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The effect of moisture on laser beam wood machining

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The effect of moisture on laser beam wood machining

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Abstract. Wood moisture can affect various parameters of the engraving process, such as the depth of engraving, the structure and surface of the wood, and thus the overall quality of the created image. The investigation of the influence of moisture contained in different types of wood on their machining was carried out on samples of oak, beech, pine, spruce, alder, ash and cherry produced using the laser device ILS 3NM, CO_2, with a wavelength of 10.6 μm and a maximum power 100 W, with a maximum feed speed of 1524 $mm \cdot s^{-1}$. The depth of ablation and the surface of the machined surface were studied for selected samples with the moisture of the wood plants in the laboratory room, the outdoor and with the moisture created by immersion in the water bath.

1. Introduction

Laser technologies are gradually replacing the final methods of material processing in various sectors of industry. It has many advantages as it is a non-contact technique. This is due to its accuracy, low operating costs without consumables, easy maintenance, and long life that conventional machining methods usually cannot offer. LBM technology achieves low temperature zone, high speed, flexibility, versatility and easy automation and computer control, and short processing time. Laser machining of materials is influenced by a number of factors. The result of the optimisation process is to evaluate the influence of the different factors, to emphasise the most important ones, to neglect the less important ones and, in general, to be able to adjust the laser parameters in order to maximise the utility of the product. The quality of the work piece depends on the properties of the surface to be machined, its shape and dimensional accuracy, and the properties determined by the material and its processing. These changes can also affect the future function of the finished article and are used to assess the quality of its integrity. The concept of surface integrity (technological inheritance) is very complex and, in simple terms, is a set of characteristics that summarise the functional properties of a surface. Among the most important are the surface topography, the structural, physical, and chemical changes of the surface, the degree, depth and nature of hardening, the nature, magnitude and progression of residual stresses. [1-5]

Depending on the product and the wood surface treatment process, changes in the physical or biological properties of the wood occur, which ultimately also affect the surface. For the final graphic layer, not only the technical requirements are important, but also the aesthetic requirements. One way to change the appearance of a wooden surface is through laser engraving. Each material reacts to the laser beam individually, and its properties and structure have a major influence on the final result of the processing. Wood is one of the oldest and most widely used materials, which is obtained from tree trunks. Its properties, such as strength, durability, or aesthetic value, make it an ideal material for various structural, decorative and utilitarian purposes. Wood is primarily made up of cellulose, lignin and other organic substances found in the cellular structure of the tree. This makes the wood lightweight, but at the same time highly strong. Wood is valued for its eco-friendly and renewable nature, making it an increasingly popular material in modern architecture and design; it has a positive impact on human health by regulating humidity and improving interior acoustics; and it is a popular material for these purposes due to its lightness, availability and ease of handling. Wood is divided into two basic groups - hardwood and softwood. Hardwoods come from trees with slower growth and are generally denser and more durable than softwoods, which come from trees with faster growth.

The energy concentrated in the laser beam and delivered to a specific point on the engraved wood surface is converted into heat. This heat causes thermal degradation of the surface structures of the wood in the area of the heat-affected zone. The high energy values cause sublimation of the surface layer of the wood, which is accompanied by the formation of a carbonised or molten layer. The wood surface thus treated shows changes in its chemistry and structure, which are subsequently reflected in changes in morphology, colour, and liquid wettability. [6-7]

This energy can be controlled by laser power, laser head speed, focal length, and raster density. In addition to the amount of energy delivered and its concentration, the thickness of the thermally affected zone depends largely on the type of wood.

The aim of this study is to analyse laser-treated wood surfaces at different wood moisture contents, focusing on the depth and assessment of the treated area by CO_2 beam [8-15].

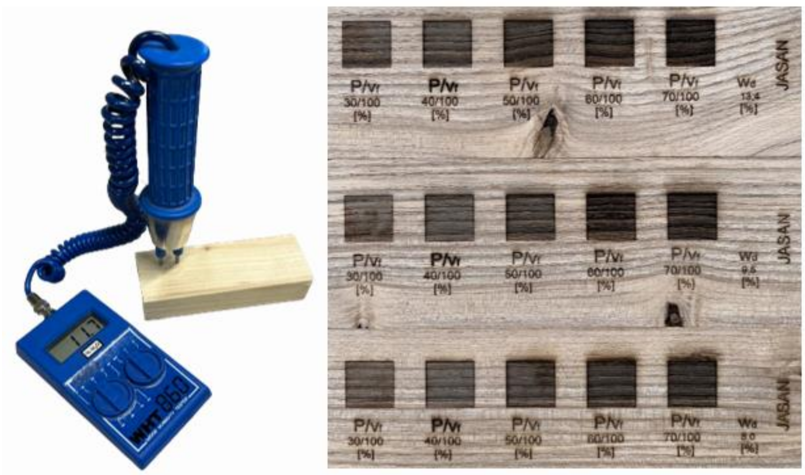
To determine the moisture content of wood, the relative moisture of wood is used. This moisture value is important in applications such as drying wood before processing, storage, or moisture control in indoor environments. Changing the relative moisture of wood can also affect its strength, stability, and durability. It is expressed as the ratio of the weight of water to the weight of wet wood and is calculated according to the following formula, where is m_w weight of wet wood, m_o weight of absolutely dry wood, m_v water weight:

$$W_{rel} = [(m_w - m_o)\, m_w^{-1}] \times 100\ \% = (m_v\, m_o^{-1}) \times 100\ \% \qquad (1)$$

Measuring the relative moisture of wood is usually done with hygrometers [16-17].

2. Sample preparation

For the experiment, samples were made from different types of wood, oak, beech, pine, spruce, alder, ash and cherry, for each group with a moisture laboratory environment, outdoor environment and exposed to a water bath for 12 hours.



a) WHT 860 hygrometer b) Production samples

Figure 1. Sample preparation.

The machining was preceded by moisture measurement using the WHT 860 hygrometer, see figure 1a, which works on the principle of measuring the electrical resistance between the electrodes (tips) of the measuring probe with a measuring range of 8 - 60 % moisture, measuring range of 200 × 100 × 40 mm. The moisture content of wood was always measured at five location, at the greatest distances from each other, to achieve the most accurate measured value. Average moisture values of were used to evaluate the individual samples. These samples were then exposed to a laser beam with a power of 30 W, 40 W, 50 W, 60 W, 70 W (P) and a constant speed of 1524 mm·s^{-1} (v_f), the value of the number of pulses per inch was the same in all cases 1000 (PPI), using lenses with focal lengths of 38.1 mm (f), see figure 1b.

3. Measurement sample

The depth measurement was carried out using the Mitutoyo H0530, see figure 2 digital dial indicator with the resolution 0.001 mm and the measurement range from 0 to 30 mm, in order to determine the effect of moisture contained in the woods on the depth of layer removed by engraving. Due to the surface segmentation, which in caused by the density in the incremental layer of wood (growth rings) of the examined samples, disk and needle styluses were used.

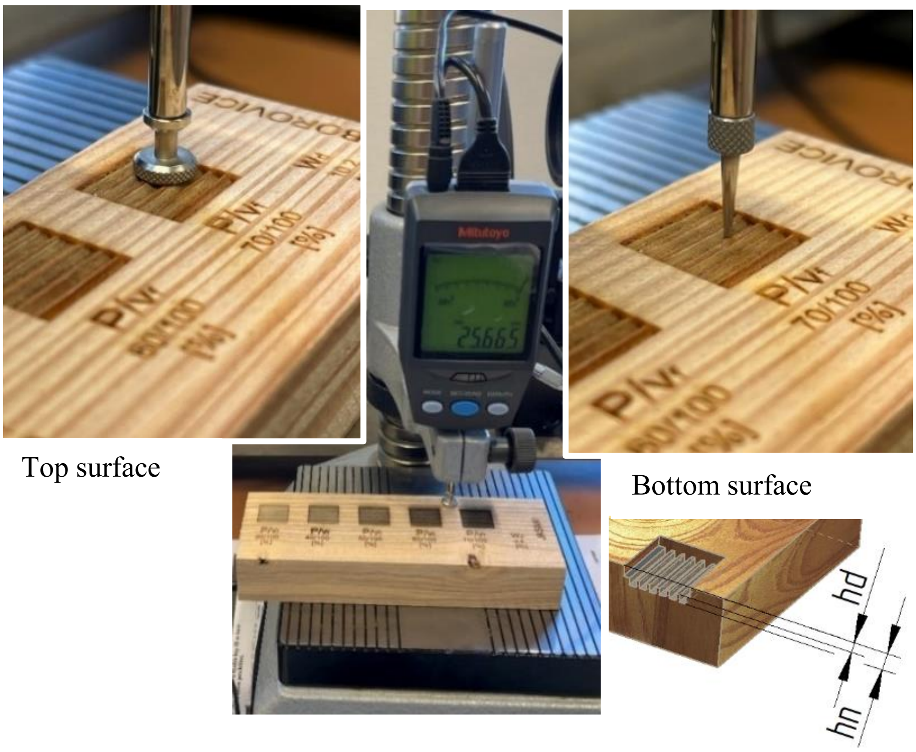


Figure 2. Measurement samples with Mitutoyo H0530.

As the zero point, the plane of the fixture was chosen, which anchors the device in a stationary position. Each sample was measured twice, using both above measuring touches. The measurement was first performed on the unmachined surface of the sample to determine the height of the upper layer. The top layer (h_d) was measured using 10 measurements by disk stylus, and the bottom layer (h_n) was measured using 10 measurements by needle stylus. Subsequently, machined surfaces were measured, namely 10 measurements by disk stylus and 10 measurements by needle touch. The total output of this measurement was 120 height values for each sample, see table 1.

To compare the surface texture of the above samples, a Carl Zeiss microscope with magnification of 50 was used (figure 3).

Table 1. Measured heights by engraving the removed layers.

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Oak	9.7	0.1885	0.2233	0.3125	0.3809	0.5179
	11.3	0.0996	0.1614	0.1968	0.2464	0.3971
	12.6	0.2343	0.2189	0.2547	0.2873	0.2651
		h_a **(mm)**				
	9.7	0.1171	0.3303	0.5125	0.5520	0.7107
	11.3	0.2576	0.3705	0.3972	0.5078	0.7619
	12.6	0.2694	0.4053	0.5309	0.5807	0.7416

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Beach	6.3	0.1736	0.2154	0.3136	0.3790	0.4006
	9.2	0.1104	0.1836	0.2434	0.3180	0.3684
	16.3	0.0312	0.0374	0.2184	0.3596	0.5112
		h_a **(mm)**				
	6.3	0.1517	0.2757	0.3967	0.4744	0.5656
	9.2	0.2231	0.2757	0.3558	0.4478	0.5271
	16.3	0.1140	0.1506	0.3728	0.4875	0.6706

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Spruce	6.1	0.4314	0.5990	0.6650	0.9400	1.1052
	8.5	0.2418	0.3516	0.4162	0.6644	0.7292
	11.5	0.0968	0.1994	0.2192	0.3622	0.6126
		h_a **(mm)**				
	6.1	0.4710	0.6545	0.8284	0.8459	1.1633
	8.5	0.4542	0.5317	0.7129	0.9002	1.1433
	11.5	0.3299	0.4929	0.6031	0.7278	0.7747

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Chery	7.6	0.1896	0.2010	0.2864	0.3842	0.4322
	8.9	0.0851	0.1873	0.3185	0.3985	0.5101
	11.0	0.1988	0.2236	0.3190	0.3892	0.4386
		h_a **(mm)**				
	7.6	0.2867	0.3325	0.4577	0.5350	0.6702
	8.9	0.1672	0.2880	0.4177	0.5216	0.7087
	11.0	0.2546	0.3091	0.4058	0.5586	0.6188

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Ash	8.1	0.1758	0.1990	0.2196	0.3470	0.3198
	10.7	0.0680	0.1578	0.2632	0.3342	0.3852
	15.5	0.1332	0.1570	0.2164	0.2514	0.3155
		h_a **(mm)**				
	8.1	0.2908	0.3539	0.4076	0.5523	0.5531
	10.7	0.2436	0.4162	0.5183	0.5896	0.7489
	15.5	0.2429	0.3665	0.5007	0.5894	0.8521

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Alder	9.6	0.2468	0.3136	0.4052	0.5096	0.5662
	11.5	0.1486	0.2588	0.3498	0.4432	0.6044
	14.5	0.2785	0.2817	0.3105	0.4689	0.5603
		h_a **(mm)**				
	9.6	0.2910	0.3939	0.4874	0.6212	0.7214
	11.5	0.2301	0.3587	0.4553	0.5985	0.7373
	14.5	0.3895	0.4145	0.5091	0.6463	0.8059

		P **(W)**				
	W_d(%)	**30**	**40**	**50**	**60**	**70**
		h_d **(mm)**				
Pinie	8.7	0.0572	0.1224	0.1862	0.2560	0.3744
	11.6	0.1575	0.1841	0.1957	0.2477	0.3439
	13.1	0.1976	0.1876	0.1468	0.2344	0.3384
		h_a **(mm)**				
	8.7	0.4066	0.5815	0.7634	0.9262	1.1203
	11.6	0.4444	0.5996	0.7499	0.8715	1.0952
	13.1	0.4335	0.5988	0.6333	0.9019	1.0253

Figure 3. Microscope Carl Zeiss.

4. Results

Dendrograms were used for the possibility of choosing machining conditions for different types of wood with different moisture with a requirement for the depth of engraving.

Dendrograms, created using Minitab, were used to evaluate the measured data, to compare the depth of the cut depending on the moisture content of the samples and the changing power of the laser beam. Dendrogram provides a clear comparison of samples, different groups, and identification of their similarities. The vertical axis of the graph shows the percentage of similarity between the examined samples. The horizontal axis represents the moisture content wood W_d (%) and the power value P (W) for each sample. Due to the large volume of data, are given here only as an example of the Dendrograms for oak, pine and alder.

4.1. Oak

The moisture content of the oak wood has a significant impact on the depth of the engraved layer. The highest similarity is between a sample with a moisture (W_d) of 9.7%, which was machined at a laser power of 40 W, and a sample with a with moisture (W_d) of 12.6%, which was machined with a laser power of 30 W. In general, it could be assumed that samples with lower moisture would need less power to burn through the same layer than a sample with higher moisture, because dry wood contains less water and is more susceptible to laser damage. The cause of this phenomenon could be the fact that wood with higher moisture is more efficiently machined at lower outputs, as can be seen from the graph (figure 4a) that in the other pairs of samples with bottom moisture machined with higher powers with similarities above 75%, lower engraving performance was needed to machine the same deep layer than in samples with higher moisture.

When measuring data with needle touch (figure 4b), the effort was always to measure the deepest layer of wood removed, usually the layer taken in the tree growth rings incremental part. There is a large frequency of similarities between samples with lower moisture that were machined with higher power and samples with higher moisture that were machined at lower power. This could be due to the characteristics of the growth rings increment layer, where a layer with lower moisture content can generally be denser than a layer with higher moisture. Denser material usually requires higher laser power to achieve the same engraving effect.

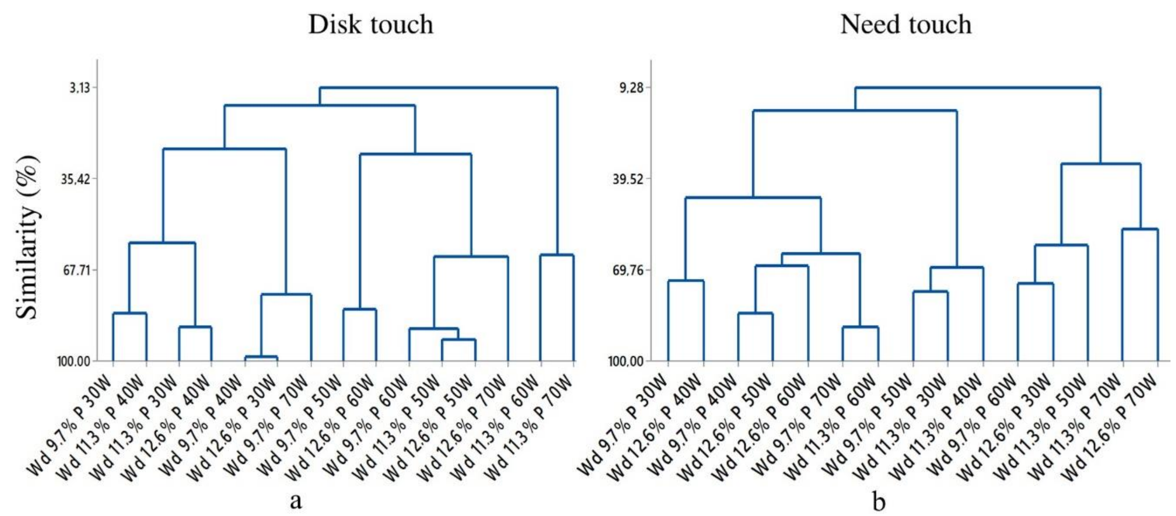


Figure 4. Dendrogram for oak.

Laser engraving in oak wood creates an evenly removed layer without greater surface roughness. With the same cutting conditions, but with a different percentage of water content in the wood, it can be stated that the percentage of water contained significantly affects the resulting structure and appearance of the machined surface, see figure 5.

The cause of this phenomenon could be the effect of higher moisture in wood on heat transfer. For samples with a higher water content, the heat from the laser penetrates the interior of the wood faster and deeper, causing more wood to heat up and more pronounced chemical changes in the wood's cellular structures, which could lead to a darker shade of wood.

Conversely, a sample of oak wood with lower moisture content could be lighter after processing because the heat from the laser would spread more slowly and have less effect on the chemical changes in the wood. This different behaviour of wood with different moisture content after laser treatment may be due to the physical and chemical properties of the wood and its interaction with the heat of the laser beam.

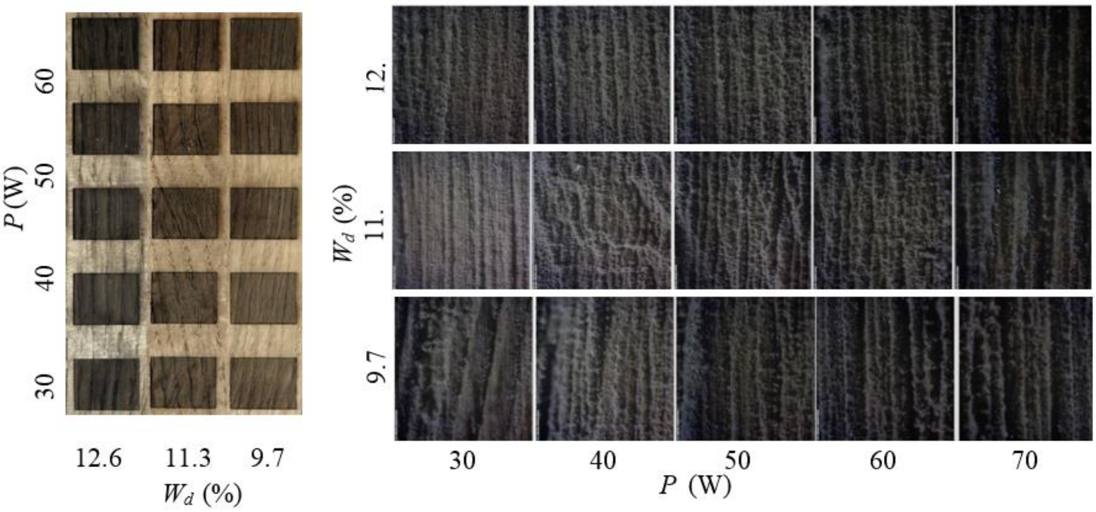


Figure 5. Comparison of the shade of the engraved surface oak.

4.2. Beech

At low laser beam power, higher moisture has a significant effect on the depth (h_d) of the removed layer, where it is possible that most of the moisture was on the surface of the sample, preventing the formation of a deeper layer. Using higher power for samples with higher moisture, the removed layer formed deeper (table 1).

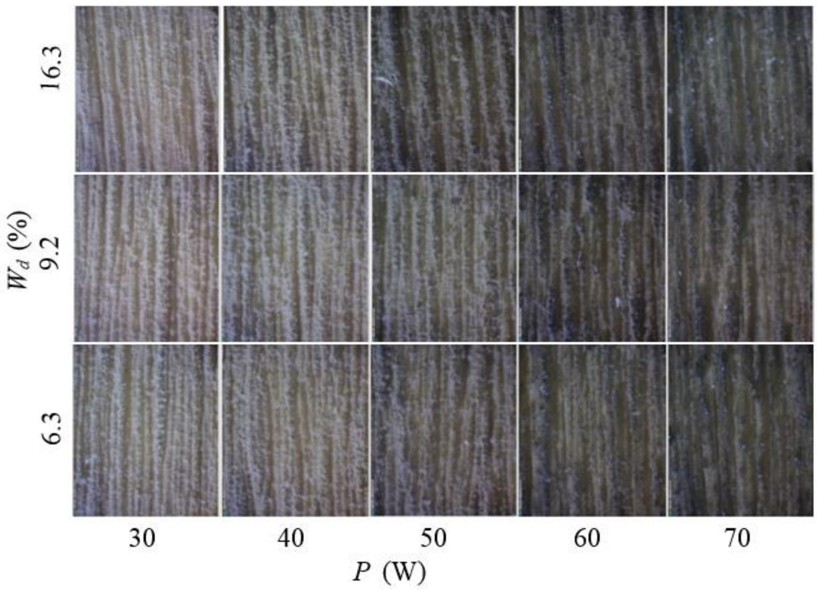


Figure 6. Comparison of the shade of the engraved surface beech.

In beech wood, higher moisture supports cutting depth at higher power. Samples with higher moisture at the same power achieved the same deep cut as samples with lower moisture.

In beech wood, we can observe a similar type of behaviour as in oak wood. Samples with higher moisture show a darker colour of the machined surfaces. The structure itself after machining is homogeneous with little difference between the individual layers. When engraving into beech wood, an evenly removed layer is created without larger surface roughness, see figure 6.

4.3. Pine

In pine wood, the difference between the incremental layers was most noticeable. Using a plate touch, the top surface h_d (winter incremental) of the removed material was measured, see table 1. In the summer growth layer, the moisture (W_d) has a significant influence on the processing according to the laser beam power (P) values. At lower power, there will be more material removal from the sample with higher moisture, and at higher power, material with lower moisture will be removed more efficiently.

The dendrogram (figure 7) shows that the effect of moisture on depth of cut is reduced for samples machined at higher power. Data measured by needle touch indicate that the summer growth layer is removed by the laser beam much better than the spring growth layer (table 1, figure 7).

When machining pine wood (figure 8), we can notice the biggest difference between the summer and springer growth layer.

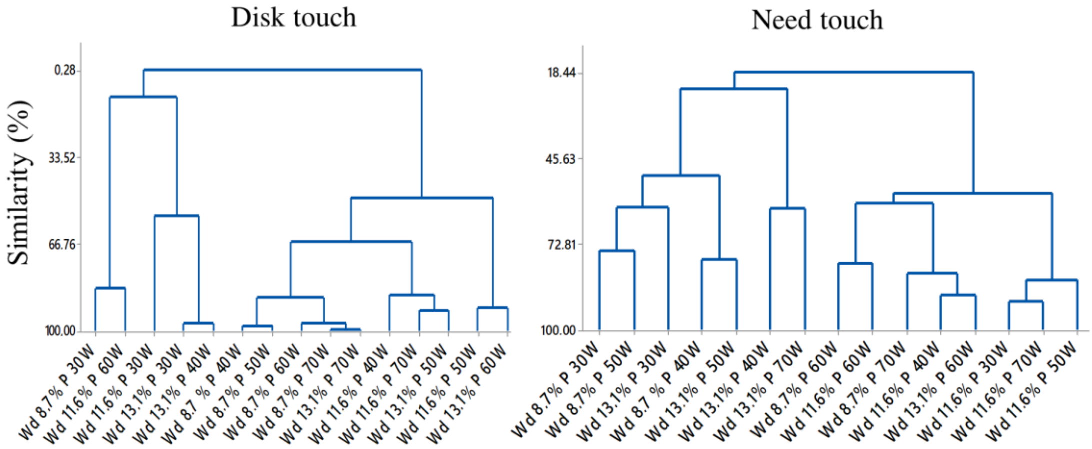


Figure 7. Dendrogram for pine.

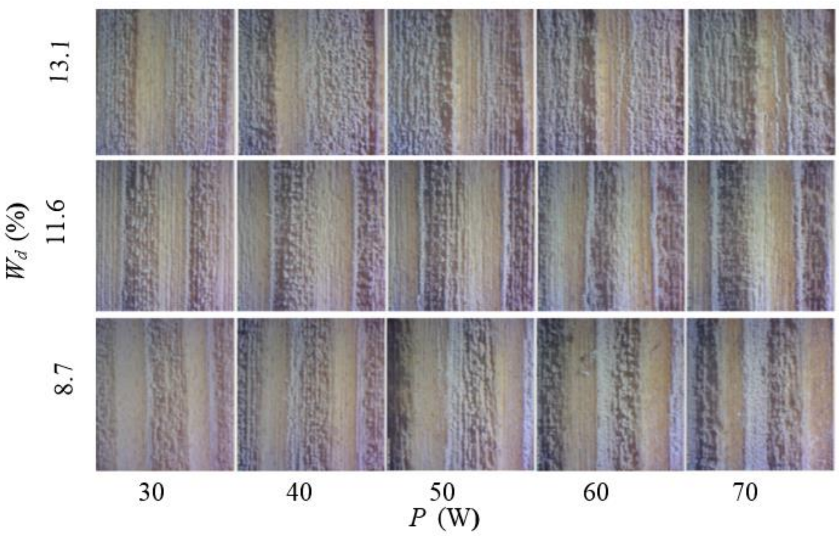


Figure 8. Comparison of the shade of the engraved surface pine.

The cause of this phenomenon is the difference in wood density between the summer and springer growth of pine. The summer growth layer of wood is usually softer and has a lower density than the springer layer, which means that the laser beam penetrates and removes this layer more easily. The springer layer has a higher density and is harder, which makes the removal of this layer by the laser slower and more demanding.

4.4. Spruce
In spruce wood, moisture has a significant effect on machining. The lower the percentage of moisture contained in spruce wood, the deeper the engraved layer (h_d).

In the case of needle touch (h_n) measurements, it was found that this is similar to the measurement with a disk stylus, only the depths of the removed layers differ (table 1). The most effective material removal occurs with drier wood. Furthermore, we can state that moisture has the same effect on engraving in both cases of contact for measurement.

Overall, it can be observed that after laser engraving, spruce wood has a smoother and more united surface with fine texture and emphasizes details, we can also see fine differences between the growth layers (figure 9). The surface structure is symmetrical and there are no large differences in the depth removed, as was the case with pine.

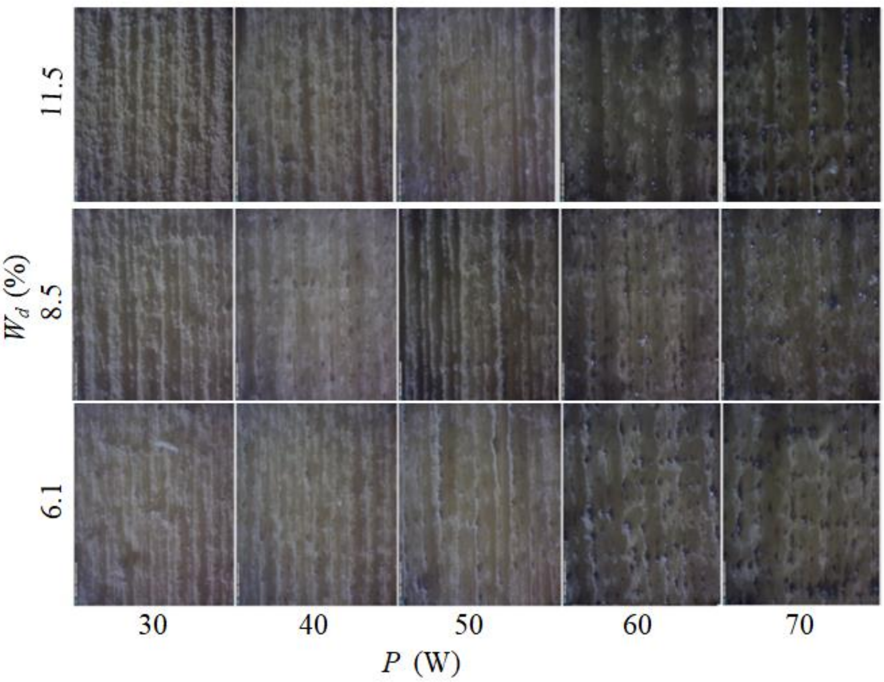


Figure 9. Comparison of the shade of the engraved surface spruce.

4.5. Alder
Measurements for alder wood show that it was most effectively engraved in samples with higher moisture, which may be due to the properties of the wood itself, where at higher moisture it consequences less resistance to the laser beam.

The greatest frequency of similarities is for specimens that had lower moisture and were machined at higher power with specimens that had higher moisture and were machined at lower power, see figure 10.

With the structure of alder wood (figure 11) after laser engraving, we see a fine structure with a changing shade of colour depending on the power of the laser and moisture. Higher power and higher moisture cause a darker colour of the machined surface as well as an increase in surface roughness.

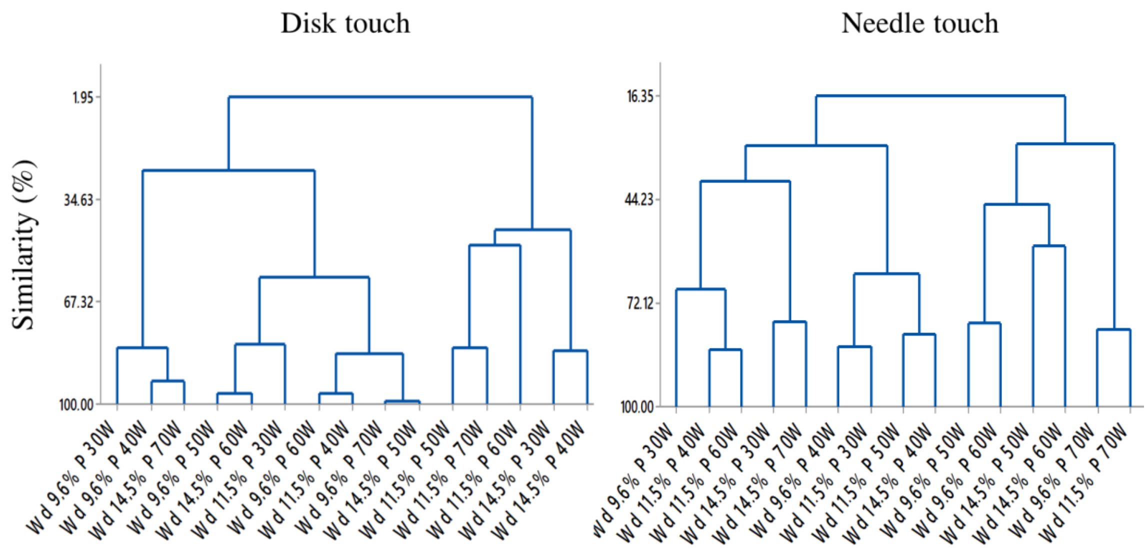


Figure 10. Dendrogram for alder.

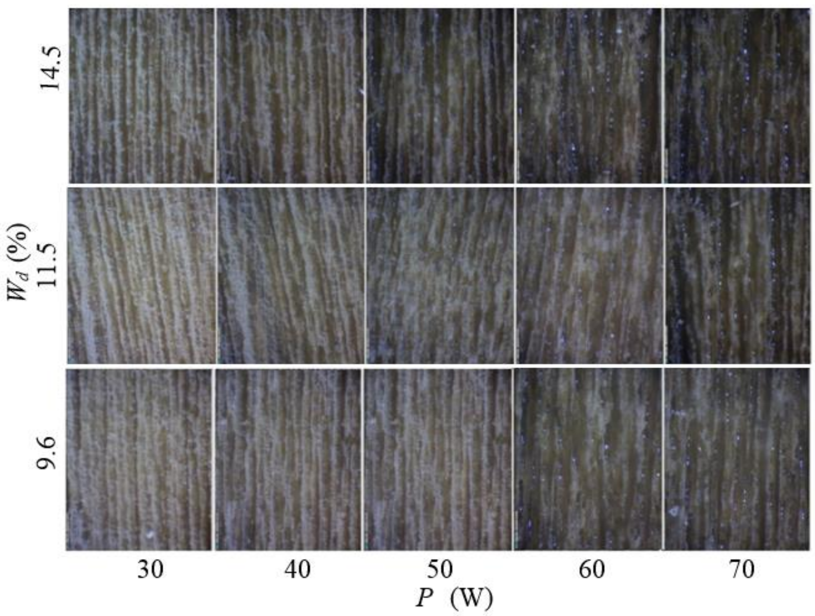


Figure 11. Comparison of the shade of the engraved surface alder.

4.6. Ash

In ash samples, table 1 shows that at lower powers, the laser penetrated deeper into the material with lower moisture. This could be due to the high moisture content on the surface of the wood. As the power increased, the laser removed a deeper layer of material from the with higher moisture. This could be due to the properties of ash wood, where at higher moisture the ash softens and becomes easier to laser beam machine.

The values measured using needle touch h_n (table 1) show that ash wood with a higher moisture content offers less resistance to the laser than dried ash wood.

Ash samples (figure 12) have a small change in colour due to higher power or higher humidity. The overall structure of the removed material is uniform, but we are able to notice longitudinal segments and unevenness in the form of vessels of different densities or resin channels, which can be influenced differently during laser engraving. This would indicate that different layers of ash wood have different hardness and laser light absorption capacity, which can cause uneven removal of material and the formation of longitudinal depressions.

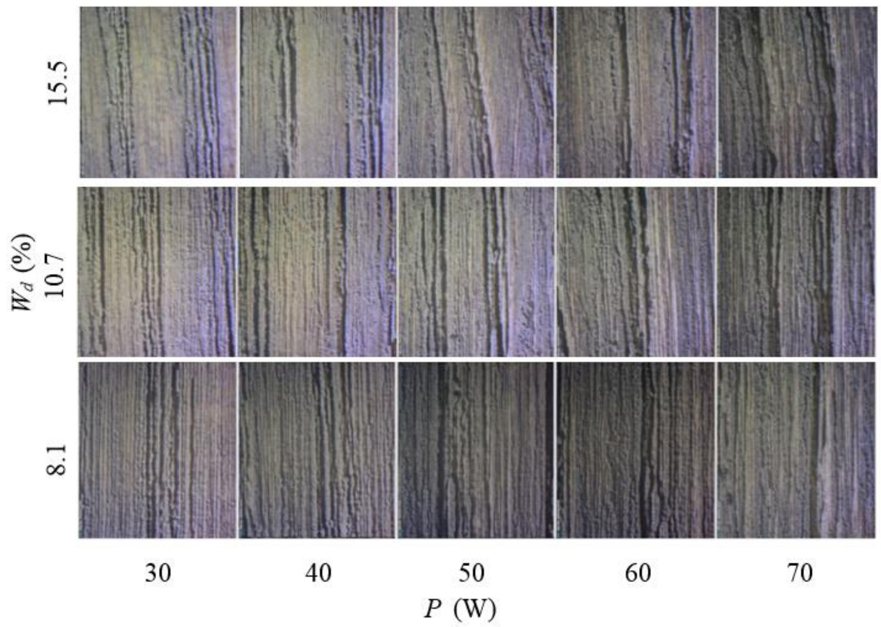


Figure 12. Comparison of the shade of the engraved surface ash.

4.7. Cherry

In the case of cherry wood samples, it was evident that the most effective material removal occurred at medium moisture. As with ash samples, only at lower powers, up to about 40 W, is the most effective remove of material for samples with the lowest moisture content, see table 1, measurement with disk stylus.

When measuring the summer increment layer using needle touch, the most effective material removal was again achieved at a medium moisture content (8.9 %), which is the optimal value for laser engraving.

In the case of cherry specimens (figure 13), the material was removed most evenly.

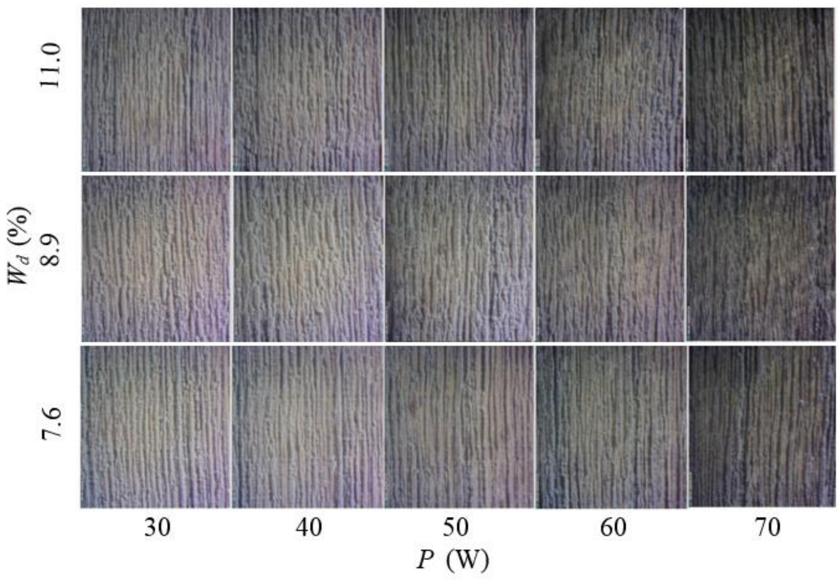


Figure 13. Comparison of the shade of the engraved surface cherry

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One of the reasons why cherry wood is very evenly removed during laser engraving without visible unevenness is the composition and structure of this type of wood. Cherry wood usually has a fine and homogeneous surface structure with minimal resin and other impurities, which facilitates laser engraving and allows you to achieve very precise and uniform engraving.

5. Conclusion

In conclusion, we can say that the moisture content of wood plays a crucial role in laser engraving, and this effect varies significantly for different types of wood. Experimental results have shown that each type of wood responds uniquely to moisture in terms of engraving depth and surface quality. For oak wood, higher moisture content allowed more efficient processing at lower laser power, while drier samples showed darker surfaces at higher power due to thermal effects on lignin and other wood components.

Beech wood showed a more homogeneous structure during laser engraving, with the surface remaining consistent despite varying moisture levels. However, at lower power levels, the lower moisture content of the samples allowed better machinability. Pine wood, on the other hand, revealed significant differences between summer and springer growth rings; the lower moisture in the thicker springer growth layers resulted in greater resistance to laser treatment, while the softer summer growth layers were more easily removed. This finding is significant for technological applications and suggests potential optimization for laser processing of wood with similar properties.

Spruce wood responded more effectively to engraving at lower moisture levels, resulting in a uniformly smooth engraved surface and improved fine detail. Moisture affected the depth of engraving consistently across measurement methods, underscoring the overall uniformity of the spruce wood. Alder wood was found to be easier to process with higher moisture content, probably due to the natural properties of the wood that reduced the resistance to the laser beam. In the case of ash wood, better machinability prevailed in samples with a higher moisture content, where the laser beam penetrated more effectively and achieved uniform material removal. Similar conclusions were reached for cherry wood, which was most effectively processed at a medium moisture level, providing an even, homogeneous structure without significant surface irregularities.

Overall, this study provides valuable insights for industrial applications of laser engraving on various types of wood, which increases not only aesthetic quality but also energy efficiency. Data from these experiments can help optimize laser engraving parameters based on the specific moisture content of the wood, allowing better control of the final quality of the processed surfaces.

Future research could focus on a more detailed analysis of different types of lasers and their suitability for specific moisture conditions in other wood species. Another important area could be to study the effects of variables such as focal length and spectral wavelength, potentially leading to more precise optimization of engraving parameters. Further research could also include the application of these findings in an industrial setting to minimize energy consumption while maintaining high-quality engraved surfaces. This study thus opens up new avenues for efficient and environmentally friendly applications of laser technology in wood processing and offers promising opportunities in craftsmanship, industrial design, and mass production of durable, high-quality wood products with significant aesthetic value.

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