

The impact of CO₂ laser power and scanning speed on various wood and thermowood samples

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Abstract. In this study, the impact of CO₂ laser engraving and scanning on various types of wood before and after thermal treatment is investigated. An infrared CO₂ laser with a wavelength of 10640 nm is used in the study for engraving various wood samples before and after thermal treatment at a specific processing temperature of 214°C. All samples had a similar moisture content - approximately 8%. The engraving depth and width were measured for each wood sample. The findings reveal that thermal pre-treatment exert a discernible influence on the efficacy of laser engraving, and the engraving depth is notably influenced by the particular wood species involved. Consequently, the study offers a platform for assessing the optimization of laser engraving parameters applicable to different wood types and thermally modified wood, thereby facilitating the enhancement of product quality through judicious parameter selection.

Keywords: CO₂ laser, laser engraving wood, laser processing parameters, wood thermally modified.

I. INTRODUCTION

Laser technologies are widely used in various industries and offer many advantages as they can offer a precise and efficient way to process materials and perform various functions. Here are some industries where laser technology is common: manufacturing and engineering, metalworking, materials processing, electronics, optics, science, medicine, military industry and much more [1], [2], [3]. Laser engraving and marking technologies are used to create precise and aesthetic graphic designs on various wood materials [4].

A popular decorative and construction material is wood. Wood is a natural material that comes from the trunk and branches of trees. It has been used in many industries including construction, furniture, interior design and more. Here are some examples of how wood is used decoratively and in construction - furniture, floors and carpets, doors and windows, wood trim, walls and roofs, decorative elements. Wood is an attractive material due to its natural beauty, and many people choose it to introduce elements of their homes and interior design. In addition, wood is a sustainable material if its management takes place in a responsible manner, thus contributing to environmental protection [5].

Heat treatment of wood is a process in which wood is treated at high temperatures in order to change its properties or improve its resistance to various physical influencing factors. This type of treatment is carried out to obtain better properties of wood products, such as wooden structures or finishing materials [6], [7].

The laser processing technology is considered a very modern and effective way to process wood and perform material processing operations by adjusting the correct parameters. This technology uses laser beams to cut, engrave, mark, or otherwise process materials. To optimize the pruning process based on processing time, knowing the linear energy density, when cutting a tree [8]. Lasers can have different wavelengths and intensities and are used for various purposes depending on the requirements [9]. Considering that different lasers, such

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as those with wavelengths of 1.06 μm and 10.6 μm, interact differently with materials [10].

The aim of this study is to investigate the laser ablation process using infrared laser radiation at a wavelength of 10.6 μm (CO₂ laser) on various wood and thermally modified wood samples.

II. MATERIALS AND METHODS

A. Thermowood

In this study, ten types of wood materials were used (Ukrainian ash, Latvian spruce, alder, birch, maple, pine and beech, New Zealand pine Taeda and Radiata, Finnish pine) that were thermally processed by drying the wood at high temperatures, without using any chemical substances, heating it up to 214°C [11]. Processing wood affects various thermally treated wood physico-mechanical properties, increases resistance to brown rot fungi decay and compressive strength, reduces moisture adsorption, and improves hygroscopic hysteresis [12], [13]. Various weather conditions indicate that thermally treated wood is more resistant to photodegradation than untreated reference wood [14], [15], [16]. Thermowood is indeed a notable construction material with a series of unique properties that contribute to its popularity and versatility, including natural beauty and aesthetic appeal, versatility, environmental sustainability, carbon sequestration, energy efficiency, positive microclimate, durability, and ease of construction [17].

The experiment utilized wood material samples that underwent thermal treatment at 214°C, with a processing duration of 36 hours in a cycle, where the peak thermal treatment period itself lasts 2 hours. All samples used in the experiment were equally treated in a single thermal process.



Fig. 1. Ten wood samples both before and after thermal treatment.

As seen in Fig. 1, ten types of wood samples, thermally untreated and after thermo-treatment, include Ukrainian ash, Latvian spruce, alder, birch, maple, pine, and beech, New Zealand pines (Taeda and Radiata), and Finnish pine. All samples, before and after thermo-treatment, were measured with the digital moisture meter HT632, and the moisture content was determined to be 8%.

B. Equipment

The CO₂ laser system used in the experiment (SUNTOP ST-CC9060) with a wavelength of 10640 nm. (see Fig. 2).



Fig. 2. SUNTOP ST-CC9060 CO₂ laser system.

Technical specifications of the SUNTOP ST-CC 9060 laser system in Table 1.

TABLE 1. LASER SYSTEM SUNTOP ST-CC9060 TECHNICAL SPECIFICATIONS

| | |
|--------------------------------|----------------------|
| CO ₂ laser, CW mode | Laser type |
| 4 | Laser Safety Class |
| 10640 nm | Wavelength |
| 100 W | Maximum output power |
| 0,02 mm | Precision |
| 0 – 1000 mm/s | Scan speed |
| dxf, plt, bmp | Data formats used |
| Water cooling | Cooling system |
| 1500 W | Total power |

The digital microscope Dino-Lite Edge AM7115MZT was used for measuring engraving width and depth (shown in Figure 3).



Fig. 3. Digital Mikroskope Dino-Lite Edge AM7115MZT.

Technical specifications of the digital microscope Dino-Lite Edge AM7115MZT are provided in Table 2.

TABLE 2. DINO-LITE EDGE AM7115MZT MICROSCOPE TECHNICAL SPECIFICATIONS

| | |
|--------------------|---------------------|
| 2592 × 1944 pixels | Resolution |
| Windows | Operating System |
| 20x~220x | Magnification Range |
| USB 2.0 | Connectivity |
| 8 (FLC) | LEDs |

C. METHODOLOGY

In this experiment, ten types of wood samples were used (Ukrainian ash, Latvian spruce, alder, birch, maple,

pine, and beech, New Zealand pine Taeda and Radiata, Finnish pine) with dimensions of 15 x 60-70 x 200 mm, engraved with a laser using various power densities q_s and scanning speeds v . The power densities used for engraving are 0.71, 3.83, 6.52, and 8.31 ($\times 10^5$) W/cm², as indicated in Table 4. For each set of parameters, five lines were engraved with a distance of 2 mm between each line and a length of 50 mm. The depth h [mm] and width d [mm] of each engraved line were measured, and graphs were constructed as a function of laser parameters.

Before conducting the experiment, the laser power was measured using the OPHIR F150A-BB-26 laser power meter. Power values used for the experiments are shown in Table 3.

TABLE 3. POWER VALUES USED FOR THE EXPERIMENTS

| | | | | |
|-------------|-----|------|------|------|
| P, W | 5.6 | 30.1 | 51.2 | 65.2 |
|-------------|-----|------|------|------|

The power density q_s [W/cm²] was calculated using formula (1):

$$q = \frac{P}{S} \quad (1)$$

where P [W] is the power and S [cm²] is the cross-sectional area of the laser beam on the surface of the material to be engraved, as given in formula (2):

$$S = \pi \frac{d^2}{4} \quad (2)$$

where d [cm] is the diameter of the laser beam ($d = 0,01$ cm). The values of power density calculated in W/cm², corresponding to the measured power values in W (shown in Table 3), are presented in Table 4.

TABLE 4. CALCULATED POWER DENSITY VALUES FOR THE CO₂ LASER SYSTEM

| | | | | |
|---|------|------|------|------|
| P, W | 5.6 | 30.1 | 51.2 | 65.2 |
| $q_s \times 10^5$, W/cm² | 0.71 | 3.83 | 6.52 | 8.31 |

To create a laser cutting workflow, an engraving parameter matrix was established using the RDWorksV8 program (see Fig. 4), which supports drawing points, lines (horizontal/vertical), and applicable formats such as DXF, PLT, and AI, facilitating engraving and cutting operations.

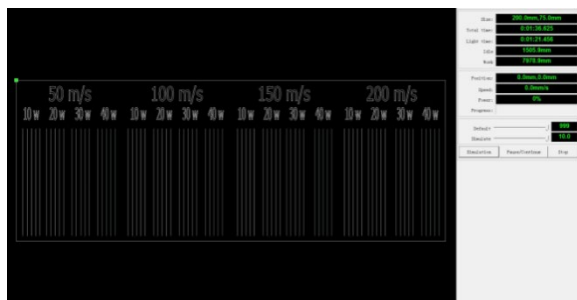


Fig. 4. Line engraving matrix in the RDWorksV8 program.

All twenty wood samples, including ten natural wood samples and ten thermally modified wood samples, were engraved according to the visible matrix (see Fig. 4) using the RDWorksV8 program (see Fig. 5).



Fig. 5. Photograph of a thermally treated radiata wood sample engraved according to the created matrix.

To measure the engraved line depth more accurately, all twenty wood samples were cross-cut through the center of the engraved line using a precise woodworking panel saw, Altendorf F45.

Fig. 6 and Fig. 7 shows depth and width measurement samples are shown respectively, where measurements were taken with the digital microscope Dino-Lite Edge AM7115MZT.

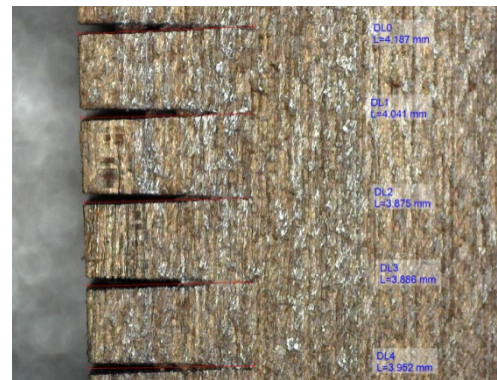


Fig. 6. Measurement of engraving depth in maple wood sample at 214°C thermal treatment and magnification x32.

Fig. 6 shows a thermally treated maple sample at 214°C temperature is shown with five cuts, obtained using a power density $q_s = 8.31 \times 10^5$ W/cm² and scanning speed $v = 50$ mm/s. The average depth of the cut is calculated as $h = 3,99$ mm.

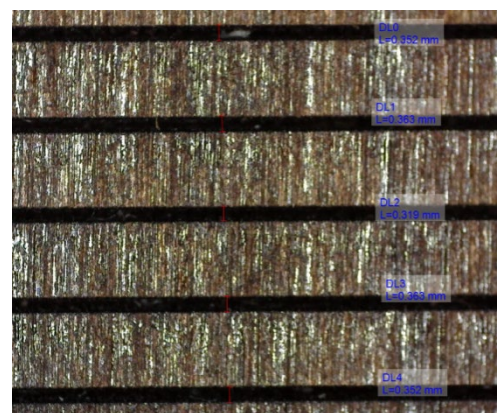


Fig. 7. Measurement of line width in a maple wood sample at a thermal treatment temperature of 214°C and at a magnification of x32.

Fig. 7 shows a thermally treated maple sample processed at a temperature of 214°C with five cuts, obtained using a power density $q_s = 8.31 \times 10^5$ W/cm²

and a scanning speed $v = 50$ mm/s. The cut width was measured, and the average width calculated is $d = 0,35$ mm.

III. RESULTS AND DISCUSSION

The research findings are presented in graphs illustrating the influence of laser power density and scanning speed on the width and depth of laser-engraved lines. The graphs depict relationships between line width and depth as functions of power density and scanning speed for various pre- and post-processed thermally modified wood samples at a specified temperature.

Table 5 and table 6 shows the relationships between line width (d) and two power densities ($q_s = 0.71 \cdot 10^5 \text{ W/cm}^2$ and $q_s = 8.31 \cdot 10^5 \text{ W/cm}^2$) at two scanning speeds (50 mm/s and 200 mm/s) for ten wood samples subjected to thermal treatment at 214°C.

Calculation of the percentage change in width Δd as a function of untreated (base) wood and thermally modified wood, obtained using equation (3).

$$\Delta d = \left(\frac{d_{max}}{d_{min}} - 1 \right) \times 100\% \quad (3)$$

TABLE 5. WIDTH CHANGES Δd IN PERCENT OF TEN THERMAL WOOD SAMPLES COMPARED WITH UNTREATED WOOD SAMPLES AT MIN POWER DENSITY $q_s = 0.71 \cdot 10^5 \text{ W/cm}^2$ AND MAX SCAN SPEED $v = 200 \text{ mm/s}$

| Wood | base d , mm | 214°C d , mm | Δd , % |
|------------|---------------|----------------|----------------|
| Ash UA | 0,21 | 0,21 | 0 |
| Spruce LV | 0,21 | 0,21 | 0 |
| Alder LV | 0,22 | 0,22 | 0 |
| Birch LV | 0,22 | 0,23 | 4,55 |
| Maple LV | 0,22 | 0,22 | 0 |
| Beech LV | 0,22 | 0,23 | 4,55 |
| Taeda NZ | 0,23 | 0,23 | 0 |
| Radiata NZ | 0,23 | 0,23 | 0 |
| Pine LV | 0,20 | 0,21 | 4,35 |
| Pine FIN | 0,22 | 0,22 | 5 |

At a high scanning speed of 200 mm/s, the average line width is 0,218 mm for all baseline wood samples, and for thermally treated wood at 214°C, it is 0,22 mm. This indicates a difference of $\Delta d = 0,92$ %. At a lower scanning speed of 50 mm/s, the average line width is 0,32 mm for baseline wood, and for thermally treated wood at 214°C, it is 0,331 mm, resulting in a difference of $\Delta d = 3,44$ %. Tables 5 and 6 reveal that line width variations are minor, including both non-thermally treated and thermowood samples. The variations are dependent on power density, with the line width being slightly larger at higher power density and slightly smaller at lower power density.

TABLE 6. WIDTH CHANGES Δd IN PERCENT OF TEN THERMAL WOOD SAMPLES COMPARED WITH UNTREATED WOOD SAMPLES AT MAX POWER DENSITY $q_s = 8.31 \cdot 10^5 \text{ W/cm}^2$ AND MIN SCAN SPEED $v = 50 \text{ mm/s}$

| Wood | base d , mm | 214°C d , mm | Δd , % |
|------------|---------------|----------------|----------------|
| Ash UA | 0,32 | 0,32 | 0 |
| Spruce LV | 0,32 | 0,32 | 0 |
| Alder LV | 0,31 | 0,32 | 3,23 |
| Birch LV | 0,30 | 0,30 | 0 |
| Maple LV | 0,31 | 0,33 | 6,45 |
| Beech LV | 0,32 | 0,33 | 3,13 |
| Taeda NZ | 0,29 | 0,31 | 6,9 |
| Radiata NZ | 0,36 | 0,37 | 2,78 |
| Pine LV | 0,36 | 0,37 | 2,78 |
| Pine FIN | 0,31 | 0,34 | 9,68 |

Fig. 8 shows the dependence of the line depth h on the power density (q_s) at two scanning speeds (v) 50 mm/s and 200 mm/s for a sample of natural maple.

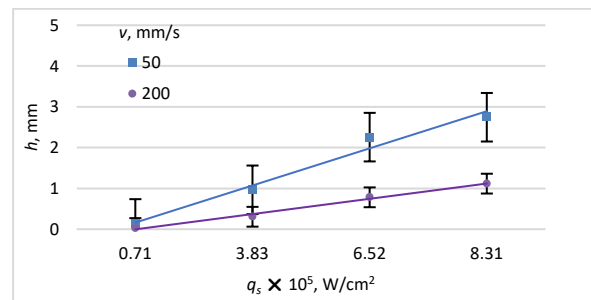


Fig. 8. The dependence of line depth (h) on power density (q_s) at two different scanning speeds (v) for a natural maple sample.

Fig. 9 shows the dependence of line depth (h) on power density (q_s) for two scanning speeds, 50 mm/s and 200 mm/s, for a maple thermowood sample that has undergone thermal treatment at 214°C.

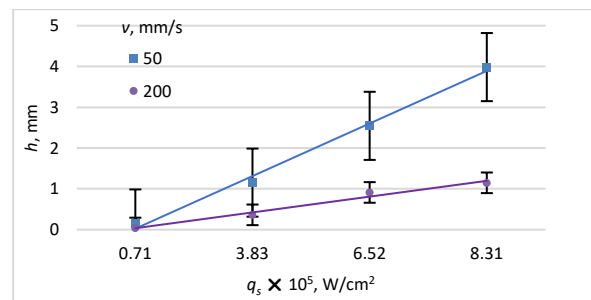


Fig. 9. The dependence of line depth (h) on power density (q_s) at two different scanning speeds (v) for a maple thermowood sample that has been thermally treated at 214°C.

In Fig. 8 and Fig. 9, it is observed that the line depth is significantly smaller at low power density and much greater at high power density. The maximum depth for untreated wood is 2,75 mm and for thermally treated wood it is 3,99 mm, achieved at a power density of $8.31 \cdot 10^5 \text{ W/cm}^2$ and a scanning speed of 50 mm/s for a maple thermowood sample treated at 214°C. The minimum depth, less than 0,15 mm, is attained at a power

density of $0.71 \cdot 10^5 \text{ W/cm}^2$ and a scanning speed of 200 mm/s for both samples. Diagrams for other pre- and post-processing samples show similar trends within this range. The line depth for all samples exhibits an increase close to linear.

The depth change rate $\text{tg } h(q_s) [\frac{\text{mm}}{\text{W} \times \text{cm}^2}]$ depending on the power density is calculated using equation (4).

$$\text{tg } h(q_s) = \frac{\Delta h}{\Delta q_s} \quad (4)$$

Where $\Delta h = h_{\text{max}} - h_{\text{min}}$ is the difference between maximum depth and minimum depth, and $\Delta q_s = q_{s \text{ max}} - q_{s \text{ min}}$ is the difference between maximum power density and minimum power density. The calculated results of the depth change rate are shown in Table 7.

TABLE 7. RATE OF CHANGE OF DEPTH $\text{tg } h(q_s)$ DEPENDING ON POWER DENSITY

| $\text{tg } h(q_s), \frac{\text{mm}}{\text{W} \times \text{cm}^2}$ | $v, \text{ mm/s}$ | |
|--|-------------------|-------|
| | 50 | 200 |
| base | 0,35 | 0,143 |
| 214°C | 0,505 | 0,146 |

The two graphs below illustrate the dependence of line depth (h) on scanning speed (v) at the lowest power density $q_s = 0.71 \cdot 10^5 \text{ W/cm}^2$ (see Fig. 10) and the highest power density $q_s = 8.31 \cdot 10^5 \text{ W/cm}^2$ (see Fig. 11) for samples of natural maple and thermally modified maple. The samples were subjected to thermal treatment at 214°C temperature.

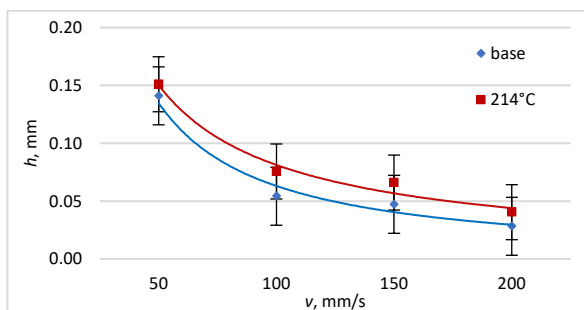


Fig. 10. The dependence of line depth (h) on scanning speed (v) at a specific power density. $q_s = 0.71 \cdot 10^5 \text{ W/cm}^2$.

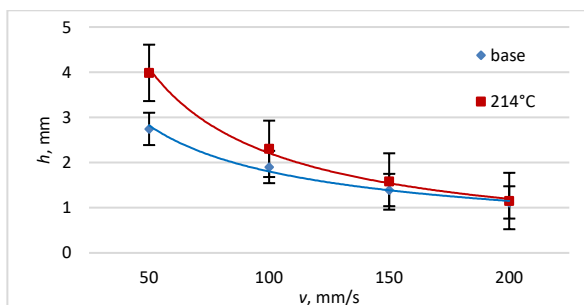


Fig. 11. The dependence of line depth (h) on scanning speed (v) at a specific power density. $q_s = 8.31 \cdot 10^5 \text{ W/cm}^2$.

The depth is greater at a low scanning speed of 50 mm/s and smaller at a high scanning speed of 200 mm/s. The maximum depth is achieved at a power density of $8.31 \cdot 10^5 \text{ W/cm}^2$ for a maple thermowood sample,

reaching 3.99 mm, treated at 214°C. The minimum depth is 0,15 mm at a power density of $0.71 \cdot 10^5 \text{ W/cm}^2$ for a natural maple sample. The reduction in line depth in the graphs is nonlinear.

The rate of change of depth, $\text{tg } h(v) [\text{s}^{-1}]$, is calculated based on the scanning speed using the equation (5).

$$\text{tg } h(v) = \frac{\Delta h}{\Delta v} \quad (5)$$

Where $\Delta v = v_{\text{max}} - v_{\text{min}}$ is the difference between maximum and minimum scan speed. The calculated results of the depth change rate are shown in Table 8.

TABLE 8. RATE OF CHANGE OF DEPTH $\text{tg } h(v)$, DEPENDING ON SCANNING SPEED.

| $\text{tg } h(v), \text{ s}^{-1}$ | $q_s \times 10^5, \text{ W/cm}^2$ | |
|-----------------------------------|-----------------------------------|-------|
| | 0,71 | 8,31 |
| base | 0,001 | 0,011 |
| 214°C | 0,001 | 0,019 |

Calculate the percentage change in depth, denoted (Δh), based on heat-treated maple wood using equation (6).

$$\Delta h = \left(\frac{h_{\text{max}}}{h_{\text{min}}} - 1 \right) \times 100\% \quad (6)$$

In Table 9, the calculated depth changes in percentage are presented for ten different wood samples, with thermowood samples compared to untreated wood samples. Depth measurements are conducted on lines engraved at maximum power density ($q_s = 8.31 \cdot 10^5 \text{ W/cm}^2$) and minimum scanning speed ($v = 50 \text{ mm/s}$).

TABLE 9. THE PERCENTAGE VARIATIONS IN DEPTH, DENOTED AS Δh , AMONG TEN THERMALLY TREATED SAMPLES AND UNTREATED SAMPLES, OBSERVED AT THE MAXIMUM POWER DENSITY $q_s = 8.31 \times 10^5 \text{ W/cm}^2$ AND THE MINIMUM SCANNING SPEED $v = 50 \text{ mm/s}$.

| Wood | base $h, \text{ mm}$ | 214°C $h, \text{ mm}$ | $\Delta h, \%$ |
|------------|-------------------------|--------------------------|----------------|
| Ash UA | 2,35 | 2,4 | 2,13 |
| Spruce LV | 4,94 | 5,55 | 12,35 |
| Alder LV | 4,34 | 4,67 | 7,6 |
| Birch LV | 3,57 | 3,72 | 4,2 |
| Maple LV | 2,8 | 3,99 | 42,5 |
| Beech LV | 3,34 | 3,41 | 2,1 |
| Taeda NZ | 3,98 | 4,88 | 22,61 |
| Radiata NZ | 4,16 | 5,19 | 24,76 |
| Pine LV | 4,08 | 4,47 | 9,56 |
| Pine FIN | 4,16 | 4,46 | 7,21 |

IV. CONCLUSION

This research employed a laser engraving process to examine the influence of power density and scanning speed on the depth and width of etched lines. The outcomes revealed that both power density and scan speed significantly impact the depth of etched lines, with

higher power density and lower scan speed resulting in greater depths, while line width variations are minor.

The calculation of the depth change rate was performed separately for power density and scanning speed, and the outcomes are presented in Tables 7 and 8, respectively. Additionally, Table 9 illustrates the percentage variation in depth among ten distinct wood samples (Ukrainian ash, Latvian spruce, alder, birch, maple, pine, and beech, New Zealand pine Taeda and Radiata, Finnish pine) when comparing heat-treated and untreated samples at maximum power density and minimum scanning speed.

The implications of this study hold significance for the application of laser engraving in the woodworking industry, especially in the creation of decorative or functional wooden items. By comprehending the factors influencing the depth of etched lines, manufacturers can optimize their laser engraving procedures to attain desired outcomes.

Subsequent investigations could explore the effects of other laser parameters, such as pulse duration and spot size, on the depth of etched lines. Furthermore, more detailed analyses could delve into the microstructural changes occurring in wood during the laser engraving process, along with exploring the impact of various wood types on engraving results.

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