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Optimization of CO_2 Laser Cutting Variables of Sengon Plywood (*Paraserianthes falcataria*) Using Response Surface Methodology

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ABSTRACT

Sengon (*Paraserianthes falcataria*) wood is used for various purposes, including furniture, plywood, pallets, and building materials. Consumer demand for decorative wood is increasing, so innovation is needed to make it more productive and efficient. A laser cutting machine is one of the alternatives to answer this problem. Because CO_2 gas wavelength and energy density offer the highest cutting quality, CO_2 lasers are appropriate for wood processing. This study aims to determine the effect of laser power intensity and cutting speed on cutting plywood to get the best results. The plywood used has a thickness of 12 mm. The laser intensities used were 30 Watt, 35 Watt, 40 Watt, 45 Watt, and 50 Watt with cutting speeds of 2 mm/s, 4 mm/s, 6 mm/s, and 8 mm/s, with nozzle standoff distance set to 10 mm. In each repetition on the same sheet determine the comparison or variation of each variable used. Based on the measurement results, the highest width was obtained at 50 Watt power and 2 mm/s speed, and the lowest at 35 Watt power and 8 mm/s. The highest depth was 50 Watt and 2 mm/s, and the lowest was 30 Watts and 4 mm/s. The overall color change (ΔE*) increased with increasing laser power. The higher the laser power, the more the color change increases. The change in ΔE* decreased as the laser speed increased. The optimization of cutting sengon plywood with CO_2 laser using RSM method resulted in an optimum combination at 40 Watt laser power and 8 mm/s speed with a desirability value of 0.623.

Keyword: CO_2 Laser Cutting, Kerf Depth, Plywood, Response Surface Methodology, Roughness, Width

1. Introduction

Wood is generally used as a construction material in the building industry. However, the availability of solid wood in Indonesia has decreased, and its price continues to increase from year to year [1]. To overcome this, using composite wood is an alternative, one of which is using plywood [2]. Plywood is a wood composite product made from gluing veneer sheets arranged crosswise perpendicularly [4]. In Indonesia, plywood production in 2022 was 8,871,091 m^3 [5].

In the forest industry, plywood has an important role, one of which is as a building material in interior design [6], especially for home decoration. Wood as a home decoration material is highly popular, with the process involving manually cutting wood featuring repetitive designs typically installed on fences or house walls [7]. Consumer demand for decorative wood is increasing, with Indonesia's total exports increasing by 8.3% in 2022 [5].

To meet this demand, wood is needed from fast-growing trees. Sengon (*Paraserianthes falcataria*) has great potential to be chosen because it has high economic and broad ecological value [3]. The economic advantage of the sengon tree is that it is a fast-growing species, its management is relatively easy, and market demand continues to increase. Sengon wood has now become a type of wood that supplies industrial raw materials, such as carpentry wood and pulp wood. Sengon woods are used for various purposes, including furniture, sawn timber, plywood, pallets, and building materials [8].

Innovation is needed to be more productive and efficient so that producers can compete in the world market. Laser-cutting machines are also here to answer this problem. During the 1960s, lasers were discovered, and lasers began to be applied in various cutting industries, considering that lasers have a high level of accuracy. Lasers were successfully used to cut plywood molds in the packaging industry [9]. A laser is a device that amplifies an intense and narrow coherent beam of light. Lasers are currently widely used in the cutting and engraving industry, in surgery for medicine, and in scientific research [11].

Laser cutting has higher precision than conventional cutting, such as using a circular saw, because it produces narrow stroke widths, flexibility in starting and finishing cuts in various board positions, and a smooth surface [11], [12]. Apart from that, other advantages include reducing noise and reducing the amount of sawdust [13]-[15]. Much research has been conducted regarding using CO_2 lasers in wood cutting. Amany et al. in [16] and Rahman et al. in [17] examined meranti wood and particle board using a CO_2 laser on color and consumer preferences. Eltahwani et al. [18] concluded that CO_2 lasers are very suitable in wood processing because the CO_2 gas wavelength and energy density provide the best quality in cutting. Using a CO_2 laser creates a laser signal polarized in the cutting direction, creating narrow scratches with sharp, straight edges. In wood cutting using a CO_2 laser, parameters such as laser power and cutting speed affect the plywood cutting process. Eltahwani et al. [19] examined CO_2 laser cutting parameters on MDF (Medium Density Fiberboard) composite wood. They stated that the cutting quality was influenced by laser power, cutting speed, air pressure, and focus point position. According to Yusoff et al. [20], nozzle height and size also determine the cutting quality of several types of wood.

The way to save energy, time, and costs and optimize factors in the cutting process is to use statistics-based experimental planning, namely Response Surface Methodology (RSM). RSM is an optimization method for adjusting the values of independent variables or factors to obtain the highest or lowest optimum response value [21]. Agustian et al. in [22], explain that this method aims to maximize response. The advantages RSM offers include determining interactions between independent variables, developing mathematical models for the system, and reducing experimental time and costs by minimizing the number of experiments required [22], [23]. De Melo et al. [38], explain that by using the response surface, we can find that cutting speed, feed rate, cutting depth, and wood moisture content influence the Es value to determine the optimal point for lower power consumption. Li et al. [39], explain that a mathematical model of cutting power can be created and utilized in the particle board milling process to forecast cutting power and optimal milling parameters through RSM. There has been no research regarding cutting plywood using response surface methodology, especially on sengon wood species. Therefore, this research aims to determine the effect of laser power intensity, nozzle height, and cutting speed on plywood cutting to get the best cutting results.

2. Methods

This research used sengon plywood with a 12 mm thickness. The tools used in this research were a 50-watt CO_2 laser machine, Corel Laser DRW X7 software, stereo microscope, surface roughness tester, Colorimeter, and Design Expert 13 software. Before laser cutting is carried out, the power intensity and cutting speed parameters are first determined, and these two factors' lower and upper limits are specified. In terms of power intensity, a range of 30–50 watts is utilized, while in terms of speed, 2–8 mm/s is the range of values used. After that, an experimental design was carried out using Design Expert software, and the combination was produced, as seen in Figure 1.

Std	Run	Factor 1 A: Laser Power Watt	Factor 2 A: Laser Speed Watt
3	1	35	8
1	2	30	4
10	3	45	8
6	4	40	6
9	5	40	8
4	6	45	2
7	7	30	2
5	8	35	6
12	9	50	2
8	10	50	4
2	11	30	6
13	12	40	2
11	13	35	4

Figure 1. Cutting combinations recommended by Design Experts software

The cutting design will be created using Corel Laser Draw X7 by forming a cutting line pattern. Then, the power intensity and laser cutting speed are set according to the recommendations of the design expert software (Figure 1). The laser point size utilized during the cutting process has a diameter of 0.1 mm. The nozzle standoff distance was set to 10 mm. Then, the plywood is cut into straight lines using a CO_2 laser (Figure 2).

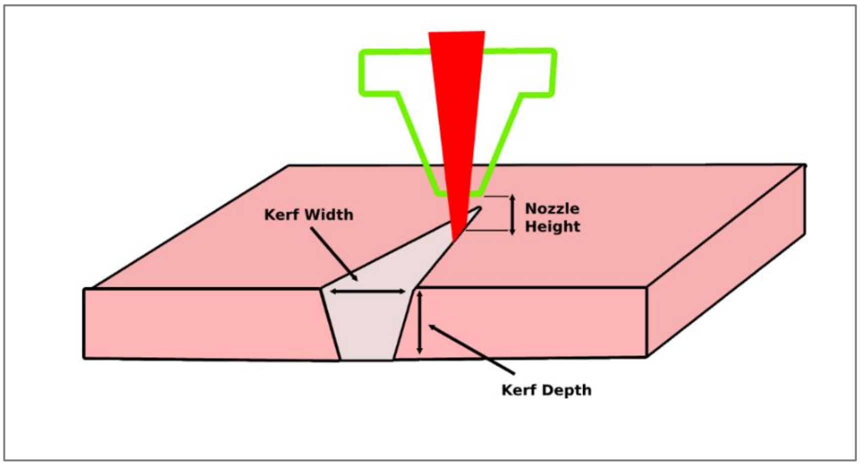

Figure 2. Plywood Cutting Process (modified from [40])

The width and depth of the kerf are measured at various heights, beginning from the upper surface of the test object, as illustrated in Figure 3. Specifically, 13 width measurements of the kerf are collected from the upper surface of the workpiece processing in the beam direction. Kerf depth and width are measured with a stereo microscope with an accuracy of 0.001 mm.

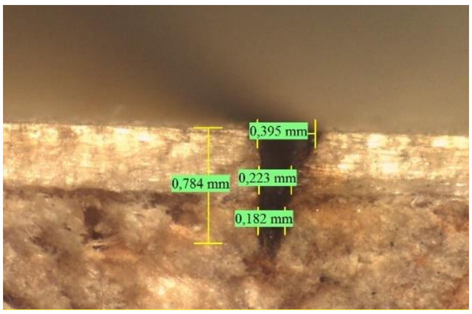

Figure 3. Measuring kerf depth and width using a stereo microscope

The wood roughness test carried out in this research used a Surface Roughness Tester (SJ-201, Mitutoyo, Kawasaki, Japan). The surface roughness test tool is used to test the level of roughness on the surface of plywood that has gone through the cutting process using a CO_2 laser machine. The roughness testing process on plywood is carried out before and after the laser process using various laser power intensities. Measurements are made using a straight line across the surface as an indicator to measure the test object's surface roughness.

Color testing of sengon plywood was performed before and after laser cutting using an Amtast AMT507 colorimeter. Color changes ΔL*, Δa*, Δb*, ΔE* can be calculated with the equation Color change assessment using the CIE-Lab system to measure brightness (L*), red/green chromaticity (a*), yellow/blue chromaticity (b*) and total color change (ΔE*). The total color change (ΔE*) can be calculated using the formula (1) and be interpreted in Table 1.

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2} \qquad (1)$$

Table 1. Color Changes Classification

Classification Value.	Description
0.0<AE*≤0.5	Negligible
0.5<AE*≤1.5	Slightly perceivable
1.5<AE*≤3	Noticeable
3<AE*≤6	Appreciable
6<AE*≤12	Very appreciable
<AE*>12	Totally changed

The laser sample test value is input with the specified combination of laser power and speed in the experimental design that has been created (Figure 4). Next, the data is analyzed using Design Expert software to produce a mathematical model and ANOVA result. The response will then be optimized by determining minimum, maximum, and within specific value criteria to determine the requirements needed for optimizing the variable. The program will produce one recommended optimal value.

Std	Run	Factor 1 A:Laser Power Watt	Factor 2 B:Speed mm/s	Response 1 Width mm	Response 2 Depth mm	Response 3 L*	Response 4 a*	Response 5 b*	Response 6 Delta E	Response 7 Roughness µm
1	2	30	4	0,465	0,681	33	4,5	22,9	55,9028	4,89
5	8	35	6	0,472	1,16	32,2	4,3	22,7	56,8673	4,75
7	7	30	2	0,476	1,06	32,1	4,7	23,5	57,4689	4,54
9	5	40	8	0,467	1,13	32,5	4,2	22,4	57,8272	2,94
3	1	35	8	0,458	1,86	33,5	4	22,5	58,1299	4,87
6	4	40	6	0,481	1,55	32,2	4,7	22,5	58,1528	2,84
2	11	30	6	0,461	0,784	34,5	4,2	22,6	58,2453	4,92
13	12	40	2	0,494	2,31	31,9	4,9	22,8	58,4901	2,77
11	13	35	4	0,484	1,3	31,9	4,7	23,6	58,5721	4,69
10	3	45	8	0,484	1,53	31,5	5,2	22,4	58,8601	2,11
4	6	45	2	0,497	2,73	31,3	5,3	22,7	59,0938	2,04
8	10	50	4	0,478	2,07	30,2	5	22,4	60,1437	1,81
12	9	50	2	0,503	2,67	29,4	5,6	22,7	60,9966	1,64

Figure 4. Sample Test Result

3. Result and Discussion

3.1 Width and Depth of Kerf

Research on sengon plywood (*Paraserianthes falcataria*), after cutting it with different laser powers and speeds, produces various kerf width and depth values. The factors influencing the laser's ability to cut wood are laser power, laser speed, and laser nozzle height [19]. Based on the measurement results, the highest width was obtained at a power of 50 Watt and a speed of 2 mm/s, and the lowest was at 35 Watt and 8 mm/s (Table 2). The highest depth is 50 Watt and 2 mm/s, and the lowest is 30 Watt and 4 mm/s. These results are in accordance with previous research, which shows that the smaller the speed of the fabrication process, the greater the energy pulse given [11].

In Table 2, the kerf's width and depth rise at greater laser power levels, but at higher speeds, they decrease. According to Li et al. [24], with higher laser power and slower cutting speed, the kerf width increases. Higher laser power or a lower laser speed ratio results in a deeper laser engraving depth. Lower laser speed and power ratios result in a greater color difference value, while higher ones cause the etched zone to appear brownish [25]. According to Petru and Lunguleasa [26], the width of the cut decreases with increasing speed. In addition, increasing wood density causes the cutting width to decrease. This aligns with expectations because when laser cutting slowly, more material is burned and ejected, causing the kerf width to increase as more heat is introduced into the sample. Increasing the laser power increases kerf due to increased heat at higher laser powers.

Table 2. Kerf Width and Depth Values

No.	Laser Power (Watt)	Laser Speed (mm/s)	Width (mm)	Depth (mm)
1.	30	2	0.47	1.06
2.	30	4	0.46	0.68
3.	30	6	0.46	0.78
4.	35	4	0.48	1.3
5.	35	6	0.47	1.16
6.	35	8	0.45	1.86
7.	40	2	0.49	2.31
8.	40	6	0.48	1.55
9.	40	8	0.46	1.13
10.	45	2	0.49	2.73
11.	45	8	0.48	1.53
12.	50	2	0.50	2.67
13.	50	4	0.47	2.07

In general, there is a real correlation between power and speed with kerf width. The ANOVA test results show a relationship between power, speed, and kerf width, producing a P value of 0.0006. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted coefficient of determination (adjusted R_2) is 0.7240. The adjusted R_2 value can measure the confidence level in adding independent variables appropriately to increase the model's predictive power [27]. The predicted value of R_2 (coefficient of determination) is 0.5811, and it is stated that the data distribution with the model is reasonable because the difference is less than 0.2. The R_2 value of 0.7240 indicates that the model can describe 72% of the factors that cause changes in kerf width in the plywood-cutting process. The analysis's data precision value (adeq precision) is 10.623, which is a good value because it is greater than 4 and can be used for modeling.

There is a real correlation between power and speed and kerf depth. The results of the ANOVA test show a relationship between power and speed and kerf depth which has a P value of 0.0007. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted R^2 value is 0.8754, and the predicted R^2 value is 0.7267, declared reasonable because the difference is less than 0.2. The R^2 value of 0.8754 shows that the model can describe 87% of the factors that cause changes in kerf depth in the plywood-cutting process. The adeq precision value in the analysis is 12.8046, which is a good value because it is greater than 4 and can be used for modeling. This response produces mathematical modeling (2) and (3).

$$\text{Kerf Width} = 0.489 + (0.0087A) + (-0.0100B) \quad (2)$$

$$\text{Kerf Depth} = 1.63 + (0.1850A) + (-0.4833B) + (-0.3648AB) + (-0.2030A2) + 0.3826B2 \quad (3)$$

A value is laser power (Watt) and B is cutting speed (mm/s).

3.2 Color Changes

Visually, in this study, there was a color change after the burning process with a CO_2 laser machine on sengon plywood. The most obvious change that occurs visually after burning or heat treatment of wood is the darkening of the color or decrease in the brightness level of the wood [28]. According to Petru and Lunguleasa [26], the coloring of the wood surface is influenced by the type or species of wood burned, laser power, laser speed, material thickness, and energy flow density. The resulting color varies from pale brown to black.

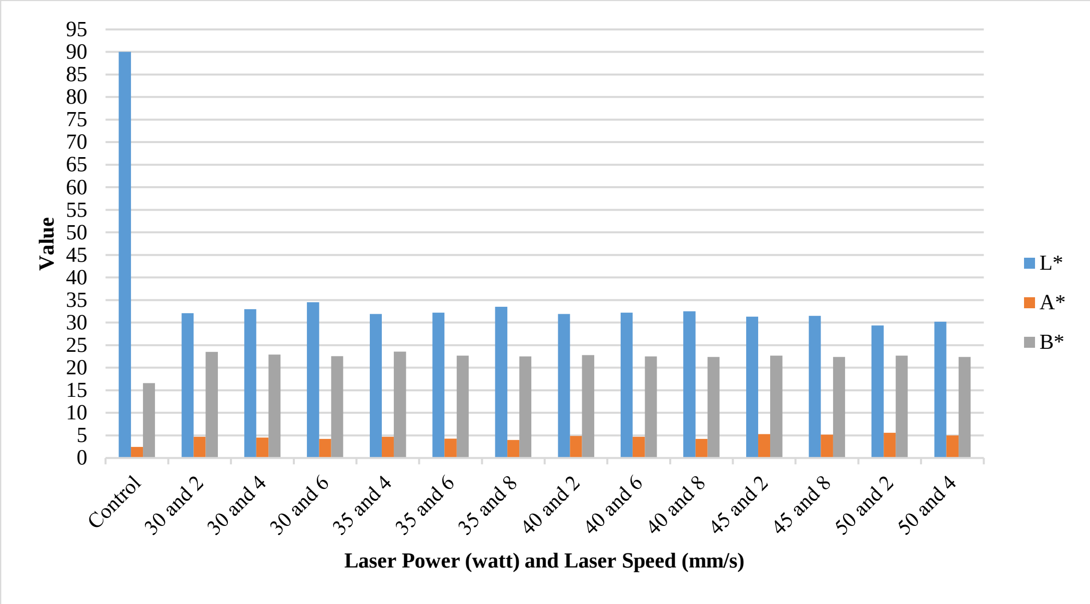

Figure 5. L*. A* and B* Value

The sengon plywood had a brightness value (L*) before lasering with a value of 90.01 (Figure 5). After lasering, the wood board experienced a brightness level (L*) change. The higher laser power resulted in a remarkable decrease in the L* value, while the faster cutting speed slightly reduced the L* value. According to Petru and Lunguluesa [26], by reducing the laser speed, the wood has more time to carbonize itself, thereby increasing the energy released per unit of cutting length.

The ANOVA value on the brightness value shows a P value of <0.0001. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted R^2 value is 0.8100 and the predicted R^2 value is 0.7291, and it is stated that the data distribution with the model is appropriate because the difference is less than 0.2. The R^2 value of 0.7291 shows that the model can describe 72% of the factors that cause changes in brightness values in the plywood-cutting process. The adeq precision value in the analysis is 13.558, which is a good value because it is greater than 4 and can be used for modeling. This response produces the following mathematical modeling (4).

$$\text{Brightness value} = (L^*) = +31.53 + (-1.08A) + 0.6206B \quad (4)$$

A value is laser power (Watt) and B value is cutting speed (mm/s). The 3D graph representation of brightness values can be seen in (Figure 6).

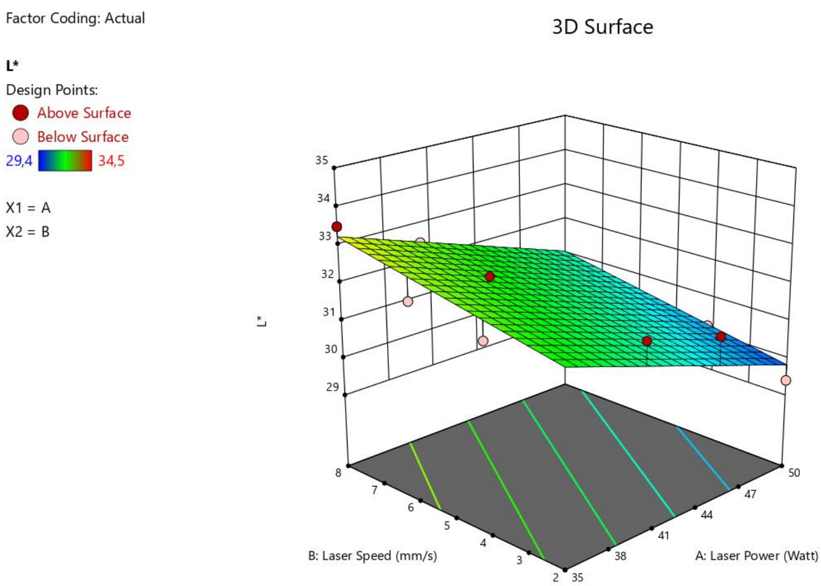

Figure 6. 3D graph of L* value

The sengon plywood had a red/green chromatization (A*) before lasering had a value of 2.45 (Figure 6). After lasering, the wood board experienced a change in red/green chromatization (A*). The higher the laser power, the higher the A* value increases, while the faster the cutting speed, the more the A* value decreases. The A* value for all combinations shows a positive value. This positive A* evaluation result leads to a more reddish color change. On the other hand, negative A* evaluation results lead to a more greenish color change [28].

The ANOVA value on the red/green chromatization value shows a P value of 0.0003. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted R^2 value is 0.7566 and the predicted R^2 value is 0.5950, and it is stated that the data distribution with the model is appropriate because the difference is less than 0.2. The R^2 value of 0.7566 indicates that the model can describe 75% of the factors that cause changes in red/green chromatization values in the plywood cutting process. The adeq precision value in the analysis is 11.5129, which is a good value because it is greater than 4 and can be used for modeling. This response produces the following mathematical modeling (5).

$$\text{Brightness value } (A^*) = 4.86 + 0.3378A + (-0.3018B) \quad (5)$$

A value is laser power (Watt), and B value is cutting speed (mm/s). The 3D graph representation of A* values can be seen in (Figure 7).

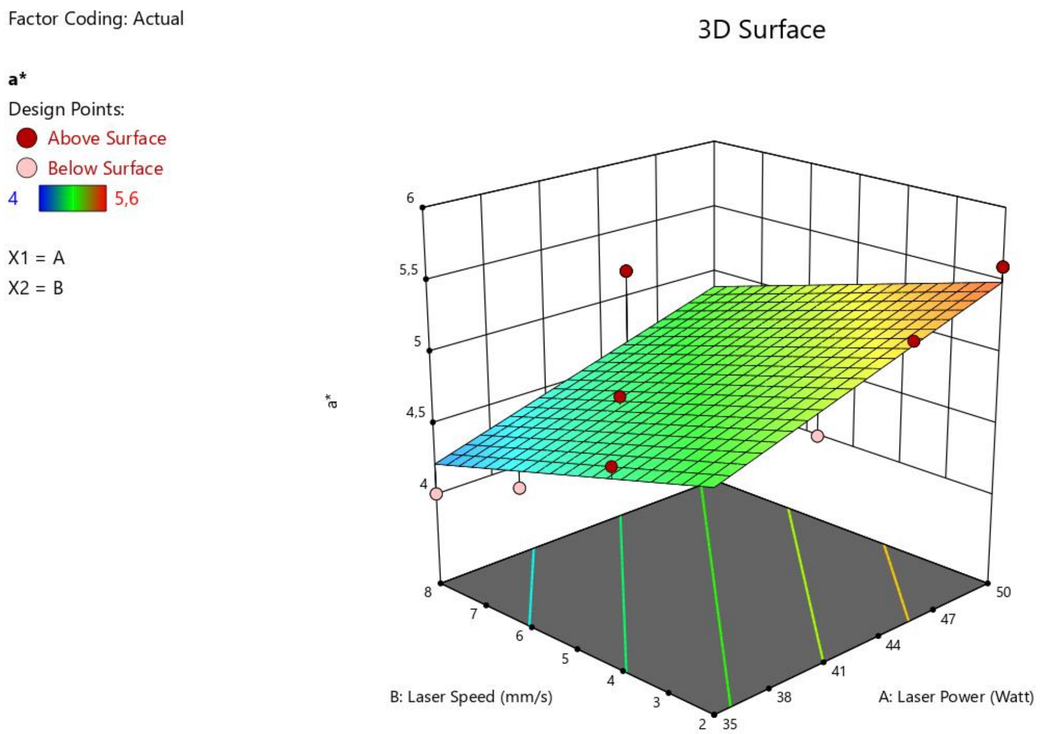

Figure 7. 3D graph of A* value

The yellow/blue chromatization value (B*) has the same tendency as the change in brightness value (A*). The higher the laser power, the higher the B* value increases, while the faster the cutting speed, the more the B* value decreases. The B* value for all combinations shows a positive value. The evaluation results for the B* value show positive results. A positive B* value leads to a more yellowish color change, and a negative value leads to a more bluish color change [29].

The ANOVA value on the B* value shows a P value of 0.0081. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted R^2 value is 0.5421 and the predicted R^2 value is 0.4366, and it is stated that the data distribution with the model is appropriate because the difference is less than 0.2. The R^2 value of 0.5421 indicates that the model can describe 54% of the factors that cause changes in yellow/blue chromatization values in the plywood cutting process. The adeq precision value in the analysis is 8.5466, which is a good value because it is greater than 4 and can be used for modeling. This response produces the following mathematical modeling (6).

$$\text{Yellow/blue chromatization value } (B^*) = 22.61 + (-0.2371A) + (-0.3057B) \quad (6)$$

A value is laser power (Watt), and B value is cutting speed (mm/s). The 3D graph representation of B* values can be seen in (Figure 8).

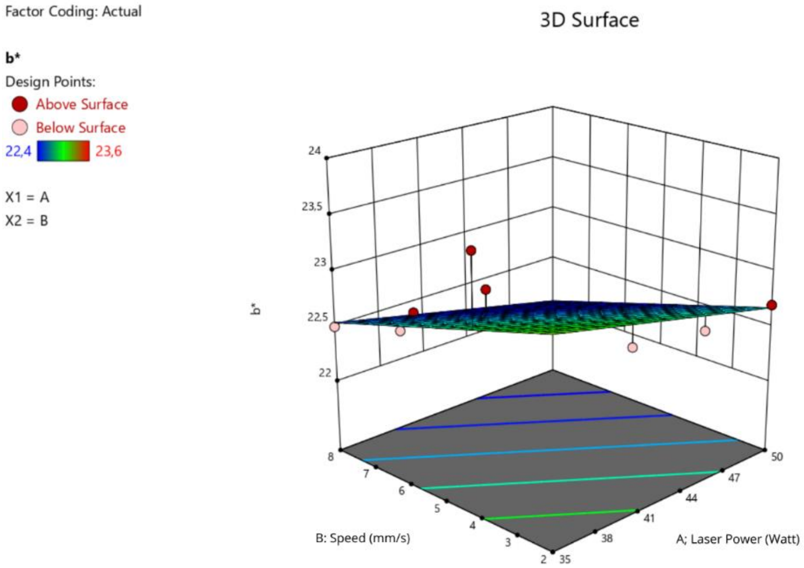

Figure 8. 3D graph of B* value

The overall color change (ΔE*) increases as the laser power increases. The higher the laser power, the more the color change increases. The change in ΔE* decreases as the laser speed increases (Figure 9). The total color change in each treatment is indicated by a value of ΔE*>12. According to Li et al. [30], When the laser power increases, the ΔE* value increases but drops as the laser speed increases. The ΔE* value rises with increased heat penetration into the wood surface and surface exposure duration. As the laser power decreases, the amount of heat transfer per unit surface area of the wood decreases. According to Ding et al. [31], color changes that occur during heat treatment of wood are due to changes in chemical functional groups on the surface of the wood.

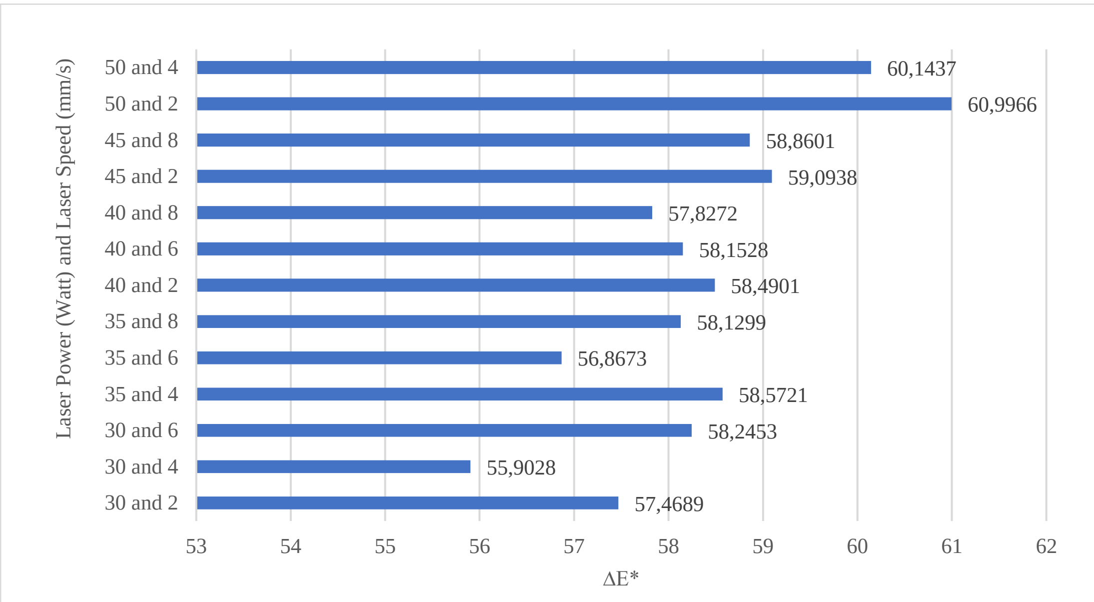

Figure 9. The ΔE* Value

The ANOVA value on the ΔE* value shows a P value of 0.0019. This value is less than 0.05 (real level), meaning the treatment model is declared significant. The resulting adjusted R^2 value is 0.6569 and the predicted R^2 value is 0.5268, and it is stated that the data distribution with the model is appropriate because the difference is less than 0.2. The R^2 value of 0.6569 indicates that the model can describe 65% of the factors that cause changes in the overall color value in the plywood-cutting process. The adeq precision value in the analysis is 9.0016, which is a good value because it is greater than 4 and can be used for modeling. This response produces the following mathematical modeling (7).

$$\text{Total color change } (\Delta E^*) = 58.89 + 1.11A + (-0.2515B) \tag{7}$$

A value is laser power (Watt), and B value is cutting speed (mm/s). The 3D graph representation of ΔE* values can be seen in (Figure 10).

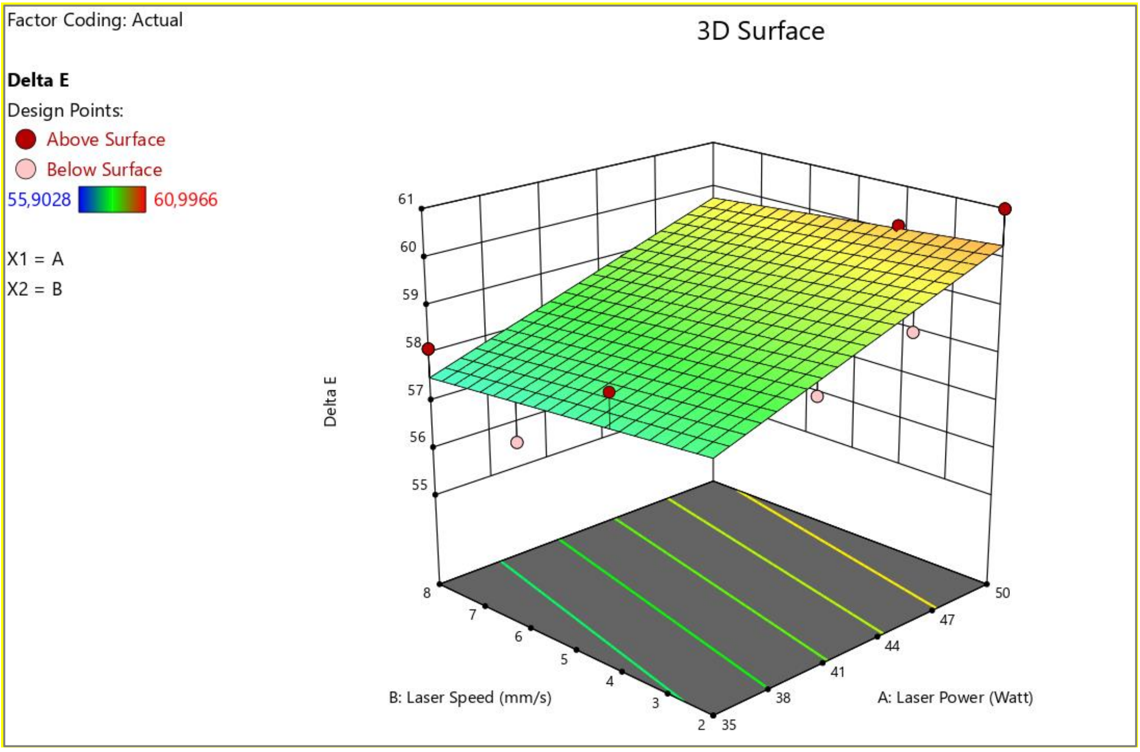

Figure 10. 3D graph of ΔE* value

3.3 Roughness Test

This research produces various values for the width and depth of the kerf. The initial roughness value for sengon plywood is 1.64 μm. The research results show that the highest roughness value is found at 30 Watt laser power with a speed of 6 mm/s and the lowest at 50 Watt with a speed of 2 mm/s (Figure 11). The higher the laser power, the roughness value will decrease, while the faster the cutting speed, the roughness value will increase. When the laser speed increases, the roughness value increases. This is because vibrations during the laser process increase as the speed increases [32]. In the laser process, the roughness of the cutting results decreases with increasing focus point position and laser power [11]. The laser frequency and engraving speed have an inverse relationship with surface roughness, meaning that as the laser frequency increases and the engraving speed decreases, the surface roughness also increases. The surface roughness, measured by the Ra parameter, and the engraving depth on stainless steel decrease with increasing laser speed and decreasing laser power [33,34].

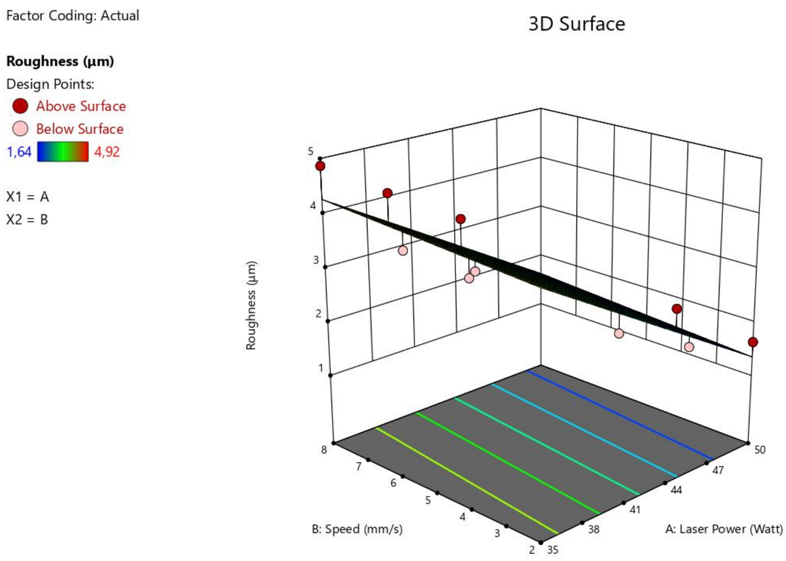

Figure 11. Changes in roughness values in sengon plywood

The ANOVA value on the roughness response shows a P value < 0.0001. This value is less than 0.05, which means the treatment model is declared significant. The resulting adjusted R^2 value is 0.8811, and the predicted R^2 value is 0.8382. This value is declared reasonable because the difference is less than 0.2. The R^2 value of 0.8811 indicates that the model can describe 88% of the factors that cause roughness changes in the plywood-cutting process. The adequate precision value in the analysis is 16.7017. Adequate precision is a measure of error ratio with a ratio greater than 4, indicating that each model can navigate the design space [35]. This response produces the following mathematical modeling (8).

$$\text{Roughness} = 2.82 + (-1.32A) + 0.1428B \tag{8}$$

A value is laser power (Watt), and B value is cutting speed (mm/s).

3.4 Optimization and verification of Laser Process

Optimization results use each optimization variable's target value, upper limit, lower limit, and importance. Minimum target laser power variable in the range of 30 Watt - 50 Watt. The speed variable has a maximum target of 2 mm/s – 8 mm/s. This determination is carried out to obtain optimum values with low laser power and the highest cutting speed. The width response uses a minimum value target, while the depth response uses a maximum value target. This is to get good cutting quality with a small width and maximum depth. The response values L*, A*, B*, and ΔE have a minimum target. Meanwhile, for the roughness response, a minimum target is set to get the lowest roughness value (Table 3), this is done because the cutting quality is good if it has a low roughness value. Because all components have the same amount of importance, the importance value for each variable is set to equal to 3 (+++). The software's optimal process will be determined by the importance value of a response. The significance of a response can be determined on a scale of 1 (+) to 5 (+++++). The higher the importance value, the higher the importance of the response to be achieved in the resulting optimum process [36].

Table 3. Criteria for Determining the Optimum Combination of the Sengon Plywood Cutting Process

Variable	Target	Lower Limit	Upper Limit	Importance
Laser Power	Minimum	30 Watt	50 Watt	3
Laser Speed	Maximum	2 mm/s	8 mm/s	3
Kerf Width	Minimum	0.45 mm	0.50 mm	3
Kerf Depth	Maximum	0.68 mm	2.73 mm	3
L*	Minimum	29.4	34.5	3
A*	Minimum	1.64	4.92	3
B*	Minimum	22.4	23.6	3
Total Color Change	Minimum	55.90	60.99	3
Roughness	Minimum	1.64 µm	4.92 µm	3

Optimization values produce the most optimal combination of laser power and cutting speed at 40 Watt laser power and 8 mm/s speed. The resulting desirability value is 0.623. The optimum point value is determined through the resulting desirability value because the desirability value shows how much the optimum point is met [37]. The expected value is a high value or close to 1. The recommended values are then verified by repeated experiments with the recommended laser power and cutting speed. Verification results must be between a 95% confidence interval (CI) and a 95% prediction interval (PI). Verification values with a combination of 40 Watt laser power and 8 mm/s cutting speed produce a response with values in the range of 95% Confident Interval (CI) and 95% Prediction Interval (PI) (Table 4). This shows that the model can be used and has a good response.

Table 4. Model verification response for the combination of Laser Power and Laser Speed

Response	Prediction	Verification	95% PI low	95% PI high	95% CI low	95%CI high
Width	0.46	0.47	0.45	0.48	0.46	0.47
Depth	1.56	1.63	0.90	2.21	1.23	1.88
L*	32.51	32.64	31.09	33.93	31.89	33.14
A*	4.44	4.27	3.85	5.02	4.18	4.69
B*	22.38	22.37	21.72	23.03	22.09	22.66
ΔE*	58.26	58.41	56.36	60.16	57.43	59.10
Roughness	3.39	3.87	2.25	4.54	2.89	3.90

4. Conclusion

Laser power intensity affects the quality of cutting in sengon plywood. Higher laser power increases the values of width, depth, red/green chromaticity (A*), yellow/blue chromaticity (A*), and total color change (ΔE*) in CO_2 laser cutting. Higher laser power decreases the brightness value (L*) and reduces the roughness value in CO_2 laser cutting. Laser cutting speed influences the quality of cutting in sengon plywood. Higher cutting speed decreases the values of width, depth, red/green chromaticity (A*), yellow/blue chromaticity (B*), and total color change (ΔE*). Conversely, higher cutting speed increases the brightness value (L*) and raises the roughness value in CO_2 laser cutting. The optimization of sengon plywood cutting with a CO_2 laser using the RSM method produced an optimum combination of 40 Watt laser power and a speed of 8 mm/s with a desirability value of 0.623.

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