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INFLUENCE OF DRYING ON DOUGLAS-FIR HEARTWOOD IMPREGNABILITY TO WATER

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ABSTRACT

Within the next ten years, the Douglas-fir will be the main softwood resource harvested in France, largely due to the growing market for wood frame construction in Europe. A large part of this supply will be devoted to EWP production, particularly plywood and LVL. To process these products, bolts must be peeled and therefore require a heat treatment of around 50 °C. Usually, bolts are soaked in hot water for12 to 72 hours, depending on the wood species and bolt diameter. However, Douglas-fir green wood shows two particularities that complicate boiling efficiency: (i) the heartwood has a MC near FSP (30 to 40 %) i.e. there is nearly no free water in the tracheid; and (ii) it is impossible to impregnate this heartwood at atmospheric pressure with water. As a result, wood material being a very efficient insulator, boiling Douglas-fir prior to peeling for veneer production will take a very long time, since free water is the main medium allowing heat transfer into green wood.

This paper includes a review of the anatomical, chemical and physical factors responsible for the very low impregnability of Douglas-fir heartwood. In this analysis, a first set of preliminary tests was performed in order to improve impregnation. It consisted of (i) soaking small samples (20 × 20 × 120 mm^3 in RTL basis) in hot water at atmospheric pressure at different temperatures (every 10°C between 50 and 90 °C for different treatment durations (5 to 22 hours)); (ii) putting a tensoactive product into water; and (iii) applying ultrasonic waves (200 kHz / 400 W) in order to provoke micro-cavitation and then rupture the bordered pit torus. The results proved the inefficiency of such treatments on Douglas-fir impregnability, even on small samples. A second set of tests was conducted to quantify the influence of extractives and of drying (heating, vacuum) under the FSP on heartwood permeability. If extractives do not appear to have a real impact, then drying treatment will also not greatly improve permeability. One of the hypotheses is that the drying process may have caused micro cracking in the cell walls.

Other tests are in progress to quantify the speed of absorption of liquid in both longitudinal and transverse directions.

Key words: Douglas-fir, permeability, boiling, ultrasonic treatment, drying.

INTRODUCTION

Contrary to its sapwood, rotary cutting of Douglas-fir heartwood (Pseudotsuga menziesii Franco), which is extensively planted in France, is a very difficult process. These difficulties come mainly from its dryness. The moisture content in the green wood varies between sapwood and heartwood. The sapwood moisture content is frequently higher than 120 %, while the heartwood always has a moisture content near the fibre saturation point (30 %–40 %) (Crown, 1992). This disproportionate distribution of moisture content greatly influences its peeling (Hecker, 1995).

On an industrial scale, bolts require a heat treatment of around 50 °C. Usually, bolts are soaked in hot water for 12 to 72 hours, depending on the wood species and bolt diameter. Heat treatment or steaming is primarily done to plasticize and liquefy the resin timber, thus reducing the cutting force and improving the life of cutting tools and the quality of veneer. However, steaming incidentally allows water penetration, even in wood deemed difficult or impregnable. Free water is the main medium allowing heat transfer into green wood, while Douglas-fir green heartwood shows a moisture content (MC) near FSP (30 to 40 %). Without free water in the tracheid, boiling efficiency is complicated. As a result, because wood material is a very efficient insulator, boiling Douglas-fir prior to peeling in order to produce veneer will take a very long time.

Mothe et al., 2000 found that proper Douglas-fir peeling could be done with a rise in moisture content of the heartwood to around 10 % – but homogeneously enough to significantly improve veneer quality. Takano and Kinoshita 1992, on the other hand, observed a decrease in roughness of Sugi veneers when moisture varied between 100 and 250 %.

Impregnability determines how easily a fluid passes through a porous medium by following a given pressure gradient, but like other properties of wood, impregnability differs depending on the anatomical direction (direction of anisotropy) (Agoua 2001,) and according to a number of structural factors (i.e. fiber length, fiber width, density, statement of pits) (Hansmann et al., 2002). Tibaut (1988) found that with poor impregnability, water cannot get into the wood and veneer becomes second quality due to wrenching and cracking, thus hindering industrial logging.

Researchers have identified two barriers to wood impregnability. The first barrier is physical in nature and is caused by pit aspiration in the green wood (Matsumura et al. 2005). Pits are the main communication system between tracheids, mostly found in conifers, with about 90 % of all wood cells (Polg, 1982). In the heartwood, some pits seem to interrupt transit by aspiration especially in early wood. The torus can be held against the pit border and permanently lose its flexibility (Hecker, 1995).

The second barrier is chemical. Wood shows some hydrophobicity mainly due to its intrinsic extractives. These chemical substances produced during the heartwood formation process play a major role in the humidity of wood and strongly influence the balance of surface energy. Impregnability of wood in tree rings freshly formed is very high. However, with age, the same rings undergoes chemical transformation during heartwood formation: extractives are deposited in the cell lumens and on the pit membranes and pit occlusion can occur (Matsumura et al. 2005). Extractives tend to block the flow of fluids in heartwood and explain the difference between sapwood and heartwood permeability (Chen and Simpson, 1992)

The purpose of this study was to test some technical soaking and put in order some of the factors having an influence on Douglas-fir heartwood low impregnability at atmosphere pressure. Applying ultrasonic waves (200 kHz / 400 W), putting a tension-active product into water and drying samples before soaking were also evaluated for resultant water impregnation.

1. MATERIALS AND METHODS

1.1. Wood samples

Treated samples were from one 40-year-old Pseudotsuga menziesii Franco tree that was 47 cm in diameter at breast height, selected from the Montsauche Settons Morvan Forest in the northeast of the Massif Central. The choice of this tree was based primarily on its straightness and secondly on its ability to represent the rest of the population given its average diameter.

Moisture content cartography of the chosen tree

Four disks (2 cm thick) were cut from different heights of the tree (2,4,6 and 8m aboveground),put into plastic bags to prevent them from drying out and then brought to the laboratory.

Each disk was cut into a board (4 cm radial and tangential sides). Moisture content in each board was calculated using the following formula:

$$\mathbf{H}\,(\%) = \left(\frac{\mathbf{Ms - M0}}{\mathbf{M0}}\right) * \mathbf{100} \qquad \textbf{(1)}$$

Ms = Green weight and M0 = Dry weight.

Moisture content profile in the treated sample

Two bolts (50 cm in length) were selected from 0.3 m above the ground. Samples were taken from the heartwood with 20 × 20 mm × 120 mm^3 in RTL basis. Dimensions were chosen that provided a length-section ratio comparable to that which can be found on logs ready to proceed with peeling.

After applying different treatments, the moisture content (MC) of each sample was calculated using Formula 1on approximately 5-mm thick cross sections obtained using a small band saw.

The different treatments used were analyzed using graphs of moisture distribution within each sample.

1.2. Soaking tests

Small samples (20 × 20 × 120 mm^3 in RTL basis) taken from the heartwood are put into hot water at atmospheric pressure using 4 modalities.

a) “simple soaking” at different temperatures (every 10°C between 50 and 90°C) and for different treatment durations (5 to 22 hours).

b) “hot/cooling soaking” keeping the wood in water during the cooling process: This treatment is based on variations in air temperature depending on volume and is similar to vacuum / pressure treatment.

c) Putting a tenso-active product into water: Using the Wilhelmy method, the dynamic contact angle between a drop of water and the surface of the Douglas heartwood was measured. The tests done showed the hydrophobicity of Douglas heartwood; the contact angle was often found above 90 °.

To improve the humidity of Douglas heartwood, the surface tension of the water was lowered using a surfactant: Brij 30, Sigma-Aldrich. The critical micelle concentration (CMC) of the surfactant was 0.181 g/L.

Finally, the behavior of the standard samples was examined in the mixture water / TRITON.

d) Applying ultrasonic waves (200 kHz/400 W) to provoke micro-cavitation and then rupture of the bordered pit torus: Samples were immersed in water of different temperatures while being bombarded with ultrasonic waves. The ultrasound probe was placed in front of one of the ends of the tested sample which was placed horizontally in water in an oven. The ultrasonic transmitter had a frequency of 20 kHz and a power of 400W. Treatment lasted for 22h.

e) Drying samples before soaking using three drying methods:

- Thermal drying: Putting samples in an oven at 103°C to obtain anahydrous mass;
- Vacuum drying: Putting samples under vacuum at 0.3 mbar for 30 min;
- Natural drying: Using a sample from a board naturally dried in a ventilated area for 2 years.

2. RESULTS AND DISCUSSIONS

2.1. Moisture content analysis

The MC cartography obtained from the four disks was very similar (Figure 1). They showed a sharp decline of moisture between the sapwood and heartwood. The results indicated an average moisture content of 120 % in the sapwood (outer part) and 32 % in the heartwood (heart). Our results agreed with those which are generally observed in the Douglas. These values are approximately constant and independent of the height within the tree or the position in the sapwood or heartwood.

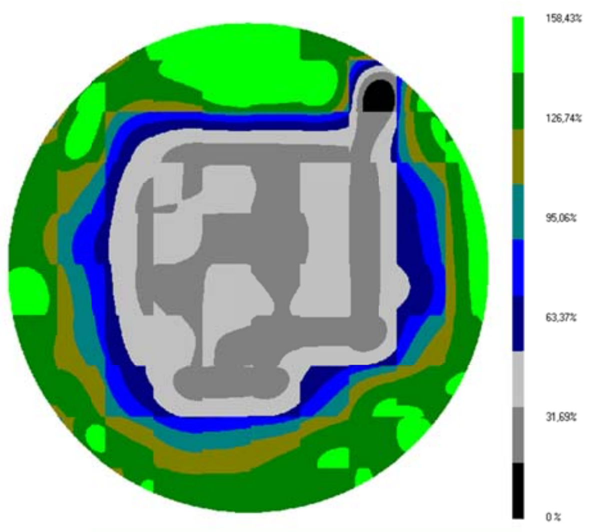

Figure 1: Moisture content cartography of one disk selected from 2 m above ground

There was then a sharp rise in the proportion of moisture in the area corresponding to the sapwood/heartwood transition and into the sapwood.

Finally, humidity levels in the area corresponding to the sapwood were not always greater than 100 %. Indeed, there were even dry areas in the sapwood (knots). Our results were similar to those reported by other researchers (Hecker, 1995).

2.2. Soaking tests

2.2.1. Simple soaking

The results obtained from impregnating samples showed that MC in the centre of the samples is low (between 30 % and 40 %). At the ends of the samples, the moisture content was higher (between 46 and 54 %); it reached 50 % in the heart as a desired MC from a bath temperature of 80 °C after 5 hours of soaking. For a bath temperature of 90 °C, MC in the centre of the samples showed some increase, rising to 55 %. Continuing treatment for 22 hours seems to have yielded better results and the desired MC was reached at a relatively low temperature. However, 22 h was still too long to be easily applied industrially. Moreover, these represent overall moisture, whereas the axial distribution is what most concerns us.

The axial distribution of MC along the length of the sample is shown in Figures 2 and 3. It can be seen that the MC at the ends of samples extends only a few millimetres. Indeed, the rise of liquid in tracheids appears to be stopped very quickly. Too high surface tension or pits aspiration could be the cause of this poor progress of the moisture in the wood. Distribution is still uneven and concentrated near the input surface. Only in the case where the bath temperature was at 90 °C for 22 hours were acceptable moisture levels reached. However, the heterogeneity of distribution of MC will most probably risk generating heterogeneity in the peeling process. The slicing blade will not have the same pressure at the centre and at the ends which could result in tearing and rupture of the veneer. In conclusion, soaking in hot water improves the impregnability with MC generally on the rise, but the uneven distribution of moisture results in a very poor impregnability and does not allow for improved conditions of wood peeling.

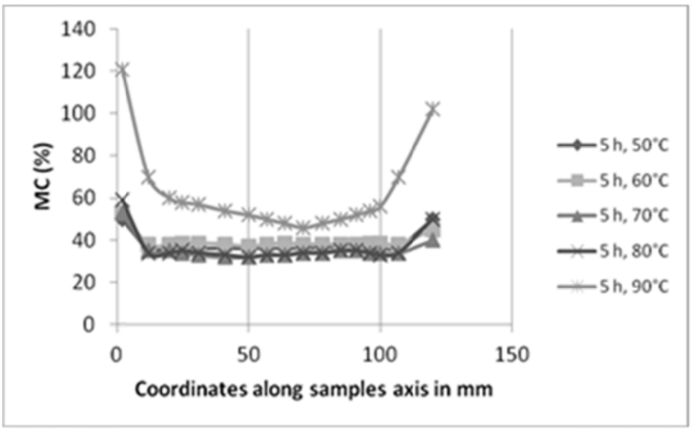

Figure 2: Moisture content after 5 h soaking in different temperatures

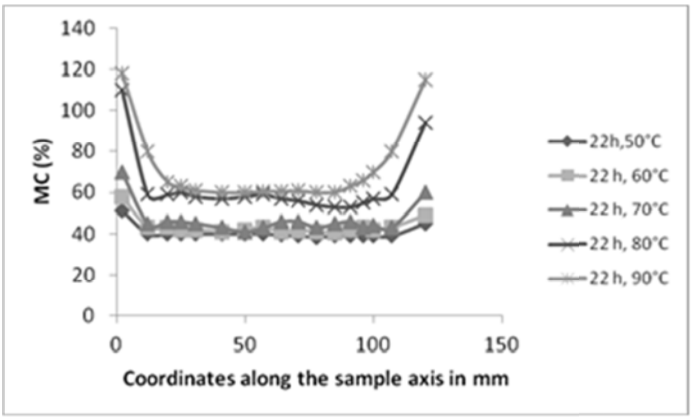

Figure 3: Moisture content after 22 h soaking in different temperatures

2.2.2. Hot cooling / soaking

This process also results in low water absorption in Douglas heartwood. Figures 4 shows the distribution of moisture on the volume of samples obtained on cross sections4-5 mm thick. It can be observed on all the low humidity results in the central portion of the sample.

The penetration of liquid appears to be increased in tracheids depending on temperature, especially from 70–80 °C. However, this trend remains weak and inadequate, given that a homogeneous humidity greater than 50–55 % is desired.

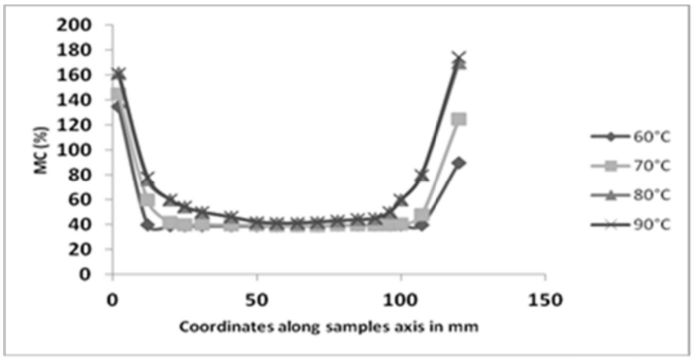

Figure 4: Changes in moisture content after soaking at different temperatures

These results are similar to the previous study (impregnation with hot water). Too unequal distribution is concentrated near the surfaces of entry. From 70°C there is an effect of the hot-cold process. However, the heterogeneity of moisture distribution once again does not achieve better conditions for the rotary cutting process.

2.2.3. Effect of tensoactive product into water

Although measuring humidity of the wood is difficult due to its heterogeneous appearance and porous nature, it was possible characterize the humidity of Douglas by water. The measurements were performed on samples of green sapwood and heartwood 10 x 20 x 1 mm^3 in RTL basis. The results of this first test showed that Douglas wood behaves differently depending on the nature of the wood (sapwood or heartwood). Heartwood hydrophobicity is confirmed by contact angles often higher than76 and 105°; these contact angles are very close to or even above 90° and beyond, marking the limits of hydrophobic materials. However, sapwood showed contact angles oscillating between 30 and 46°. The different measured contact angles are shown in Table 1.

Table 1: Contact Angle of Douglas wood

	contact Angle t à l'avancée du duramen de Douglas, [°]	Angle de contact à l'avancée de l'aubier de Douglas, [°]
Test 1	94,1	40,1
Test 2	82,3	45,7
Test 3	105,0	30,0
Test 4	76,0	32,0

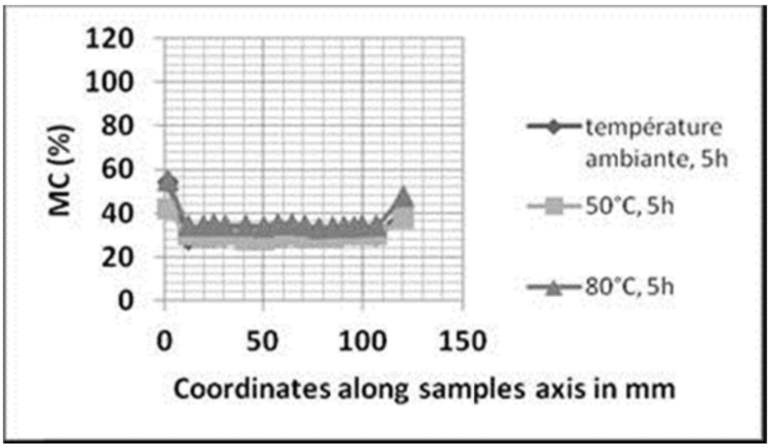

Figure 5: Changes in moisture content after 5 h soaking at different temperatures

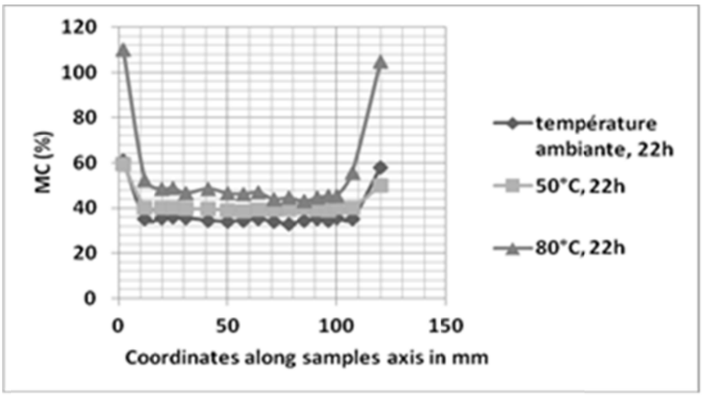

Figure 6: Changes in moisture content after 22h soaking at different temperatures

Heartwood hydrophobicity is highly disadvantageous for water impregnation. Although the surface water tension was greatly reduced and therefore the humidity increased, results show that, whatever the treatment time (5 h or 22 h) or water temperature (50 or 80 °C), impregnating the wood is restricted to entry surfaces. Water thus penetrates the heartwood of Douglas, but did not continue its way into the tracheid capillaries and penetration is limited to a few millimeters (Figures 5 and 6).

In our problem of impregnation, humidity is clearly not the limiting factor. Another parameter prevents the progression of water in heartwood.

2.2.4. Effect of ultrasonic waves

The results are generally disappointing, with low moisture content (30–34 %) in the central area for processing temperatures of 30 and 50 °C. Average moisture is, as for the other tests, highest at the ends. It was particularly noted at the end directly subjected to ultrasonic waves that moisture increased about 1 cm. The moisture distribution in the test piece is shown in Figure 7. It appears that the effect of ultrasound is real but limited to a small thickness. The wood acts as a wave absorber and ultrasound does not propagate deeply into the heartwood.

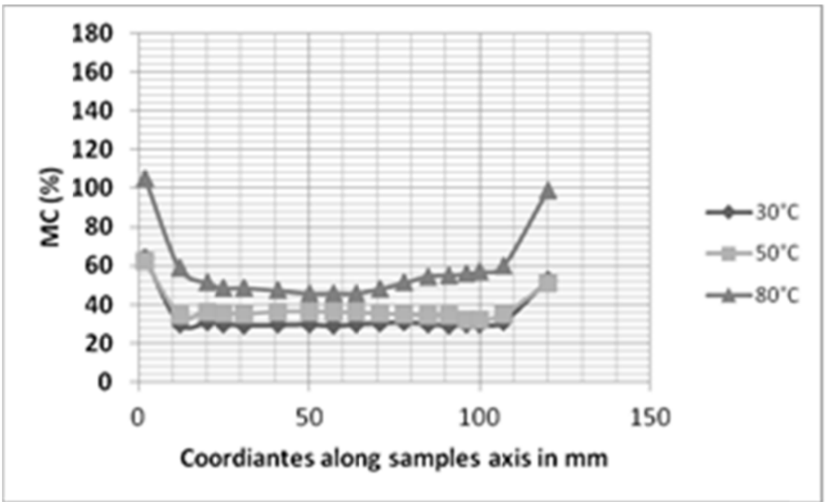

Figure 7: Changes in moisture content after 22 h soaking at different temperatures

2.3. Drying samples before soaking

The results showed that whatever the soaking time, those samples which have been dried take on more water than the rest of the samples.

After 20 hours of soaking, the moisture content of dried samples doubled compared to control samples. For the controls, moisture hardly exceeded 40 %, while for the previously dried samples, the final moisture content reached values of 80 % after20 hours of soaking, and 120 % after 92 hours of soaking. Three drying methods were used: thermal drying, vacuum and natural.

As shown in Figure 10, after 20 hours of immersion, the previously dried samples already contained moisture greater than 70 %. Except for naturally dried samples which moisten to a lesser extent at 58 %, the final moisture of the control group is less than 40 %. After 92 h immersion, water absorption no longer varies for samples dried in a vacuum or thermally; an equilibrium in fiber saturation seems to be reached. Water uptake continued to increase for samples that were dried naturally and for the controls.

It seems clear that the action of drying by heating or vacuum changes the Douglas heartwood making it more easily permeable.

The naturally dried samples are almost entirely in an intermediate position between the control and heat-dried and vacuum. Their moisture uptake remains high compared to controls.

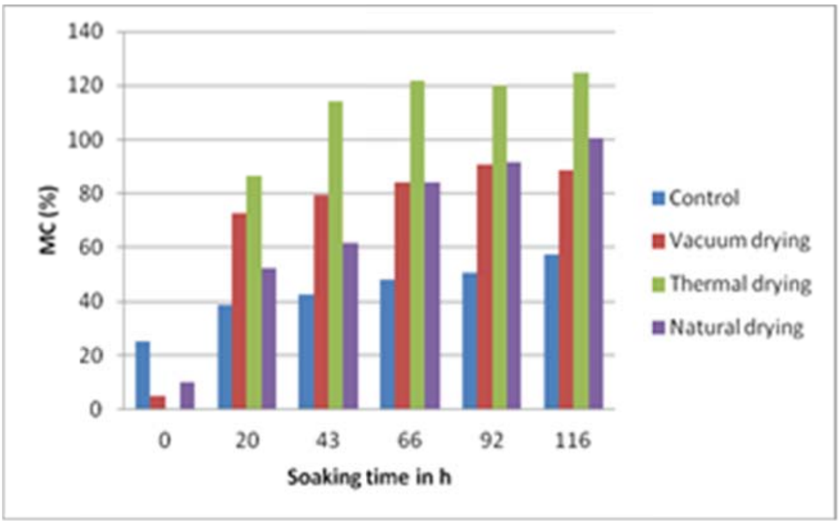

Figure 8: Kinetics of water uptake with different impregnation technique

CONCLUSION

These tests made it possible to verify the great difficulty of penetrating water into Douglas heartwood. The results are reproducible. Impregnability changed with temperature and treatment time. It was also noted that moisture content was highest at the board ends with the „hot/cold“ procedure. With surfactants, we were able to make Douglas heartwood wettable. These products reduce the surface tension of the liquid but do not improve the impregnability of heartwood. The use of ultrasound substantially enhances the depth of penetration of the water but only near the surfaces exposed to the waves. Drying is very promising. Dried thermally or in a vacuum, the heartwood becomes impregnable reaching fiber moisture saturation. Drying greatly improves the treatability of Douglas heartwood, but more studies need to be done in order to understand why.

REFERENCES

1. Agoua F. (2001). *Diffusivité et perméabilité du bois*, thèse en sciences forestières et du bois, ENGREF-Nancy.
2. Chen P., Simpson W. (1992). *Effects of ultrasonic cavitation on rate of heat propagation and longitudinal permeability of three U.S. hardwoods*, Forest Product Journal, 42, (4).

3. Crown D. J. (1992). *New Zela-fir sutabilty for processing. Part three- The wood quality of Douglas-fir*, a review, FRI Bull, 168, p. 74.
4. Hansmann C., Wolfgang G., Wimmer R., Teischinger A. (2002). *Permeability of wood*, Wood Research – Drevarsky Vyskum, 47 (4), pp. 1–16.
5. Polg H. (1982). *Ann Sci Forest*, 39 (4). pp. 379–398.
6. Hecker M. (1995). *Peeled veneer from Douglas-fir. Influence of round wood storage, cooking and peeling temperature on surface roughness*, Proceedings of 12th International Wood Machining Seminar, October 2–4, Kyoto, pp. 92–101.
7. Matsumura J., Yamasaki Y., Oda K., Fujisawa Y. (2005). *Profile of bordered pit aspiration in Cryptomeria japonica using confocal laser scanning microscopy: pit aspiration and heartwood color*, J Wood Sci (2005), 51, pp. 328–333.
8. Mothe F., Marchal R., Tatischeff W. (2000). *Sécheresse à Cœur du Douglas et aptitude au déroulage: recherché de procédés alternatifs d'étuvage. I. Répartition de l'eau dans le bois vert et réhumidification sous autoclave*, Ann. For. Sci. 57, pp. 219 – 228.
9. Thibaut. B. (1988). *Le processus de coupe du bois par déroulage*, Thèse d'état en Sciences, Université des sciences et Techniques du Langdoc, Montpellier, p. 354.
10. Takano T., Kinoshita N. (1992). *The effect of annual ring and moisture content on venner quality in soft wood peeling*, Zood Ind. 47, pp. 14–19.

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