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Investigation of Laser Texturing Parameters and their Impact on Glue Adhesion Properties on the Surface of Birch Plywood

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Abstract. **Laser technologies are wide-ranging applications in various fields such as manufacturing, medicine, research, entertainment, and more. They are used in processes, such as, for cutting, welding, marking, engraving, surgery, spectroscopy, and many other purposes, owing to their precision, versatility and etc. Birch plywood is a type of manufactured wood product made from thin layers of birch veneer bonded together with special glue under high pressure and heat. It is known for its strength, stability, and visual look, making it a popular material in woodworking, furniture making, construction, and other applications. This study investigates the effect of laser textured treatment on the adhesion properties of birch plywood surface using PVA wood glue. A SUNTOP ST-CC9060 CO_2 laser with a wavelength of 10640 nm was used to texture birch plywood samples with different power and speed parameters, including untreated samples (base). Dino-Lite Edge AM7115MZT digital microscope, and an OLYMPUS LEXT OLS5000 laser microscope were used to measure the samples. The depth and width of the treated area were measured for these samples and graphs were created to analyze the results. Material testing machine Zwick / Roell Z150 was used for tensile and shear analysis of the processed samples. These results show that laser-treated samples have an effect on glue adhesion compared to untreated samples. The study provides valuable insight into the optimization of laser processing parameters in adhesion, and also shows the potential of this type of adhesion to improve the quality of the adhesion properties of laser-treated birch plywood.**

Keywords: Adhesion, birch plywood, CO_2 laser, laser texturing, tensile shear strength.

I. INTRODUCTION

In the 1960s the laser was discovered soon after and is popular in industry especially in material processing such as cutting of engineering structures due to its high-power density and accuracy [1], [2].

Laser texturing is an effective method for the fabrication of surface structures in a single-step process for a large range of applications [3], [4]. Surface functionalities in the field of tribology, wettability etc. introduced by well-defined surface structures strongly depend on the surface texture homogeneity and quality [5]. Laser sources are used in various technological processes such as marking, engraving, cutting, texturing, hardening, welding etc. The process of laser processing is complicated, and it depends on the following groups of factors: laser source parameters, technological process parameters, structure, and physical, chemical properties of the processed material [6], [7].

Wood is one of the most popular and valuable renewable materials. Development of wood-based advanced products comprises an important, exciting, and interesting area of research. Birch plywood has superior mechanical properties compared to plywood made from most softwood species, making it suitable for structural and decorative use. Plywood is also more environmentally friendly, economical and requires less effort than metal plates [8], [9], [10].

Adhesion is the tendency of dissimilar particles or surfaces to bond to one another. The internal forces between molecules that are responsible for adhesion are chemical bonding, dispersive bonding, and diffusive bonding. These intermolecular forces can make cumulative bonding and bring certain emergent mechanical effects [11].

There are several researchers who have investigated laser marking, engraving, and cutting processes on various wood materials, such as birch plywood, pine wood, spruce wood, beech wood, MDF wood etc. [12] – [20]. However, no information is found about the laser treatment of the birch plywood surface and the adhesion of the wood glue.

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II. Materials and Methods

A. Birch plywood

In the research used a 50 × 50 × 6 (length × width × thickness) laser treated Baltic birch plywood INT FSC B/BB samples. INT means glue intended for interior work, not moisture resistant. FSC is certificate, FSC Latvia | Forest Stewardship Council and B/BB is surface quality of material [21], [22].

Birch plywood (betula spp.) is a hardwood plywood that is widely known for its panel strength, grain texture, durability, and ease of finishing [23]. Baltic birch plywood is composed exclusively of birch veneer (thin sheets of birch wood) compressed and bonded together. Each layer of birch veneer is the same thickness, resulting in a more consistent, void-free, stable, and aesthetically attractive sheet of plywood [24].

B. Equipment

CO_2 laser machine (SUNTOP ST-CC9060) was used for laser texturing of birch plywood samples with a wavelength of 10640 nm (see in Figure 1).

Fig. 1. SUNTOP ST-CC9060 CO_2 laser machine.

The technical specifications of the SUNTOP ST-CC9060 laser machine are showed in Table 1.

TABLE 1. SUNTOP ST-CC9060 LASER MACHINE TECHNICAL SPECIFICATIONS

Laser type	CO_2 laser
Operation mode	CW
Wavelength	10640 nm
Maximum output power	100 W
Workspace (Cutting area)	900 x 600 mm
Precision	0,02 mm
Scan speed	0 – 1000 mm/s
Laser Safety Class	4
Cooling system	Water cooling
Total power	1500 W

For measuring the depth and width of the laser treated samples, we used a Dino-Lite Edge AM7115MZT digital microscope (shown in Figure 2).

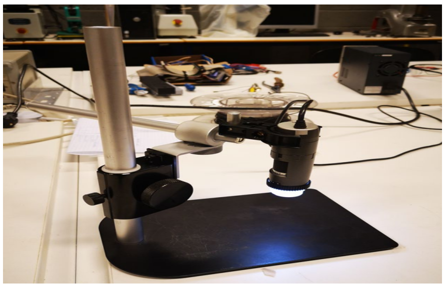


Fig. 2. Dino-Lite Edge AM7115MZT digital microscope.

The technical specifications of the digital microscope Dino-Lite Edge AM7115MZT are shown in Table 2.

TABLE 2. DINO-LITE EDGE AM7115MZT MICROSCOPE TECHNICAL SPECIFICATIONS

Operating System	Windows
Resolution	2592 × 1944 pixels
Magnification	20x~220x
Unit Dimension	10.5cm (H) x 3.2cm (D)

The structure changes of the textured birch plywood samples were explored using the Olympus LEXT OLS5000 3D Measuring Laser Microscope, as shown in Figure 3.

Fig. 3. Olympus LEXT OLS5000 3D Measuring Laser Microscope.

These measured sample structures were carried out using 5x magnification with measured area 2580 × 2580 µm ± 5 µm.

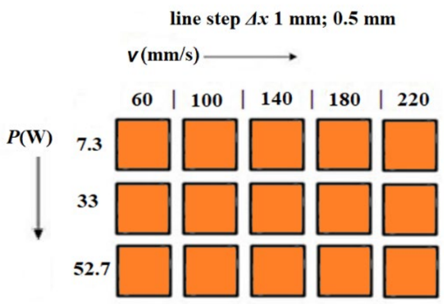
For measuring samples for tensile and shear mechanical properties using a Zwick/Roell Z150 testing machine, which is shown in Figure 4.

Fig. 4. Zwick / Roell Z150 material testing machine [25]

C. Methodology

In this experiment, birch plywood samples with dimensions of 50 × 50 × 6 mm (length × width × thickness) were laser textured using three different power densities q_s and five different scanning speeds v. The power densities used for texturing were 0.93, 4.20, 6.71 ($\cdot$ 10^5) W/cm^2, as listed in Table 4. Each set of parameters was used to texture lines in all sample dimension, with a step Δx of 1 and 0,5 mm between each line. The depth h [mm] and width b [mm] of the textured lines were measured, and graphs were constructed as a function of the laser parameters. Figure 5 shows the texturing schematics of birch plywood samples.

(a)



(b)

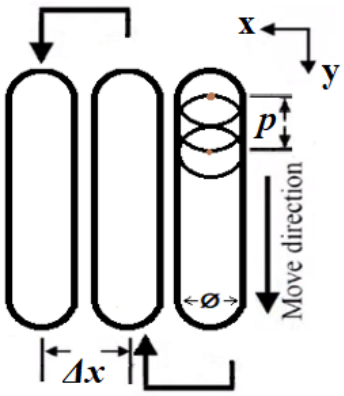


Fig. 5. Laser texturing schematics of birch plywood samples (a), (b).

After laser processing, these samples are glued together by placing one surface of the sample of the processed parameter on the surface of the other sample of the same parameters, in a perpendicular direction. PVA wood glue is used for gluing the samples. Using a professional-mini digital scale with an accuracy of ± 0.01 gram, 0.15 - 0.18 g/mm^2 PVA wood glue was applied to the surface of each sample in an area of 20 × 50 mm (length × width). Glue is applied to the samples, making sure that the entire sample is correctly glued without leaving marks or gaps. A weight of 1.7 kg was applied to these glued samples for about 20 minutes and then these samples were dried in a dry and clean room for 24 hours. At the time of gluing, the room temperature was 23.8 degrees Celsius, and the relative humidity was 21%.

The power output of the laser was measured using an OPHIR F150A-BB-26 laser power meter before starting the experiment. The recorded power values can be found in Table 3.

TABLE 3. AVERAGE LASER POWER DEPENDENCE ON RESONATOR PUMP COEFFICIENT (KP, %)

$_K$P, %	10	20	30
P, W	7,3	33	52,7

The power density q_s [W/cm^2] was calculated using formula (1):

$$q_s = \frac{P}{S} \tag{1}$$

where P [W] is the power and S [cm^2] is the cross-sectional area of the laser beam on the surface of the material to be textured, as given in formula (2):

$$S = \pi \frac{d^2}{4} \tag{2}$$

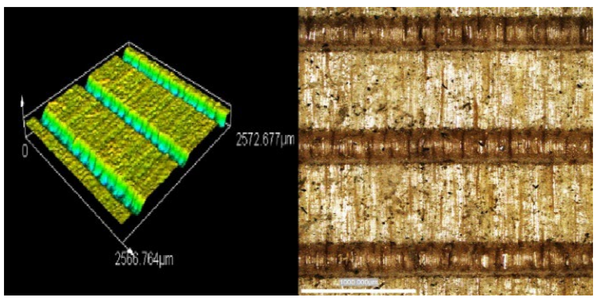
where d [cm] being the diameter of the laser beam (d = 0.01 cm). The calculated power density values in W/cm^2, corresponding to the measured power values in W, which is shown in Table 3, are presented in Table 4.

TABLE 4. CALCULATED LASER POWER DENSITY VALUES FOR THE CO_2 LASER MACHINE

***P*, W**	7.3	33	52.7
q_s×10^5, W/cm^2	0.93	4.20	6.71

To measure the surface structure of textured and tested birch plywood samples used Olympus LEXT OLS5000 3D Measuring Laser Microscope, measurements are shown in Figure 6.

(a) **(b)**



(c) **(d)**

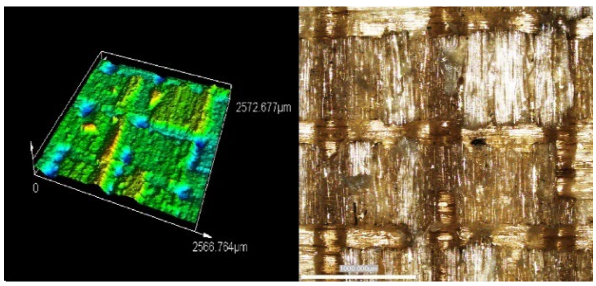


Fig. 6. Effect of laser textured birch plywood structure on the surface: (a) 3D laser scanning microscope image, (b) 2D laser scanning microscope image, (c) 3D laser scanning microscope image after adhesion test, (d) 2D laser scanning microscope image after adhesion test.

Figure 6 shows the effect of laser textured birch plywood samples structures on the surface. In case (a), (b) $q_s = 0.93 \cdot 10^5$ W/cm^2 and v = 100 mm/s and $\Delta x = 1$ mm. In case (c), (d) $q_s = 0.93 \cdot 10^5$ W/cm^2 and v = 140 mm/s , and $\Delta x = 0.5$ mm.

Texture depth measurement on one of the samples using digital microscope Dino - Lite Edge AM7115MZT is shown in Fig. 6 and width measurement is shown in Fig. 7.

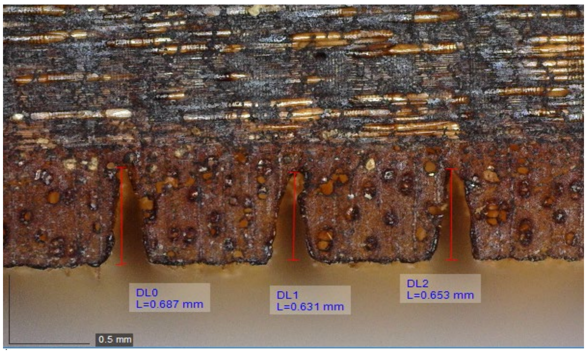


Fig. 7. Measurement of depth on a birch plywood sample with magnification x100.

Figure 7 shows a laser textured sample with three cuts obtained using a laser power density $q_s = 6.71 \cdot 10^5$ W/cm^2 and scan speed v = 220 mm/s and line step Δx = 1 mm. Depth of these cuts are measured and average depth h = 0.622 mm. Total number of measurements of cuts for each power density and scan speed parameter sample is 5.

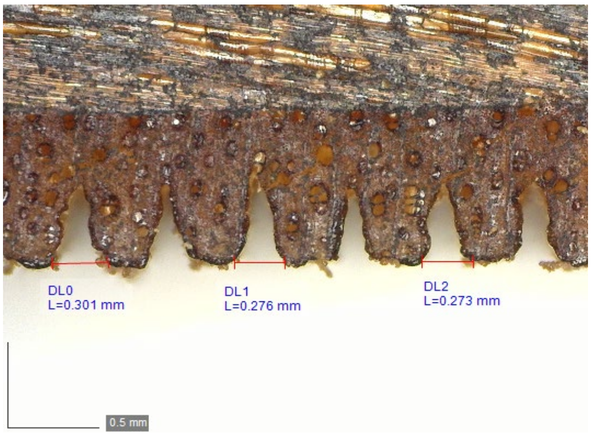


Fig. 8. Measurement of width on a birch plywood sample with magnification x100.

Figure 8 shows a laser textured sample with six cuts obtained using a laser power density $q_s = 4.20 \cdot 10^5$ W/cm^2 and scan speed v = 220 mm/s with line step $\Delta x = 0.5$ mm. Width of these cuts are measured and average width b = 0.293 mm. Total number of measurements of cuts for each power density and scan speed parameter sample is 5.

III. Results and Discussions

The study results are shown in graphs that show the impact of laser power density and scan speed on the depth and width of laser textured lines. Also, the mechanical properties of the glue adhesion of laser textured surfaces, as tensile strength was shown in graphs (Fig. 13. and Fig. 14). The graphs illustrate the relation between line depth and width and maximal tensile strength as a function of energy density and scanning speed for birch plywood samples. Figures 9 and 10 shows dependence of the line depth h on the scan speed v at power density q_s for birch plywood samples with two different line steps Δx 1 mm, Δx 0.5 mm.

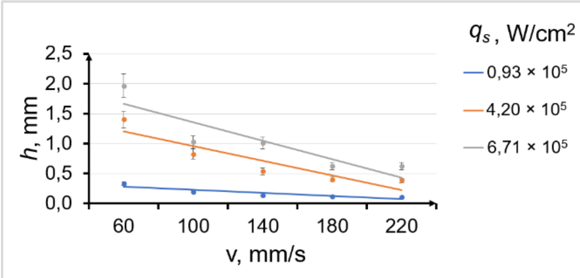


Fig. 9. Dependence of the line depth h on the scan speed v at three different power density q_s for birch plywood samples with line step Δx 1 mm.

As can see in figure 9, the depth on birch plywood sample with Δx = 1 mm is bigger at scan speed 60 mm/s, and lesser at scan speed v = 220 mm/s. The maximum line depth value is 1.964 mm at power density $q_s = 6.71 \cdot 10^5$ W/cm^2, but minimum line depth value is 0.110 mm at power density $0.93 \cdot 10^5$ W/cm^2.

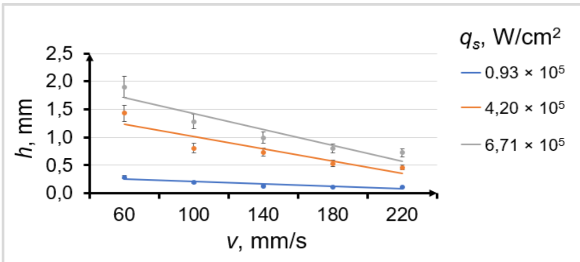


Fig. 10. Dependence of the line depth h on the scan speed v at three different power density q_s for birch plywood samples with line step Δx 0.5 mm.

In figure 10, the depth on birch plywood sample with line step 0.5 mm is bigger at scan speed 60 mm/s, and lesser at scan speed 220 mm/s. The maximum line depth value is 1.900 mm at power density $q_s = 6.71 \cdot 10^5$ W/cm^2, but minimum line depth value is 0.109 mm at power density $0.93 \cdot 10^5$ W/cm^2.

From these graphs are showed that there is a linear regularity that increasing the power density q_s increases the depth of the line, increasing the scanning speed v decreases the line depth h.

Figures 11 and 12 show the dependence of the line width b on scan speed v at three power densities $q_s = 0.93 \cdot 10^5$ W/cm^2, $4.20 \cdot 10^5$ W/cm^2 and $6.71 \cdot 10^5$ W/cm^2 for birch plywood samples with line step Δx = 1 mm (Fig. 11), Δx 0.5 mm (Fig.12).

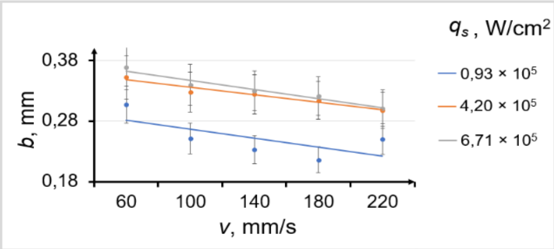


Fig. 11. Dependence of the line width b on the scan speed v at three different power density q_s for birch plywood samples with line step Δx 1 mm.

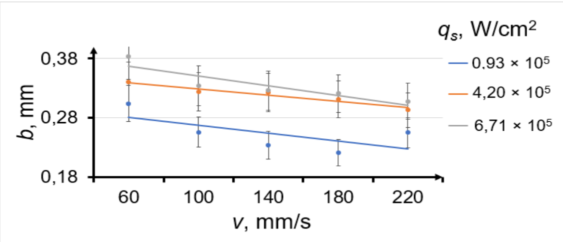


Fig. 12. Dependence of the line width b on the scan speed v at three different power density q_S for birch plywood samples with line step Δx 0.5 mm.

The graphs on Figures 11 and 12 represent dependence of the line width b with two different line steps Δx. The line width at scan speed v = 60 mm/s and power density $0.93 \cdot 10^5$ W/cm^2 is 0.307 mm for birch plywood with line step Δx = 1 mm, and 0.304 mm for birch plywood with line step Δx = 0.5 mm. Average line width b at scan speed v = 220 mm/s and power density $6.71 \cdot 10^5$ W/cm^2 is 0.301 mm for birch plywood with line step Δx = 1 mm, and 0.308 mm for birch plywood with line step Δx = 0.5 mm. From these graphs are showed that there is a regularity that increasing the power density q_s increases the depth of the line, increasing the scanning speed v decreases the line depth h.

It can be seen from these graphs that the changes of line width with power density and scan speed are linear and small, the line width being slightly smaller at lower power density and larger at higher power density.

Figure 13 show the dependence of the maximal tensile strength F_{max} on scan speed v at three power densities q_s for birch plywood samples with line step Δx = 1 mm. These treated samples are compared to untreated (base) samples.

The average maximum tensile strength F_{max} value for untreated (base) samples is 3598 N. Number of measurements of tensile strength tests for base samples is 5.

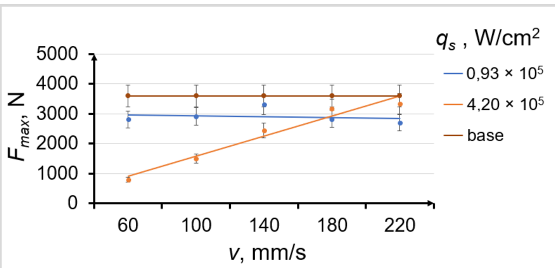


Fig. 13. Dependence of the maximal tensile strength F_{max} on the scan speed v at three different power density q_s for birch plywood samples with line step Δx 1 mm.

In Figure 13, the maximum tensile strength value F_{max} for textured samples is 3338 N at power density $4.20 \cdot 10^5$ W/cm^2, and scan speed 220 mm/s but minimum line depth value is 805 N at power density $4.20 \cdot 10^5$ W/cm^2 and scan speed 60 mm/s.

Figure 14 represent the dependence of the maximal tensile strength F_{max} on scan speed v at two power densities for birch plywood samples with line step Δx 0.5 mm which is compared to untreated (base) samples.

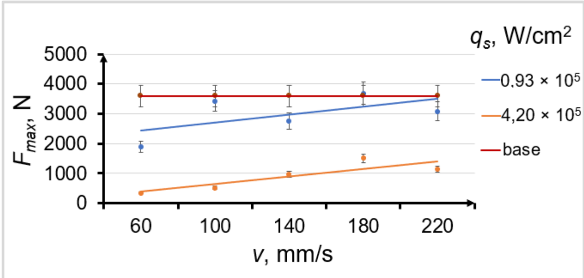


Fig. 14. Dependence of the maximal tensile strength F_{max} on the scan speed v at two different power density q_S for birch plywood samples with line step Δx 0.5 mm.

In Figure 14, the maximum tensile strength value F_{max} for textured samples is 3690 N at power density $0.93 \cdot 10^5$ W/cm^2, and scan speed 180 mm/s but tensile strength value is 349 N at power density $4.20 \cdot 10^5$ W/cm^2 and scan speed 60 mm/s. These graphs result also are changing linearly (Fig 13. and Fig. 14.)

IV. Conclusion

In this study are investigated the laser texturing process the effects of power density and scan speed on the depth and width of textured lines at different line steps on birch plywood samples, which is shown in figures 9. – 12. The results showed that the depth of textured lines is affected by both power density and scan speed, with higher power densities and lower scan speeds leading to deeper lines. Also, studies of the mechanical properties of the glue adhesion of laser textured surfaces, as tensile strength, were carried out. These results are shown in figures 13., 14. The results show that the adhesion remains higher as the scanning speed increases and decreases power density. Line step also affects the adhesive properties of the glue, as was shown in the results. The textured glued samples were compared to untreated glued samples. It was concluded that samples with a power density of $0.93 \cdot 10^5$ W/cm^2 and a scanning speed of 180 mm/s and a line step of 0.5 mm have better adhesion than untreated samples. Other textured samples have similar or smaller adhesion comparing untreated (base) samples.

The results of this study could have a real and significant impact on the use of laser processing in the woodworking industry, especially in the production of decorative or functional wooden items such as panels.

In further research could investigate the effect of laser parameters such as power density and scan speed on the bonded surface in a sample of untreated birch plywood. As well as to further investigate the effect of laser treatment with other parameters of power density, scan speed and line step. In addition, more detailed analyzes could be performed to investigate the microstructural changes that occur in the glued surface of birch plywood during the laser texturing process, as well as the effect of different types of power density and scan speed parameters on texturing and adhesive results.

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