 2002, Prasertsan and Sajakulnukit 2006) contributes to reducing the effects of the global warming (Dhillon and von Wuelhlisch 2013, Eurostat 2011, Robert et al. 2005).

The thermal treatment of the massif wood (including the lamellar panels) is a dry treatment (Esteves and Pereira 2009), which, along with the hydro- and hygro-thermal treatment (Chen et al. 2012), is used to ime some wood properties. This treatment is applied at temperatures of 180-280°C (James et al. 2015, Batidzirai 2013, Walkowiak and Bartkowiak 2012), within various periods of time, depending on the wood species and the features to be obtained

(IEA Bioenergy 2010). The main advantages of the torrefied wood are the following: it improves its dimensional stability by 30-50%; it protects the wood for a short time against putrefaction and most of the insects; it produces a pretty color; it uses no impregnation or surface protection chemicals; it decreases the hygroscopicity and increases the calorific value (Wang 2011, Wechsler 2010, Teuch et al. 2004). Due to these advantages, the thermally treated wood is profitable in terms of costs (Batidzirai et al. 2013). Usually, the first to be thermally treated are the segments; afterwards, these segments are assembled in panels, but the treatment of the sized panels is also possible. The treated wood is an improved one, i.e. a type of wood with improved properties (reduced hygroscopicity, increased dimensional stability and increased calorific value), but it also has weaker properties, such as density and some mechanical resistances. The hemicelluloses are the components which determine the biomass hydrophibility; these components are reduced through torrefaction (Moya and Tenorio 2013, Shulga 2008, *WFH 2013*). The variation in thickness of the torrefaction effects, is reduced, especially for small thicknesses up to 20 mm (Bos 2011). It is well-known that other products are also torrefied, such as sawdust, (Chen et al. 2011), briquettes (Lunguleasa 2011), wooden chips and pellets, but also vegetal waste, as rice peels (Chen et al. 2014). Some authors have emphasized that the biomass torrefaction is a preliminary treatment of the biomass pyrolysis (Bridgwater 2012, Brue 2012).

The aim of this paper is to study the lamellar panels made of massive wood and thermally treated at high temperatures of 180°C and 200°C. It analyzes the positive effects of the torrefaction, i.e. the decrease of the water absorption, of the thickness swelling and of the lamellar panel swelling, but also the negative/positive effects on the static bending strength and on the Brinell hardness.

## METHOD AND MATERIALS

Lamellar panels made of spruce and oak wood (a light and a heavy species), having the initial dimensions of 1000 x 1000 mm, were used; they were cut in 300 x 300 mm pieces for the purposes of the torrefaction. First, these samples were weighed and their thickness was measured in 5 points. Then, the samples were introduced in a laboratory oven (Fig. 1) for drying at 103 +/-2°C, for 10 hours. They were weighed once again after another drying hour (to be sure that they were completely dried) and their thickness was measured. Then the effective thermal treatment began, at temperatures of 180°C and 200°C, for 3 and 5 hours. Different samples were used for each thermal-treatment condition; the two treatment temperatures were noted with T1 and T2, and the two thermal treatment durations were noted with t1 and t2. In this way, there were four sample combinations for each species, respectively T1t1, T1t2, T2t1, and T2t2.

*Fig. 1: Laboratory oven used for torrefaction process.*

The first characteristic of the thermal treatment to be determined was the mass loss, using the following relation:

$$M_l = \frac{m_i - m_f}{m_i} \cdot 100\ [\%] \qquad (1)$$

where: $m_i$ - the initial mass of samples (g),
$m_f$ - final mass of samples (g).

From the treated samples, but also from the untreated ones, small 100 x 30 mm samples were cut in order to measure the water absorption and the thickness swelling, all the samples being brought in a dry condition. The samples were noted with T1t1-1, T2t2-2, etc., the sample quantity ranging between 34 and 45 pieces. The mass and the thickness of each sample were measured immediately after drying, the samples being kept in a desiccator for cooling. Then the samples were introduced in an immersion tank filled with clean water, at the room temperature of 20°C, at 2 cm below the water level. The water absorption was measured after 2 hours, 4 hours, 6 hours and 24 hours, using the general relation:

$$A_i = \frac{m_i - m_{0i}}{m_{0i}} \cdot 100\ [\%] \qquad (\%) \qquad (2)$$

where: $m_i$ - sample mass for each time interval (g),
$m_{0i}$ - initial sample mass in dried condition (g),
$i$=2, 4, 6 and 24 hours.

Singularized for a time interval of 4 hours, the previous relation becomes:

$$A_i = \frac{m_4 - m_{04}}{m_{04}} \cdot 100\ [\%] \qquad (\%) \qquad (3)$$

The thickness swelling of the samples was established according to the sample thickness variation, using the general relation:

$$S_i = \frac{g_i - g_{0i}}{g_{0i}} \cdot 100\ [\%] \qquad (\%) \qquad (4)$$

where: $g_i$ - the thickness at the $i$ time (mm),
$g_{0i}$ - the initial thickness after drying, at $i$ time (min).

To measure the bending strength, samples of 50 mm in width and 350 mm in length were cut (the length being established provided that the distance between test cradle feet should be 20 times greater than the sample thickness). 10 samples of each type were used, including control samples for comparison. In order to establish the bending strength, the test machine software used the following relation, valid for parallelepiped sections:

$$BS = \frac{3}{2} \frac{P_{max} \cdot l}{b \cdot g^2}\ [N/mm^2] \qquad (N \cdot mm^{-2}) \qquad (5)$$

where: $P_{max}$ - maximum breaking force of the sample (N),
$l$ - distance between the cradle feet (mm),
$b$ - sample width (mm),
$g$ - sample thickness ( mm).

The samples used for determining Brinell hardness, had a square surface of 50 x 50 mm. A universal machine for mechanical tests was used and the punching device had in its head a metallic ball of 10 mm in diameter. The trace left by the ball on the surface of the sample was imprinted through a copying paper. The diameter was determined as the arithmetic average of two perpendicular diameters of the trace left on the sample under a force of 500 N. The calculation formula, derived from the general relation between the force and the compression trace area (Croitoru et al. 2015), was the following:

$$HB = \frac{2P}{\pi D\left(D-\sqrt{D^2-d^2}\right.}\ \left[\frac{N}{mm^2}\right] \quad (6)$$

Both for the static bending and Brinell hardness, the arithmetic average of at least 10 tested samples was computed, for each type of sample and each wooden species.

## RESULTS AND DISCUSSION

The research results were placed in tables and then processed in Microsoft Excel™. A first evaluation for the torrefaction of lamellar panels was made on the mass loss of the samples. Most researchers (Chen et al. 2011, James et al. 2015, Esteves and Pereira 2009) have stated that mass loss is the most important property of torrefied wood. In general, the treatment severity results in an increased mass loss for both wooden species (Fig. 2).

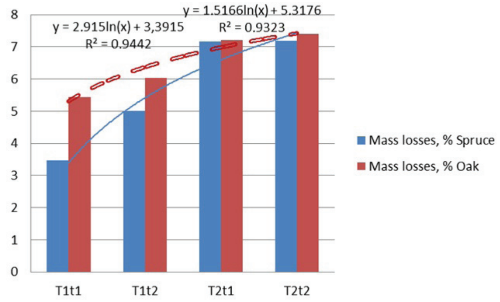

*Fig. 2: Mass losses of spruce and oak panels.*

The curves which better model this rise, in mathematical terms, are the logarithmic ones, with a Pearson coefficient R2 over 0.93. This coefficient is higher for the oak (R2=0.94) as compared to the spruce (R2=0.93), the thermal treatment effects being a little more predictable for the oak species. Statistically speaking, besides the Pearson coefficient, in interpreting the results it was used the arithmetic mean and standard deviation. It followed that the distribution values are symmetrical with form of Gauss's bell and extreme limits should not exceed three times the standard deviation. One can see in Fig. 2 that the oak generally has greater mass losses than the spruce. Also, for higher severities of the treatment condition, the mass losses of the two species come very close, the differences between the two species practically disappearing for T2t2 treatment degree. Working with other wooden species (Norway spruce, Common ash and Turkey oak) (Todora et al. 2015) have found the same percentages of mass losses.

The water absorption (i.e. the water quantity received by the lamellar panels when they are immersed) generally decreases for the treated panels as compared to the control ones, for both analyzed species (Fig. 3). Most of the authors (Uslu 2008, Esteves and Pereira 2009, Shulga et al. 2008) consider that this fact is due to the decrease of the hemicellulose content in the wood, the hemicelluloses being more hydrophilic than the cellulose and the lignin. The linear equations model quite well the absorption decrease, with a Pearson coefficient over 0.85. From this point of view, the decrease is more predictable for the oak, as the coefficient is higher. This fact is attributed to the structural unevenness of spruce wood, and especially to the differences between the early and late wood (Lunguleasa 2011, Todora et al. 2015). Another idea, visible in Fig. 3, is that of the slope of the two curves corresponding to a 24-hour water absorption, the slope being greater for the oak (2.54) as compared to the spruce (1.53). This means that the water absorption for the oak A24 is higher, starting with 22.93 % for the control sample, up to 13.16 % for the most severe condition T2t2, which means a decrease of 42%, as compared to the spruce, which has a slighter decrease of 12.7 % only for the same A24 and T2t2.

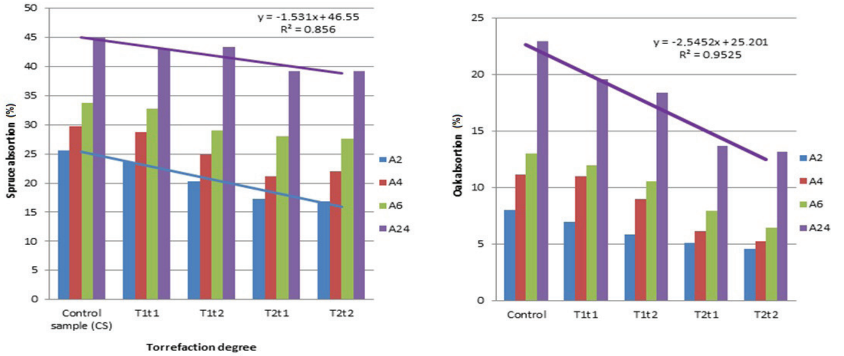

*Fig. 3: Water absorption of lamellar panels related to torrefaction degrees.*

The thickness swelling is the main parameter of the dimensional stability of the lamellar panels (Aytin et al. 2015). This parameter is stabilized after the torrefaction, decreasing from 6.01 % for the control sample, to 2.2 % for the T2t2 treatment applied to the spruce, i.e. a percentage decrease of 63 % (Fig 4). The mathematical modeling of the decreased thickness swelling is performed with high precision by the polynomial curves of second order, the approximation being nearly identical (the Pearson coefficients are almost identical). The curve is nearly linear for the oak, which indicates once more that it is a predictable species in terms of torrefaction and its related anticipated effects.

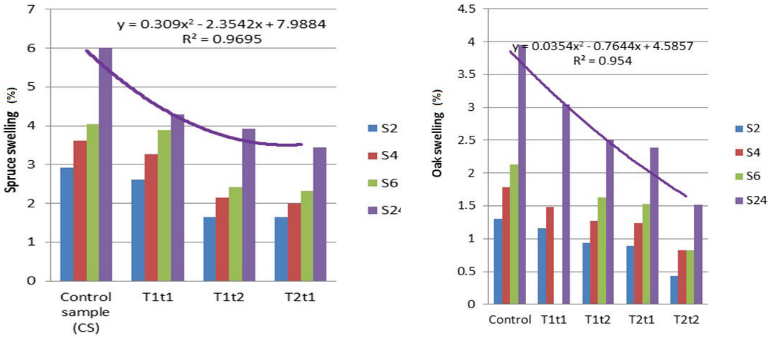

*Fig. 4: Thickness swelling of lamellar panels*

The bending strength of the thermally treated lamellar panels is the main strength which shows whether the panels maintain their properties, or otherwise, the extent to which they decrease. One can see that the strength highly decreases once with the increased severity of the torrefaction condition for the oak panels, the decrease ranging from 118 N·mm$^{-2}$ for the control sample, to 28.6 N·mm$^{-2}$ for the T2t2 samples, i.e. a percentage decrease of 75.7 %. The equation that best models this issue, is that of the polynomial of second degree, with $R^2$ coefficients over 0.94.

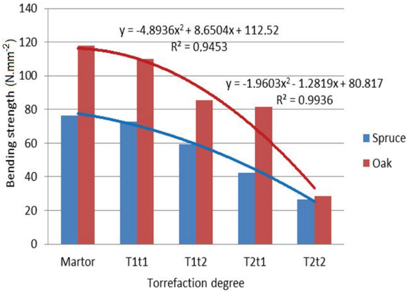

*Fig. 5: Bending strength of lamellar panels.*

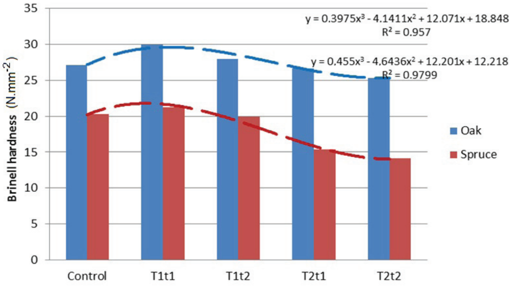

*Fig. 6: Brinell hardness of lamellar panels.*

As for the mass losses, Fig. 5 clearly shows how the two curves become very close at the maximum severity of the thermal treatment, so that practically there are no differences between the two analyzed wooden species. Similar values have been obtained by other authors (Walkowiak and Bartkowiak 2012, Aytin et al 2015, Todora et al. 2015) for different species, such as S*alix Viminalis,* Wild cherry; *Triplochiton scleroxylon*.

The Brinell hardness of the lamellar panels shows the value of the panel surface resistance (Croitoru et al. 2015), being known that, at high temperatures, the wood surface decays, and the cellular membrane collapses in the cellular lumen, a flaws which is generally referred to as "collapse".

Fig. 6 shows that the phenomena occurring in the surface layer of the panels are much more complex; there is a minor increase in the first stage (from 20.34 N·mm$^{-2}$ for the control sample, to 21.25 N·mm$^{-2}$ for the T1t1 condition, in case of the spruce, i.e. an increase of 4.4 %); thereafter the decrease in hardness is significant (from 21.25 N·mm$^{-2}$ for T1t1, to 14.12 N·mm$^{-2}$ for T2t2, i.e. a decrease of 33.5 %). This behavior is attributed to the superficial hardening of the panel surface at less severe thermal-treatment conditions (T1t1), after which, once with the increasing temperature and treatment time (T2t1), the cellular membrane of the wood significantly decays. In this respect, an optimal point of the thermal treatment is at 180°C for 3 hours, for both spruce and oak. One can see that the equation which best models this process, is the polynomial equation of third degree, with Pearson coefficients over 0.95.

Additional analyses can be performed, with a view to correlating various factors, such as temperature combined with mass loss, mass loss with bending strength, thickness swelling with temperature etc. For example, Fig. 7 shows the extent to which the torrefaction influences the mass loss and thickness swelling. It highlights a continuous increase in mass loss and decreased thickness swelling. Taking into account the high costs (Batidzirai et al. 2013, Lunguleasa et al. 2015) and their rise along with increasing torrefaction degrees, it is recommended a moderate heat treatment 180/3, with a loss of 4.2 % mass and a similar thickness swelling.

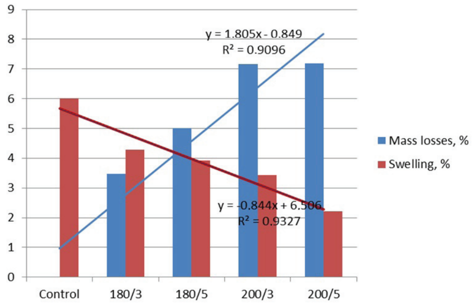

*Fig. 6: Influence of torrefaction degree on mass losses and thickness swelling.*

During the experiment, other secondary torrefaction effects were also noted, the beautiful brown color being darker at the oak than at the spruce. Moreover, the resin in the spruce panels melted during the treatment and leaked out; likewise, other areas of the panels with poor adhesive-gluing, detached, however such areas representing less than 3 % of the total gluing of the panels.

## CONCLUSIONS

The thermal treatment of the lamellar panels brings significant improvements to their properties. In terms of positive torrefaction effects, there are visible significant decreases in the lamellar panel density, as mass losses, water-absorption decreases and thickness-swelling decreases; however, in terms of negative effects, there are also visible significant decreases in the bending strength and Brinell hardness. The variation laws are much clearer in case of the oak than in case of the spruce, due to the structural uniformity of the oak and to the better penetration of the warm air in its structure through its large pores. Nevertheless, these variations differ, depending on the way of determining them; there is a logarithmic variation for mass losses, a polynomial variation for the Brinell hardness and the static bending strength, as well as a linear variation for the water absorption. Because the torrefied panels are more hydrophobic and dimensionally more stable, their use is recommended in wet environments, such as for the bathroom-, kitchen- and garden-furniture and for other decorative objects.

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