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Analyzing the Best Cutting Parameter Configurations for Acrylic and Plywood Materials with an 80W CO_2 Laser Engraving and Cutting Machine

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Abstract: CO_2 laser engraving and cutting machines is often popular among creative artists. The machine's ability to form logos, text, drawings, and much more allows artists to produce more complex artwork quickly. CNCKB Industry (CNCKB), a local machine manufacturer, has successfully produced several models of this machine to meet demand. However, research on the ideal parameters based on the workpiece material used and the cutting accuracy produced using this machine is limited. This study aims to identify the ideal parameters for cutting plywood and acrylic of different thicknesses and to determine the accuracy of the cutting results. A powerful 80W CO_2 laser engraving cutting machine was used to conduct this study. Basic circular shapes with diameters of 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm were cut from 3 mm and 5 mm thick plywood and acrylic workpieces. The study findings indicate that the ideal cutting parameters for 3 mm plywood are a laser head speed of 20 mm/s with a laser power of 30%. For 5 mm thick plywood, the ideal cutting parameters are a laser head speed of 25 mm/s with 50% laser power. For acrylic workpieces, the ideal parameters for cutting 5 mm thick material are a laser head speed of 5 mm/s with 50% laser power. Meanwhile, for 3 mm acrylic, the laser head speed is 10 mm/s with a laser power of 30%. The study findings also show that the cutting accuracy for both materials is within a difference range of 97% to 99.7%. In conclusion, the ideal parameters for cutting plywood and acrylic materials depend on the thickness of the workpiece and the type of material used. Additionally, the cutting accuracy using the machine produced by CNCKB is in the range of 97% to 99.7% of the desired dimensional size.

Keywords: Laser, CO_2, Plywood, Acrylic

1. Introduction

Cutting and engraving technology using carbon dioxide (CO_2) laser machines is gaining increasing attention in various industries, particularly in the creative arts and non-metallic material-based product manufacturing sectors. CO2 laser machines offer advantages in terms of precision, processing speed, and the ability to produce complex designs without direct contact between the tool and the workpiece (Zhang et al., 2019). This feature makes it highly suitable for use in producing carved art, product prototypes, signs, logos, lettering, paintings, and decorative elements that require a fine and consistent finish. Additionally, the operation of this machine is cleaner and more environmentally friendly compared to traditional cutting methods such as saws or mechanical grinders (Lee et al., 2020).

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1.1 Problem Statement

The performance of a CO_2 laser machine depends on several critical process parameters such as laser power, laser head movement speed, beam focus, as well as the thickness and type of workpiece material. This parameter must be optimized to ensure fast, clean, and efficient cutting results. Some investigations show that uncontrolled heat effects can cause defects such as edge burning, uneven surfaces, and dimensional tolerances that do not meet specifications (Abdelrahman, & El-Ghazaly, 2022). Therefore, selecting the appropriate parameters for each type of material, especially commonly used materials like plywood and acrylic, is crucial to ensure high cutting quality and reduce material waste.

Various international studies have been conducted regarding CO_2 laser cutting parameters, but studies focusing on locally made machines such as those produced by CNCKB are still limited. This situation creates a significant knowledge gap, particularly in the context of using more affordable and locally designed machines tailored to user needs at the small and medium enterprise level.

1.2 Objective

The main objectives of this study are to:

a) Identify the ideal cutting parameters for plywood and acrylic workpieces of different thicknesses.
b) Evaluate the accuracy of the cutting results obtained using an 80W CO_2 laser machine manufactured by CNCKB.

1.3 Scope

a) CNCKB-made machine with 80W power
b) Testing was conducted on plywood and acrylic materials.

1.4 Importance of the Study

a) Development of more systematic cutting parameter guidelines
b) Supporting the effectiveness of local CNC machines in real-world applications

2. Literature Review

2.1 CO_2 Laser Machine Technology

Cutting and engraving technology using carbon dioxide (CO_2) laser machines is gaining increasing attention in various industries, particularly in the creative arts and non-metallic material-based product manufacturing sectors. CO_2 laser machines offer advantages in terms of accuracy, processing speed, and the ability to produce complex designs without direct contact between the tool and the workpiece (Samsul Hadi, 2020). This feature makes it highly suitable for use in producing carved art, product prototypes, signs, logos, lettering, paintings, and decorative elements that require a fine and consistent finish. Additionally, the operation of this machine is cleaner and more environmentally friendly compared to traditional cutting methods such as saws or mechanical grinders (Giri Halim, 2020).

2.2 CO_2 Laser Cutting Process Parameters

In the CO_2 laser cutting process, the success of producing high-quality and precise cuts heavily depends on selecting the appropriate process parameters. Among the main parameters frequently studied in previous research are laser power (%), laser head movement speed (mm/s), beam focal point position, pulse frequency, as well as the type and thickness of the workpiece material. The combination of these parameters has a direct impact on the heat-affected zone, edge quality, surface finish, and dimensional accuracy of the cut, as stated by Yilbaş (2006).

a) Laser Power

Laser power refers to the amount of energy delivered by the laser beam to the workpiece surface in a unit of time, typically measured in watts (W) or as a percentage of the machine's maximum capacity. In the context of a CO_2 laser machine, this power is determined by the voltage supply to the laser tube, which ionizes a mixture of Carbon Dioxide (CO_2), Nitrogen (N_2), and Helium (He) gasses to emit infrared waves at a wavelength of approximately 10.6 µm (Tahir & Rashid, 2016).

Laser power plays a crucial role in determining cutting depth, process speed, as well as edge quality and cleanliness. Generally, the higher the laser power, the greater the amount of heat energy supplied to the material surface, causing the material to melt or vaporize more quickly. This allows for cutting thicker and heat-resistant materials such as acrylic or medium-density fiberboard (MDF). However, excessive laser power can also lead to problems such as excessive melting, especially in thermoplastic materials like acrylic, edge burning, and carbonization effects on wood-based materials, widening of the Heat Affected Zone (HAZ) which disrupts the material's surface structure, and dimensional changes, particularly if the material is heat-sensitive (Tahir & Rashid, 2016).

Conversely, if the laser power is too low, the beam may not be able to cut the material completely, resulting in an incomplete cut or a rough cut. Therefore, power adjustment needs to be balanced with material thickness, material composition, and cutting speed. For example, a study by Tahir & Rashid (2016) shows that the optimal power for cutting 3mm acrylic is around 30%, while for 5mm thickness, it requires about 50% power from an 80W power source.

Additionally, the actual power delivered to the material is also influenced by the focal distance and the material's absorption rate for the laser wavelength. This means that the nominal power (e.g., 40%) does not necessarily work equally for all materials because the heat absorption rate varies according to the material's optical properties (Suryana & Yusuf, 2019). Therefore, other parameter adjustments such as speed and focus must also be synchronized with the power to achieve the best results.

b) Laser Head Movement

The speed of the laser head's movement, measured in millimeters per second (mm/s), refers to the rate at which the laser beam moves across the surface of the workpiece during the cutting or engraving process. This parameter directly determines the duration of exposure of a material area to the thermal energy generated by the laser beam. Therefore, this speed needs to be carefully synchronized with the laser power and material type to achieve accurate, clean, and consistent cutting results (Tahir & Rashid, 2016).

In principle, lower speeds cause heat energy to concentrate on a point for a longer duration, which can result in deeper cuts and potentially penetrate the material completely. However, it can also increase the risk of defects such as excessive burning or charring, especially on organic materials like plywood, edge melting, and scorching on materials like acrylic, leading to the widening of the heat-affected zone (HAZ) which affects the edge finish (Nugroho & Rachman, 2018).

Conversely, excessive speed can reduce the heat exposure time, leading to incomplete cuts (under-cuts), lines that don't penetrate the workpiece, and increased dimensional inaccuracies due to insufficient energy to fully melt the material. In this context, the optimal speed varies depending on the thickness and properties of the workpiece. For example, a study by Yilbas, Akhtar & Karatas (2012) showed that for 5 mm thick acrylic, the best speed is around 5 mm/s when using 50% laser power, while thinner materials like 3 mm acrylic can be cut well at 10 mm/s with lower power.

Study by Abdelrahman & El-Ghazaly (2022) also found that the laser head speed has a greater impact on surface finish compared to power, especially for polymer materials. This is due to the high heat absorption rate, where a slight change in exposure time can cause significant micro-melting at the edges of the cut. Therefore, speed control needs to be done carefully based on experiments and actual on-site adjustments to ensure consistency and repeatability of the process.

c) Beam focal point position

The laser beam focus refers to the smallest and most concentrated point where the laser beam's energy is focused, typically produced by a focusing lens on the laser cutting machine's optical system. This focal point is a critical component in determining the cutting quality, penetration depth, and heat-affected zone (HAZ) during the cutting process (Yilbas et al., 2017). Physically, the focal length and the position of the focal point play a key role in cutting performance. If the focus is directly above the workpiece surface (positive defocus), the energy is concentrated on the surface, suitable for shallow engraving. When the focus is below the surface (negative defocus), it allows for deeper penetration but can produce less clean-cut edges if not controlled. Focusing directly on the workpiece surface (zero defocus) is often used for cutting thin materials, providing the sharpest and cleanest cuts (Kumar & Dubey, 2020).

The quality of the cut is highly influenced by the size of the focal spot; the smaller the focal spot, the higher the energy density achieved, which allows for finer and more precise cutting. However, a focal point that is too small can cause thermal distortion or faster lens wear. Therefore, adjusting the laser nozzle height and focal distance to the workpiece surface must be done carefully, using either autofocus or manual techniques. According to a study by Meijer (2004), adjusting the focal point position by ±0.5 mm from the optimum point can drastically reduce cutting quality, including increased edge roughness, excessive melting, and reduced dimensional accuracy.

2.3 Workpiece Materials

When utilizing a CO2 laser cutting machine, the selection of workpiece plays a critical role in cutting performance, final quality output, and process parameter requirements. Two materials frequently used in creative arts, modeling, and light industrial applications are plywood and acrylic. Both materials have very different characteristics in terms of physical composition, thermal behavior, and laser energy absorption capability, thus requiring different approaches in setting cutting parameters (Sutton et al., 2019).

a) Plywood

Plywood is a composite material consisting of thin layers of wood (veneer) glued together crosswise using resin adhesive. This cross-laminated structure provides high mechanical strength plywood, but at the same time contributes to internal structural imperfections that can affect laser cutting performance (Saini & Dureja, 2020). The main characteristics of plywood in the context of laser cutting include high flammability due to its cellulose and resin content, which increases the risk of charring and burnt edges when laser power or speed is not optimized, uneven density due to cross-ply layers and moisture variations, leading to inconsistent penetration in deep cuts. High absorption of the CO_2 laser beam (wavelength 10.6 µm) allows for efficient cutting processes to be carried out at moderate power. Cutting thick plywood (>5 mm) requires high laser power and low speed to ensure complete penetration, but with good focus control and ventilation to reduce smoke and soot on the final product (Mokhtar et al., 2022).

b) Acrylic (Polymethyl Methacrylate – PMMA)

Acrylic is a transparent and lightweight thermoplastic polymer, known by the technical name PMMA. It is very popular in laser cutting applications because its smooth and uniform surface allows for precise cutting and clear, shiny edge results after cutting. Additionally, homogeneous density and composition contribute to high consistency in the cutting process. However, acrylic has a low melting point (around 160°C) and is prone to excessive melting and microbubbles if excessive heat energy is applied.

Acrylic absorbs CO_2 laser energy effectively but only in a shallow surface layer, making it more suitable for cutting with moderate power but low speed, especially for thicker materials (>5 mm). Cutting at excessive speeds will result in incomplete or non-penetrating cuts, while excessive power will cause the edges to darken or yellow due to thermal degradation (Kumar et al., 2021).

A study by Lim et al. (2021) showed that for materials like acrylic and plywood, there is an optimal range of parameters that allows for efficient cutting without compromising dimensional accuracy. For example, 3mm thick acrylic shows the best cutting results when cut at a laser power of around 30% and a speed of 10 mm/s, while 5mm thick plywood requires a higher laser power of around 50% and a slower speed to ensure the cut penetrates all layers of the material.

3. Methodology

3.1 Research Design

This study was conducted using a quantitative experimental approach with the aim of identifying the ideal cutting parameters and evaluating the accuracy of cutting results using a locally manufactured CO_2 laser engraving cutting machine from the CNCKB brand, equipped with an 80-Watt laser source. The design of this study involved cutting basic geometric shapes in the form of circles on two types of materials, namely plywood and acrylic, each with two thickness variations of 3 mm and 5 mm.

The two main independent variables in this study are laser power, which is a percentage of the maximum 80W varied within a specific range, and the speed of the laser head movement (mm/s), which is varied to evaluate the effect on cutting results for each material and thickness combination. Meanwhile, the dependent variables are the dimensional accuracy of the cutting results in percentage form, compared to the actual size of the design, and the ability to cut the workpiece.

3.2 Materials and equipment

The main equipment used is a CO_2 laser engraving and cutting machine produced by a local company called CNCKB. The machine used here operates with a fixed laser power of 80W. This machine supports controlling the laser head movement speed and the percentage of output laser power. The materials used are:

- Plywood - 3 mm and 5 mm thickness
- Clear acrylic – 3 mm and 5 mm thickness

The software used for design is RDWorks V8. This software was developed by Shenzhen Ruida Technology to communicate and control all laser, including the RDC6445GZ CO2 laser that are used in the machine developed by CNCKB. This controller supports two-way communication with RDWorks V8 in applications for uploading work files to the controller's memory and downloading parameters from the controller to the computer. Figure 1 shows the machine used, while Figure 2 shows the RDC6445GZ controller used to control the machine's movement.

Fig. 1: CO_2 Laser Engraving and Cutting Machine

Fig. 2: RDC6445GZ Controller

3.3 Parameters

The geometric shapes used for cutting consist of circles with diameters of 10 mm, 20 mm, 30 mm, 40 mm, and 50 mm. Each type of material and thickness is subjected to a different combination of laser power (%) and laser head speed (mm/s) parameters, as shown in Table 1. For each parameter, 5 replicates were performed to ensure data validity.

Table 1: Cutting Parameter

No	Material	Thickness (mm)	Laser Power Range (%)	Laser Head Speed Range (mm/s)
1	Plywood	3	20-50	10-30
2		5		
3	Acrylic	3		
4		5		

3.4 Procedure

The procedure for this study was carried out in several steps, starting with the workpiece being placed on the CO_2 laser engraving and cutting machine. Then, the cutting geometry shapes were drawn and cutting parameters were set using RDWorks V8 software. After that, CO2 laser machine is turned on and the origin point is set using the RDC6445GZ controller. Start the cutting in the RDWorks V8 software and finally, the cutting results are measured and evaluated. Figure 3 shows each step in this study procedure, starting from (a) to (f).

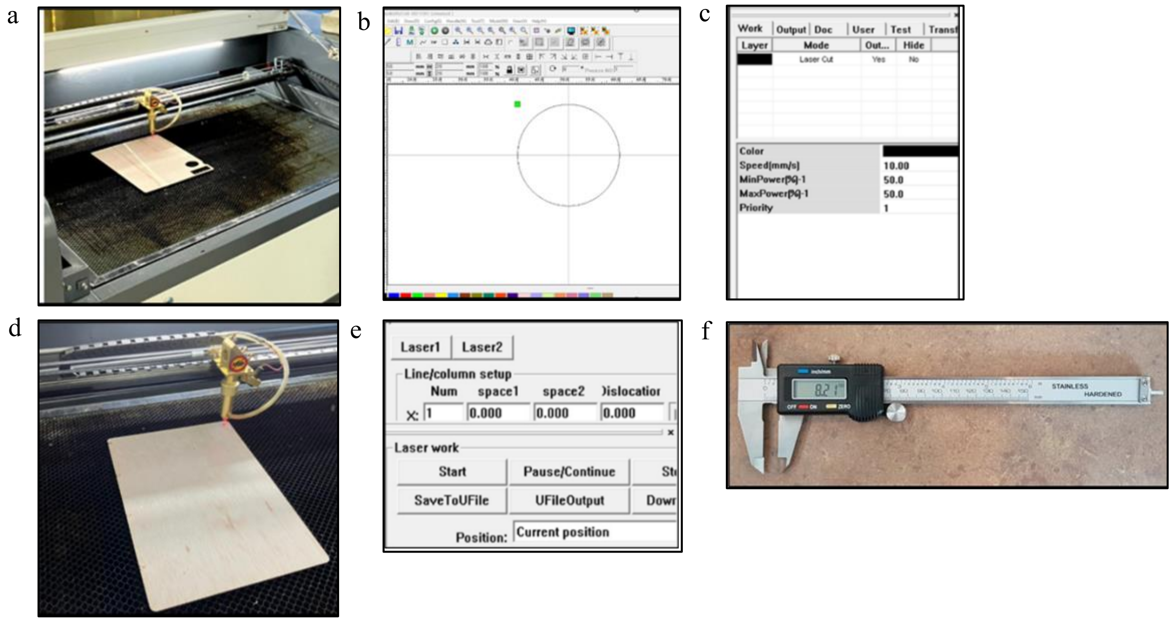

Fig. 3: (a) Workpiece Setting; (b) Cutting Geometry; (c) Cutting Parameter; (d) Origin Setting; (e) Start the Machine; (f) Measurement

3.5 Measurement and Assessment

a) Cutting Ability Study

The cutting results are evaluated using a visual method, which involves observing whether the cutting results are separated from the workpiece plate or not. If the piece is not yet separated from the workpiece plate, the process is repeated until the piece is separated from the workpiece plate. This study was conducted to determine the optimal parameters based on the type of material and the thickness of the workpiece.

b) Cutting Accuracy Study

This study was conducted based on the results of the feasibility study, where the accuracy of each optimal parameter was tested. The dimensions of the cutting results were measured using a vernier caliper with an accuracy of 0.01 mm. The accuracy of the cutting results was evaluated by comparing the actual measurements with the original design dimensions (RDWorks V8), and the accuracy rate was calculated as a percentage. The difference value is determined based on the gap between the actual difference and the specification. Next, the average value of each parameter combination is calculated to provide accurate and stable cutting results. Figure 4 shows the calculation of cutting accuracy.

$$Accuracy = \left(1 - \frac{Design\ Requirement - Actual\ Measurement}{Design\ Requirement}\right) x\ 100$$

Fig. 4: Cutting Accuracy

4. Result

4.1 Cutting Ability Study

Tables 2, 3, 4, and 5 show the results of the cutting capability study based on the type of workpiece material, workpiece thickness, and the predetermined machine parameters. For 3 mm thick plywood, the optimal machine parameters for the cutting process are 30% laser power and 20 mm/s laser head speed. The study findings also indicate that 50% laser power and 25 mm/s laser head speed are the optimal parameters for cutting 5 mm thick plywood. For acrylic workpieces, the optimal parameters for cutting a thickness of 3 mm are 30% laser power and 10 mm/s laser head speed. 5mm thick acrylic, on the other hand, requires 50% laser power and a laser head speed of 5 mm/s to make a clean cut with single cutting process.

Table 2: Study Results on 3 mm Thick Plywood

No	Material	Thickness (mm)	Laser Power (%)	Laser Head Speed (mm/s)	Repetition
1	Plywood	3	50	10	1
2			50	20	1
3			50	30	1
4			40	30	1
5			30	30	2
6			30	20	1
7			30	25	2

Table 3: Study Results on 5 mm Thick Plywood

No	Material	Thickness (mm)	Laser Power (%)	Laser Head Speed (mm/s)	Repetition
1	Plywood	5	50	10	1
2			50	20	1
3			50	30	2
4			50	25	1
5			40	25	2
6			45	25	2

Table 4: Study Results on 3 mm Thick Acrylic

No	Material	Thickness (mm)	Laser Power (%)	Laser Head Speed (mm/s)	Repetition
1	Acrylic	3	50	10	1
2			50	20	2
3			40	10	1
4			30	10	1
5			20	10	2
6			25	10	2

Table 5: Study Results on 5 mm Thick Acrylic

No	Material	Thickness (mm)	Laser Power (%)	Laser Head Speed (mm/s)	Repetition
1	Acrylic	5	50	5	1
2			50	10	2
3			50	15	2
4			45	5	2

4.2 Cutting Accuracy Study

The results of the cutting accuracy study for each optimal parameter identified in the machinability study are shown in Figures 5-8. For 3 mm thick plywood, the accuracy results show a range of 99.2% to 99.6%. Meanwhile, for 5 mm thick plywood, the cutting accuracy range is between 98.2% and 99.6%. Figure 11 shows the results for 3 mm thick acrylic, where the minimum cutting accuracy is 98% and the maximum is 99.7%. The cutting accuracy was recorded in the range of 97-99.7% for the results of the study on the cutting accuracy of 5 mm thick acrylic.

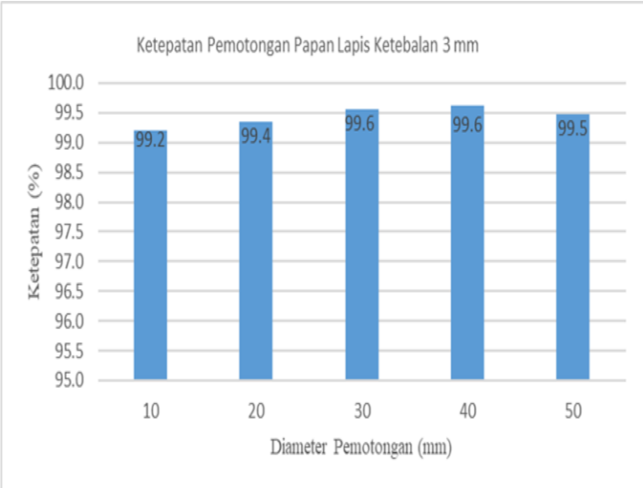

Fig. 5: Accuracy of Cutting 3 mm Thick Plywood

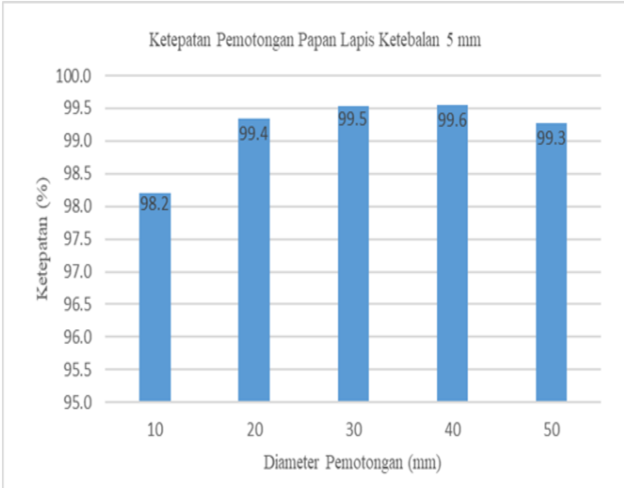

Fig. 6: Accuracy of Cutting 5 mm Thick Plywood

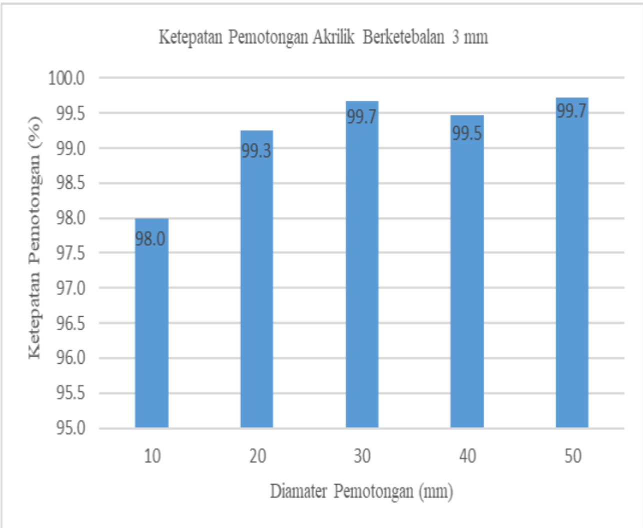

Fig. 7: Accuracy of Cutting 3 mm Thick Acrylic

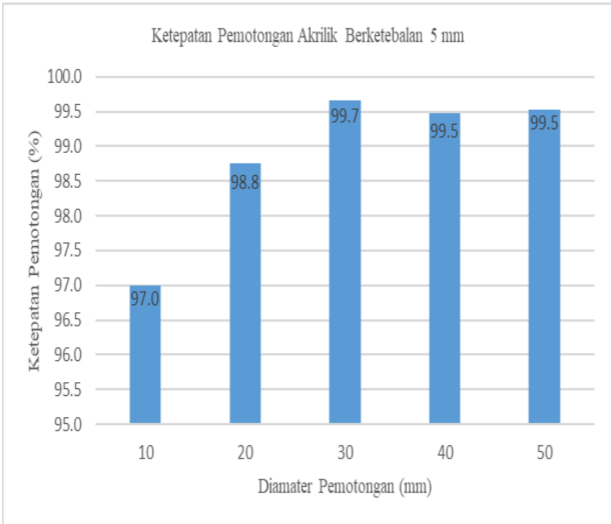

Fig. 8: Accuracy of Cutting 5 mm Thick Acrylic

5. Discussion and Recommendations

5.1 Discussion

The thickness of the workpiece plate plays an important role in the machinability of a shape. Thicker materials require higher laser power or more repetitions to ensure a perfect cut. 5mm thick plywood and acrylic require higher laser power compared to 3mm thickness. Increasing laser power can improve cutting ability, but if it's too high, it can cause burning effects on materials, as reported by Palanisamy, Efzan, & Chin (2023). A slower speed allows the laser beam to dwell in an area for longer, increasing its ability to cut a material. However, slower speeds will increase cutting time and cause the cutting edges to be less neat, as reported by Masoud et al. (2021). The optimum parameters for each type of material and material thickness are very important in ensuring that the cutting process can be carried out neatly and quickly.

The quality of the cutting results also varies depending on the thickness and type of material used. Plywood shows higher cutting accuracy compared to acrylic. This may be due to the plywood structure, which is made of natural wood layers, while acrylic is a thermoplastic polymer material that has soft properties and melts easily when exposed to high heat. In terms of thickness, the study results show that thinner materials produce better cutting accuracy compared to thicker materials. This is likely due to more effective laser energy penetration in thinner materials, which reduces heat spread and edge defects (kerf width).

However, this study has several limitations that need to be considered. The study only focuses on the influence of material thickness and type on cutting accuracy, without considering other factors that also affect cutting results, such as the focal distance of the laser beam, the ventilation system during the cutting process, and the presence of adhesive or resin on the plywood surface, which may influence heat absorption and soot formation. These factors have the potential to directly impact the cutting quality and should be considered in further studies to obtain more comprehensive and accurate results.

5.2 Recommendations

More in-depth studies using various materials and thicknesses are urgently needed to identify the optimal cutting parameters for each material and thickness combination. In addition, further studies on the combined effects of several machine parameters such as laser power, cutting speed, and assist gas flow rate are also important to serve as a reference source for users of locally made CO_2 laser machines. This approach can help machine users, especially artists and small business owners, produce products more neatly, quickly, and consistently.

It is recommended that further studies involve a wider range of parameters and microscopic analysis of the cut results to more comprehensively assess cutability and cutting accuracy. Visual and microscopic observations need to be conducted to understand the profound effects that occur on each type of material cut using this CO_2 laser machine. Items such as burn marks, edge cleanliness, and their relationship to dimensional accuracy need to be detailed to ensure users can optimize operating parameters.

In addition to qualitative observation, a quantitative experimental approach is also recommended to strengthen the study's findings. For example, surface roughness (Ra) measurements can be performed using a surface profilometer to assess the smoothness of the cut edges, while microscopic analysis or Scanning Electron Microscopy (SEM) can be used to identify microstructural changes and heat effects in the cutting area. In addition, dimensional accuracy analysis using a coordinate measuring machine (CMM) or digital microscope can help determine the level of deviation of the actual size from the original design. This combined analysis can provide a comprehensive overview of laser cutting performance and supporting the development of more efficient and competitive local CO_2 laser machines.

6. Conclusion

This study shows that the appropriate combination of laser cutting parameters depends on the thickness and type of material used. For 3 mm thick plywood, the optimal machine parameters are 30% for laser power and 20 mm/s for laser head speed. Meanwhile, for a thickness of 5 mm, a laser power of 50% and a laser head speed of 25 mm/s are the optimal parameters. For acrylic workpieces, the optimal parameters for cutting a thickness of 3 mm are 30% laser power and 10 mm/s laser head speed. Meanwhile, for 5mm thick acrylic, 50% laser power and a laser head speed of 5 mm/s are required. By understanding the relationship between laser power and the speed of the laser head's movement, users can optimize cutting results in terms of time, quality, and cost.

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Conflict of Interest

The authors declare there is no conflict of interest.

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