

AN APPLICATION OF A LASER DRILLING TECHNIQUE TO FIR AND SPRUCE WOOD SPECIMENS TO IMPROVE THEIR PERMEABILITY*

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ABSTRACT

In this work, the application of a laser drilling technique on fir (*Abies borisii regis*) and spruce (*Picea excelsa*) wood and a new approach of improvement the wood permeability is investigated. This technique is focusing on increasing the permeability of wood after surface drilling by a high power laser source. The research was involving the establishment of an effective drilling pattern protocol, which will not substantially affect the mechanical strength of wood and to improve its permeability. All lateral surfaces of the wood specimens, 2 × 2 cm in cross section and 34 cm long, were drilled by laser to a depth of 4 mm (1/5 of specimen thickness) with two drilling patterns (distance between holes 10 × 10 mm and 10 × 20 mm). Preliminary results showed that laser drilling is a promising method for improvement of wood permeability without significant effect on its mechanical strength, and this is very important for an effective treatment of the refractory to impregnation fir and spruce wood.

Key words: laser drilling, fir/spruce wood, permeability, wood impregnation.

1. INTRODUCTION

Fir and spruce wood is very important for a wide range of interior and exterior applications worldwide. Due to its low natural durability, an impregnation with wood preservatives is required when the wood is used in structural constructions of utility class 4 (EN 460 1994). However, it is known that fir and spruce wood has very low permeability and, thus, it is difficult to be impregnated with wood preservatives. Improving the permeability of the refractory to preservation

forest species is one of the major technological challenges in wood science nowadays. Several techniques have been investigated over the years involving mechanical opening of the wood structure, steaming, solvent-exchange drying, critical point drying and biological treatments. Laser drilling technology has shown high potential for liquid impregnation (Hattori 1995, Islam et al. 2007, 2008). The liquid-impregnation capability can be improved by creating deep pin holes

*This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Thales. Investing in knowledge society through the European Social Fund.

in the body of the wood to provide additional intake points.

However, incising technologies are often associated with “carbonization” and visible marks on the wood surface as well as with strength losses, which are considered to be disadvantageous for certain wood products (Richter 1989, Wang et al. 2013). In this work, a new approach of laser drilling technique applied on fir and spruce wood specimens is described in detail. The research consists of the establishment of a drilling pattern protocol, the description and application of the drilling process to avoid carbonization of wood and some preliminary tests on wood specimens.

2. EXPERIMENTAL METHODS

2.1. DESCRIPTION OF THE LASER DRILLING SYSTEM

2.1.1. Laser system

Drilling of wood specimens was achieved by a high power Class 4 pulsed laser system (Figure 1), a Q-switched Nd:YAG (EKSPALA NL-303-HT). The system is capable to operate at four (4) different wavelengths (fundamental and 3 harmonics) ranging from UV to IR with pulse duration of ~4 ns and delivering energy of 800 mJ per pulse at fundamental wavelength in IR (1064 nm). The system is also designed to operate on 2nd harmonic at 532 nm (visible), on 3rd harmonic at 355 nm (UV) and on 4th harmonic at 266 nm (UV). The optimum wavelength of operation was selected by applying a simple rule: the highest possible energy per pulse combined by the lowest possible carbonization effects around and in holes.

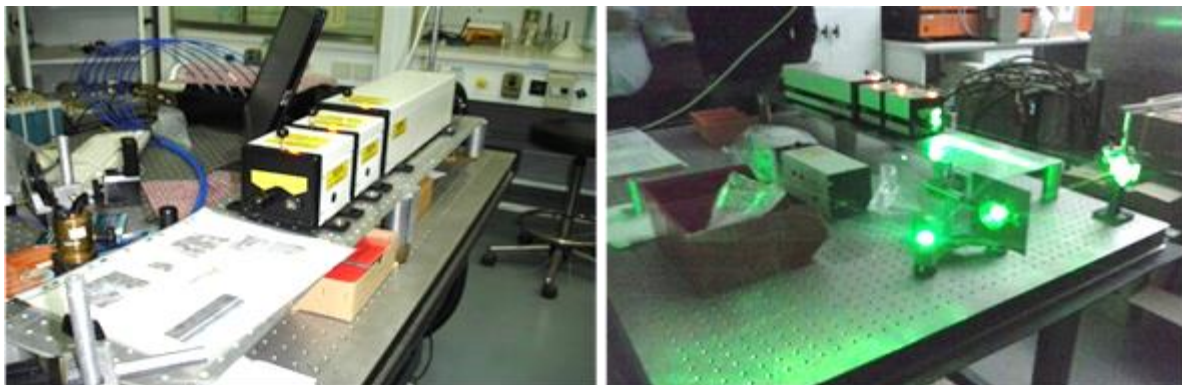


Figure 1: a) on the left: Pulsed laser Nd:YAG (EKSPALA NL-303-HT), b) on the right: Generated plasma by focusing the laser beam operated at 2nd harmonic (532 nm)

Thus, a series of tests was conducted in order to find the optimum conditions of operation. The parameters tested were: i) the wavelength, ii) the energy per pulse, and iii) the repetition rate. The tests revealed that the optimum conditions were by applying the 2nd harmonic option (532 nm) operated at the 70% of the maximum energy level at the specific wavelength at repetition rate of 1 Hz.

This is translated to 301 mJ per pulse which gives a power of order of 0.11 GW per pulse.

2.1.2. Description of fir and spruce specimens drilled

Defect-free sapwood specimens measuring $20 \times 20 \times 340$ mm (Radial \times Tangential \times Longitudinal) were prepared from air-dried boards of fir (*Abies borisii regis* Mattf.) and spruce (*Picea excelsa* Link) of Greek origin. The specimens used were 40 samples of fir

which were marked with red ink and 40 of spruce which were marked with blue ink (Figure 2). Then both fir and spruce specimens were marked equally by the letters “B” and “C”. Thus, we have 20 B and 20 C fir specimens marked with red and 20 B and 20 C spruce specimens marked with blue. All

specimens were laser drilled in order to test their static bending and toughness. For the drilling process two patterns were applied in both fir and spruce specimens: a) distance between holes 10×10 mm and b) 10×20 mm. In the figure below, specimens of both categories are depicted before laser treatment.



Figure 2: Wood specimens of fir (red) and spruce (blue) before drilling- tangential 1st side (first row on the left), radial 2nd side (first row on the right), tangential 3rd side (second row on the left), radial 4th side (second row on the right)

The wood specimens were adjusted to a manually operated XYZ positioning system (Figure 3) and all their lateral surfaces were drilled by the laser beam to a depth of 4 mm

(1/5 of specimen thickness). The system has 1 mm travel resolution in X and Z axis, and $1 \mu\text{m}$ resolution in the Y axis.



Figure 3: XYZ positioning system of wood specimens: a) front view (first row on the left), b) rear view (first row on the right), c) side view (second row in the left), d) top view (second row in the right)

2.1.4. Description of drilling pattern protocol of fir and spruce wood specimens

According to the drilling pattern protocol all lateral surfaces of the specimens will be drilled (Figure 4). The characteristics of

each hole are: preferred diameter not to exceed 1 mm, depth of 4 mm (1/5 of specimen thickness). In the figure below the specimen surfaces are depicted.

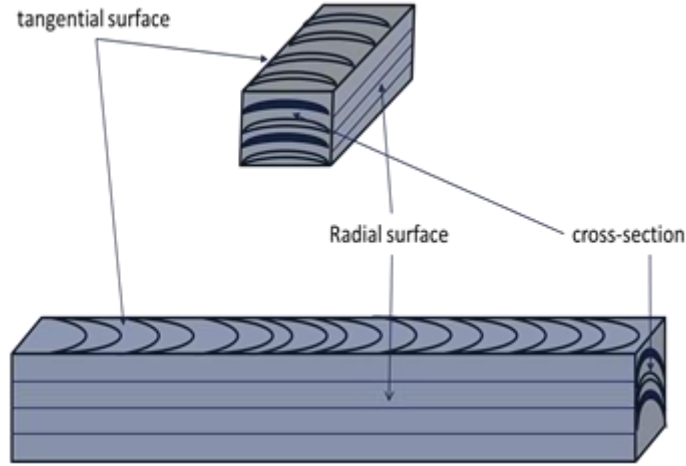


Figure 4: Surfaces of the wood specimens

The specimens will be drilled according to two (2) drilling patterns: In the first pattern (Figure 5), for the code B specimens, the 2 tangential opposing surfaces (A-C sides) as follows: initial coordinates X = 20 mm and Y = 5 mm for the first row, and X = 20 mm and Y = 15 mm for the second row, with step 10 mm for each row, i.e., each side A and C will be drilled with 30 x 2 = 60 holes.

The 2 radial opposing surfaces (B-D sides) as follows: initial coordinates X = 25 mm and Y = 5 mm for the first series, and X = 25 mm and Y = 15 mm for the second row, with a pitch of 10 mm for each row, thus 29 x 2 = 58 holes. Therefore, every B coded specimen will be drilled with 236 holes.

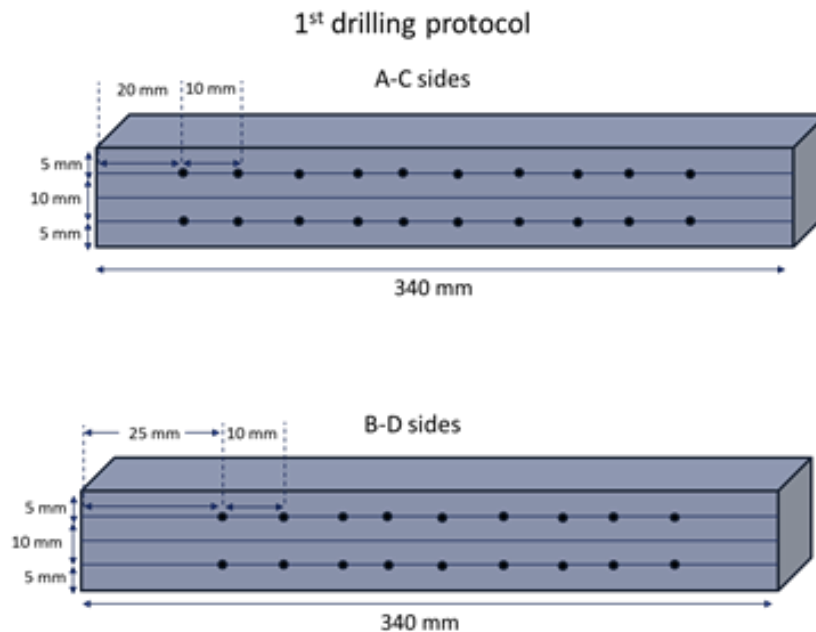


Figure 5: First drilling pattern – Code B

In the second drilling pattern (Figure 6), for the code C specimens, the 2 tangential opposing surfaces (A-C sides) as follows: initial coordinates $X = 20$ mm and $Y = 5$ mm for the first row, and $X = 20$ mm and $Y = 15$ mm for the second row, with step 20 mm for each row, i.e., each side A and C will be drilled with $15 \times 2 = 30$ holes.

The 2 radial opposing surfaces (B-D sides) as follows: initial coordinates $X = 25$ mm and $Y = 5$ mm for the first series, and $X = 25$ mm and $Y = 15$ mm for the second row, with a pitch of 20 mm for each row, thus $14 \times 2 = 28$ holes. Therefore, every C coded specimen will be drilled with 116 holes.

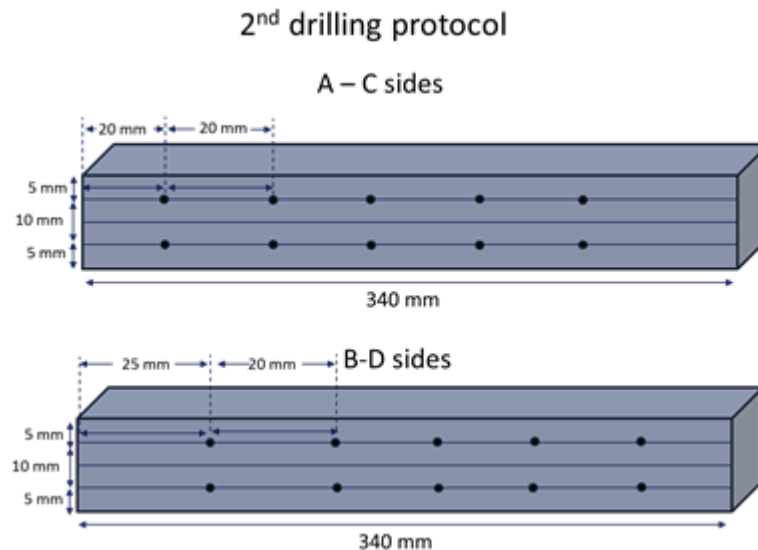


Figure 6: Second drilling pattern – Code C

2.1.5. Description on the drilling process

Before drilling the specimens, the starting points are marked in all sides according to the drilling pattern and the two drilling scenarios: in B-code pattern, sides A and C are marked the coordinates $X = 20$ mm, $Y = 5$ mm for the first row and $X = 20$ mm, $Y = 15$ mm for the second row, while the sides B and D are marked at coordinates $x = 25$ mm, $Y = 5$ mm for the first row and $X = 25$ mm, $Y = 15$ mm for the second row while the C-code pattern, all the sides are marked at coordinates $x = 20$ mm, $Y = 5$ mm for the first row and $X = 20$ mm and $Y = 15$ mm for the second row.

Before loading the specimen on the XYZ system, the laser is been turned on in idle mode in order to align of the sample to the laser beam (Figure 7). Then the specimen is placed on the XYZ system, is locked by aligning the laser beam (in idle mode) and aiming the first tackle to the side. The specimen is tested for the alignment axes: the X-axis by matching the beam to the first mark, in Y using level control and Z by controlling the height of the laser beam. Once the placement and alignment of the specimen on the XYZ system is achieved, the laser is adjusted by the appropriate parameters for the drilling (Figure 8).

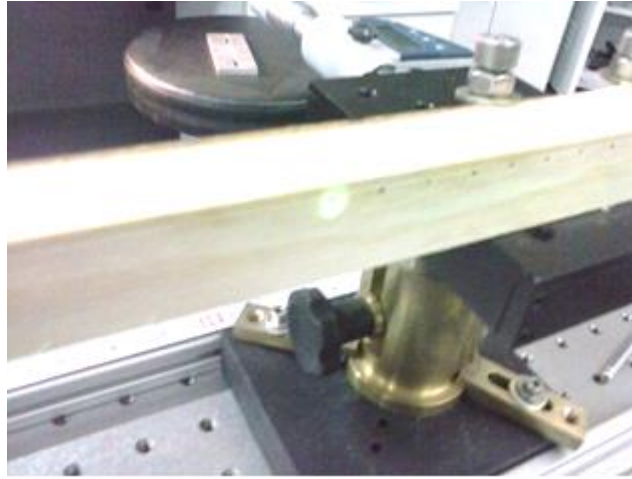


Figure 7: Laser drilling in process – just before the drill the green spot seen is the laser in idle mode (before energy burst)

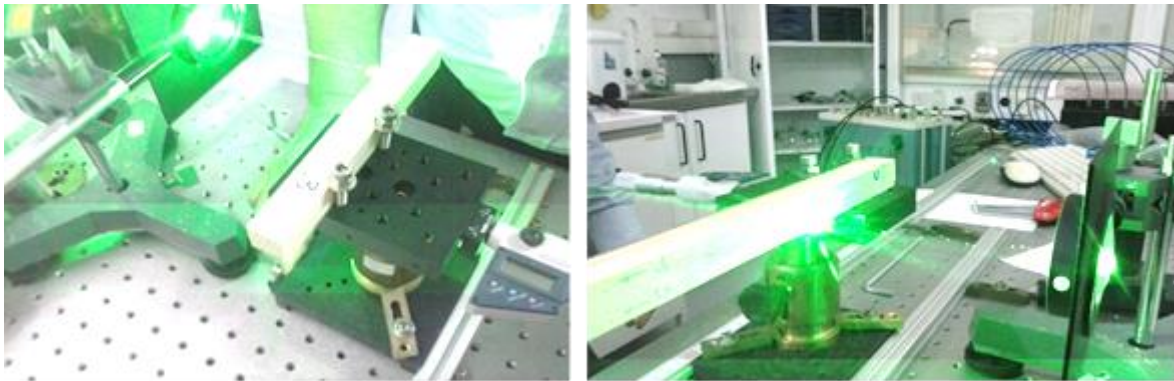


Figure 8: Laser drilling in process- The focused green laser beam as it perpetrates the wood specimen – view for side-top (on the left) – side front view (on the right)

3. RESULTS AND DISCUSSION

The parameters which are very important in this study are: optimum geometric characteristics of the hole (diameter, depth) and the limitation of carbonization effects. For the latter, the 2nd harmonic at 532 nm was chosen as the operation wavelength for the

drilling process. However, the energy of the pulses is also very significant in order not to have these thermal effects. In the image below (Figure 9), it can be shown the first attempts of drilling in various energy levels. As it can be seen for energy level above 70 % of the maximum the carbonization is present.

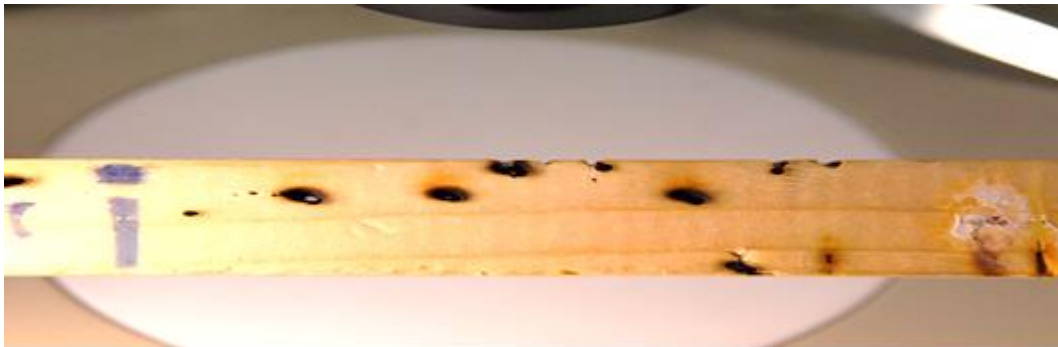


Figure 9: Wood drilling by laser at high energy level (>70 %). The carbonization around the holes is present

Another parameter was the geometric characteristics of the hole. As the laser creates the hole the focused beam gives a conic

pattern and not a cylindrical one that someone should expect. This is due to the non movement on the Y-axis during the drilling process(Figure 10).

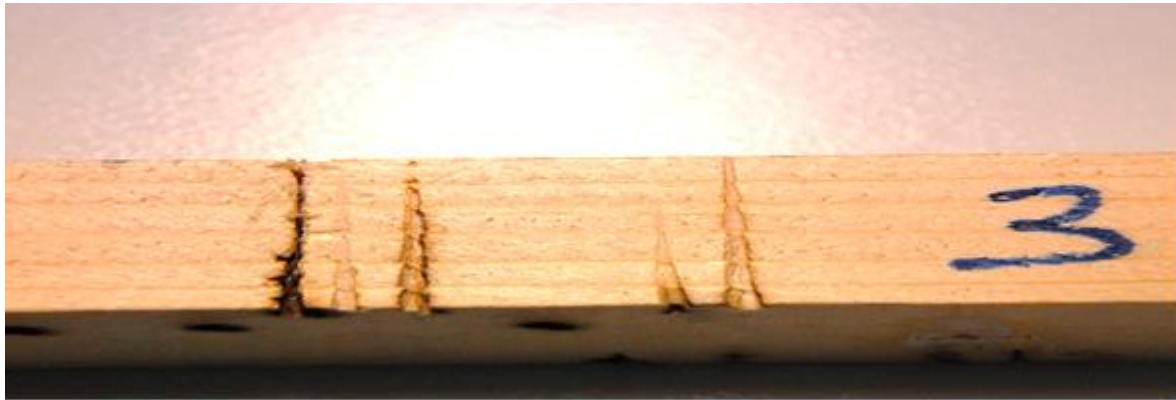


Figure 10: Drilling near the surface revealed the conic shape of the hole

In order to achieve optimum drilling conditions which are defined the drilling protocol, a series of tests had to be carried out. The parameters tested were: i) number of Table 1) the results from the tests are shown.

pulses, ii) focal distance of the converging lens, iii) hole diameter not to exceed 10 mm, iv) hole depth not to exceed 4 mm. In the table below (

Table 1: Tests on drilling conditions – laser energy 301 mJ per pulse, at 70% of max at 532 nm

A/A	Number of pulses	Focal distance [cm]	Type of specimen F(fir), S(Spruce)	Hole diameter [mm]	Hole depth [mm]	Side
1	200	15,25	F	~10	4-OK	A
2	180	15,3	S	~10	<4	A
3	180	15,4	S	~10	<4	B
4	150	15,25	F	~10	<4	A
5	120	15,35	F	~10	4-OK	B
6	120	15,3	S	~10	4-OK	A
7	90	14,45	F	~10	4-OK	A
8	90	14,45	F	~10	4-OK	B
9	70	14,5	S	~10	4-OK	A
10	70	14,5	S	~10	4-OK	B

As it can be seen from the table above, the optimum conditions were at rows 7 to 10. The energy parameters translated to number of pulses needed at the specific energy level (301 mJ per pulse at 70 % of max energy) were 90 pulses for the specimens from fir and 70 pulses for the spruce specimens accordingly. As far as the total time of drilling is

concerned, the tests showed that for the first drilling pattern (distance between holes 10 × 10 mm total 236 holes) the time needed is about 1 hour, and for the second drilling pattern (distance between holes 10 × 20 mm total 120 holes) the total time is approximately 30 minutes. In the images below (Figure 11),

the wood specimens after laser treatment are depicted.

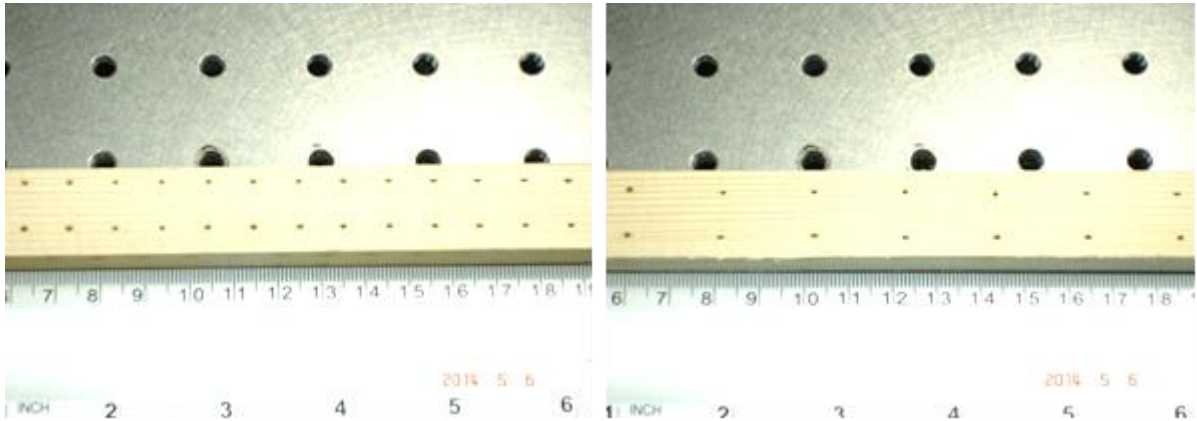


Figure 11: Laser drilling patterns- a) distance between holes 10×10 mm (left) and b) distance between holes 10×20 mm (right)

Laser drilled wood specimens were tested for mechanical properties and impregnability changes. Preliminary tests showed that the two drilling patterns 10×10 mm and 10×20 mm created by laser on all lateral surfaces of the specimens at 4 mm depth did not

impact negatively major mechanical properties of wood (Adamopoulos *et al.* 2014). Also, both drilling patterns facilitated (Figure 12) the penetration of rape oil and CCB preservative in fir and spruce wood specimens, as shown in Figure 11 (Voulgaridis *et al.* 2014).



Figure 12: Penetration of rape oil axially and transversely in fir and spruce laser drilled wood specimens (see, also, the shape and depth of non-carbonized holes ~ 0.4 cm in depth).

4. CONCLUSIONS

A new laser drilling technique was applied on fir and spruce wood specimens to improve their permeability. The drilling process was achieved by a high power Class 4

pulsed laser system (Q-switched Nd: YAG - EKSPLA NL-303-HT) and an effective drilling pattern protocol was applied by means of

optimum conditions in hole geometric characteristics as well as the limitation of carbonization effects.

The application of laser drilling on all lateral surfaces of fir and spruce specimens did not negatively affect the mechanical properties of wood (static bending strength, axial compression and toughness) and facilitated the penetration of rape oil and CCB preservative into wood.

The results suggest that the presented technique of laser drilling was applied successfully on wood surfaces and is a very promising method for improvement the permeability of wood which is very important for the impregnation processes of refractory forest species.

REFERENCES

1. Adamopoulos, S., Passialis, C., Voulgaridis, E., Moustazis, S., Kortsalioudakis, N., Petrakis, P., Karastergiou, S., Foti, D., Koutsianitis, D., Voulgaridou, E. (2014). Effect of laser drilling on mechanical properties of fir (*Abies borisii regis*) and spruce (*Picea excelsa*) wood. The 5-th RCCWS International Symposium "Wood Structure, Properties and quality 2014", Moscow State Forest University, September 22–25.
2. EN 460, (1994). Durability of wood and wood-based products – Natural durability of solid wood. Guide to the durability requirements for wood to be used in hazard classes. CEN European Committee for Standardization.
3. Hattori, N. (1995). Laser processing of wood. *Mokuzai Gakkaishi* 41: 703–709
4. Islam, M. N., Ando, K., Yamuchi, H., Kobayashi, Y., Hattori, N. (2007). Passive impregnation of liquid in impermeable lumber incised by laser. *J Wood Sci* 53: 436–441.
5. Islam, M.N., Ando, K., Yamuchi, H., Kobayashi, Y., Hattori, N. (2008). Comparative study between full cell and passive impregnation method of wood preservation for laser incised Douglas fir lumber. *Wood Sci Technol* 42: 343–350.
6. Richter, K. (1989). Perforation and impregnation methods to improve weather resistance of structural timber. Empa Research and Working Report 115/19, Dübendorf, Switzerland: 1–44.
7. Voulgaridis, E., Passialis, C., Karastergiou, S., Adamopoulos, S., Kakaras, I., Foti, D., Koutsianitis, D., Voulgaridou, E. (2014). Effect of laser drilling on impregnability of fir (*Abies borisii regis*) and spruce (*Picea excelsa*) wood. The 5-th RCCWS International Symposium "Wood Structure, Properties and quality 2014", Moscow State Forest University, September 22–25.
8. Wang, Y., Ando, K., Hattori, N. (2013). Changes in the anatomy of surface and liquid uptake of wood after laser incising. *Wood Sci Technol* 47:447–455.