TEM Journal. Volume 14, Issue 1, pages 933-939, ISSN 2217-8309, DOI: 10.18421/TEM141-82, February 2025.

Taguchi's Method for Optimum Cutting of Acrylic Materials on a 40-Watt CNC Laser Cutting Machine

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Abstract **– Optimization through parameter variation testing is a technique used in manufacturing to produce the best product in machine processing. This study aims to optimise the parameters of the 40-watt CNC *laser cutting* machine, on the laser power, cutting speed, and focusing distance of the lens to find the optimal value in the variation of surface roughness response and geometric accuracy on acrylic materials with a thickness of 3 mm and 5 mm. The research method uses Taguchi as a technique to obtain optimisation values through cutting parameters that have a significant effect on acrylic test pieces. Based on the parameter variance analysis results, the roughness quality of the optimum cutting of acrylic material using a CNC laser cutting machine is influenced by cutting speed, lens focal length, and acrylic thickness. The thicker it is, the lower the cutting speed must be to produce smoother cutting quality. With the knowledge of the optimum value, the acrylic cutting process is more effective and efficient.**

Keywords **– Optimization, CNC laser cutting, Taguchi method.**

DOI: 10.18421/TEM141-82
https://doi.org/10.18421/TEM141-82

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Received: 02 August 2024.
Revised: 08 January 2025.
Accepted: 13 February 2025.
Published: 27 February 2025.

1. Introduction

The advancement of cutting-edge technology in the manufacturing industry shows rapid progress. [1]. The application for large industries has been adopted for micro-level business actors by utilizing an automatic work system on numerical control-based metal cutting machines into non-metal cutting technology. [2]. The conventional cutting work system has been transformed into an automatic work system with high precision and an efficient cutting process. [3]. Non-metal manufacturing business actors use this trend to utilize acrylic cutting as part of handicraft products [4]—Laser cutting machines are used as a medium for cutting.

Non-metallic cutting, especially acrylic, requires attention to the type of acrylic used. [5]. There are two types of acrylics, namely casting and extrusion acrylic. Casting acrylic tends to be frozen white when engraving. [6], while extruded acrylic can be used for laser cutting machines through a flame brander but does not melt the cutting-edge parts [7]. Acrylic belongs to the group of acrylonitrile polymers. [8]. This material is used as a substitute for glass because of its transparent and flexible shape. In chemical elements, acrylic can be in the form of polymathic methacrylate (PMMA) with the property of being a thermoplastic that is elastic or flexible compared to glass [9], [10]. This causes acrylic to be in great demand as a substitute for glass and plate components.

Cutting techniques on acrylic using laser cutting are influenced by several essential variables [11]. These variables include the cutting parameters, acrylic thickness, type, and laser-cutting machine power [12]. The four variables are determined with the right settings to produce effective and efficient cutting [13].

Laser-cutting machines evolved using lasers CO2 is a technology that uses a gas laser sourced from carbon dioxide (CO2) gas and then stimulated using an electrical process to cut the material [14].

CO2 lasers work by directing a high-power laser to cut or engrave materials. Light amplification by radiation stimulation is the formation of strengthening the light from the stimulated radiation emission. The interaction between light and matter has three principles: absorption, spontaneous emission and stimulated emission.

The problem found by CNC laser cutting operators is that it is difficult to determine the selection of good parameters [13], so the cut results vary between good and bad. In certain cases, the inconsistency of cut quality is seen from CNC laser cutting with a power of 40 watts [15]. In such cases, the determination of laser cutting parameters is indispensable. The operator should understand the Taguchi method as a comparative method [16] in finding the right formulation in the laser cutting process. Taguchi method provides a preventive step for determining roughness [16], [17] in designing the optimal parameters of the experimentation process of cutting parameters on a 40-watt CNC laser cutting machine. This process is part of the research that needs to be disclosed to obtain authentic data on selecting the right parameters.

The mechanical properties of the highly heat-sensitive acrylic can be considered by understanding the precise cutting process on a 40-watt CNC laser cutting machine. This is a consideration so that the implementation of cutting does not make the acrylic quickly melt [18] at the residual stress of heating and warping. Techniques and strategies in cutting are an integral part of the research in this result.

2. Research Method

This research used a CNC laser cutting machine to find the optimum cutting parameters for acrylic material. The following sections will prove this research through comprehensive and scientific testing.

2.1. Research Concept

This experimental research uses the Taguchi method approach. The Taguchi method developed by Genichi Taguchi has the potential to make it easier to improve the quality of manufacturing or engineering production results [19], [20]. Referring to this definition, Taguchi's method will measure the experimentation of applying a 40-watt CNC laser cutting machine in acrylic cutting. The main goal of this method is to find a combination of cutting parameter factors that provide optimal results using a minimal number of experiments. Taguchi's method combines the concepts of grouping generalized unification of contributions and impacts to obtain accurate and efficient results [21]. This method makes it possible to identify important factors that affect performance, reduce the number of experiments required, and provide a better understanding of the relationships between these factors.

2.2. Research Subject and Setting

The research was conducted at the Pneumatic and Hydraulic Laboratory, Yogyakarta State University. The laboratory is used because testing and measurement support the research process. This study's subject is acrylic, which is cut into several variations in the type of composition and thickness of the material. The research target is the cutting results of a 40-watt CNC laser cutting machine.

2.3. Data Collection Design

The data collection design in this study uses an observation approach based on the results of experimentation, which is calculated from the variation in the use of speed, the use of laser power, and the use of the focal distance of the lens. The optimal value is reviewed from the surface roughness of the cut result and the geometry of the size of the cut result.

The replication stage is needed to obtain higher observation accuracy, reduce error rates, and obtain an estimated price for errors. These stages are used to test the roughness on the surface of the acrylic piece with the help of a roughness tester. The measuring tool determines the roughness value of the cutting variation on acrylic. Mechanical measuring instruments such as callipers and micrometres determine the size and cutting rate of a 40-watt CNC laser cutting machine.

2.4. Data Analysis Techniques

The data analysis stage includes data collection, arrangement, calculation and presentation of data in a certain display per the selected design. In addition, statistical data calculation and testing are carried out on the experimental data. The technique used is the analysis of response variance by describing all the variances of the parts studied and the S/N (Signal to Noise) ratio used to select factors that have contributed to reducing the variation of a response (Equation1) [22], and how to measure the average flatness of the cut (Equation 2).

$$S/N = -10*\log(\Sigma(1/Y2)/n) \quad (1)$$

$$Ra = \frac{\sum x}{n} \quad (2)$$

Confirmation experiments are the final step in the optimization process. This experiment was carried out by looking at the results of the analysis calculation from the previous stage, where the value of the S/N Ratio calculation was seen. The confirmation experiment aims to validate the conclusions drawn at the analysis stage and match the predicted results with the actual results.

3. Results

This study aims to find the optimal use of power, speed and focusing distance when cutting using CNC laser CO2, which is applied to several measurements of specimen thickness. This Taguchi method experiment was carried out to check the cutting results, which were reviewed based on the roughness of the object's surface, such as power, cutting speed, and the focusing distance of the lens when cutting. The experiment was carried out according to the predetermined parameter data with three replications to find consistent cutting results and overcome the noise during the cutting process using CNC laser cutting. Cutting and processing data is carried out in the following sequence of steps.

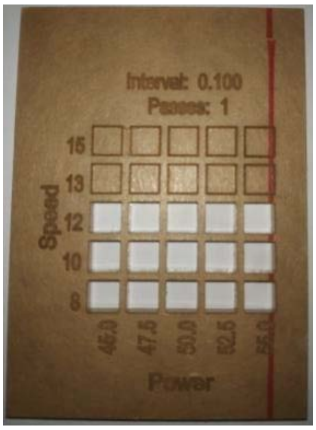
(a)

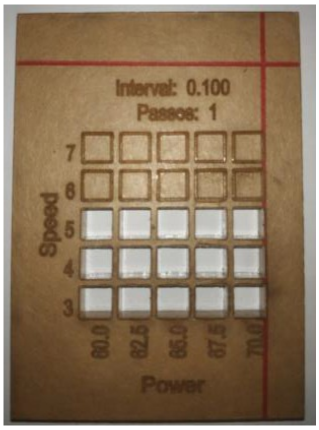
(b)

Figure 1. Acrylic cut result: (a) 3 mm; (b) 5 mm

3.1. Measurement of Cut Parameters

Measurements refer to the cutting parameters for acrylic with a 3- and 5-mm thickness. The cutting results are arranged in rows, as seen in Figure 1 and Figure 2.





(a) *(b)*

Figure 2. Acrylic cutter yield thickness: (a) 3 mm; (b) 5 mm

The cutting process is divided into 3 mm and 5 mm thicknesses. This comparison shows the difference in parameters in the electrical power used, the cutting speed and the lens focus gap produced, as presented in Figure 2. The tabulating of data variants for ten cuts for two thickness variants is presented in Table 1 below.

Table 1. Cutting parameters at acrylic thickness of 3 mm and 5 mm

Samp	Power (W)		Speed (m/s)		Gap (mm)	
	3 mm	5 mm	3 mm	5 mm	3 mm	5 mm
1	45	60	8	3	8	8
2	45	60	10	4	9	9
3	45	60	12	5	10	10
4	50	65	8	3	8	8
5	50	65	10	4	9	9
6	50	65	12	5	10	10
7	55	70	8	3	8	8
8	55	70	10	4	9	9
9	55	70	12	5	10	10

Based on Table 1 above, it can be seen that there is a significant difference in how power and speed are used. The thicker the acrylic, the greater the need for electrical power, but inversely proportional to the speed. The thicker it is, the slower the speed used. The test does not apply to the cut results where the gaps produced for different thicknesses have the same results even though there are differences in power and speed.

3.2. Surface Roughness Measurement

Surface roughness measurements were made using the Surface Roughness Test Surf Corder SE1700 tool. Measurements were performed five times for each variation of specimens adjusted to the data. The results of the fifth measurement of the cuts are as follows.

Table 2. Results of measuring the roughness of acrylic cutting with the Surface Roughness Tester

Test Sample	Surface roughness value
Ra1	0,008947 mm
Ra2	0,007118 mm
Ra3	0,004429 mm
Ra4	0,007078 mm
Ra5	0,003705 mm
Sx	0,006811 mm

Based on the results of the roughness test in Table 2, it can be explained that the average roughness of 5 mm acrylic cutting using a 40-watt CNC laser cutting machine is obtained in the range of 6.811 µm. This value is still relatively good compared to manual cutting or other tools delivered through the conduction process.

3.3. Ratio S/N

One of the efforts to test how much surface roughness response based on cutting parameters can be done by calculating the S/N (Signal to Noise Ratio) ratio value. The calculation refers to the cut's quality characteristics and surface roughness response.

The optimum level value was obtained from the calculation of the S/N Ratio, which varied in the cutting parameters between acrylic with a thickness of 3 mm and 5 mm.

Table 3. Signal to noise ratio smaller difference is better for 3 mm and 5 mm acrylic thickness

Level	Power (W)		Cutting Speed (m/s)		Lens Focal Distance (mm)	
	3 mm	5 mm	3 mm	5 mm	3 mm	5 mm
1	4.682	4.066	5.063	3.931	4.982	4.113
2	3.497	3.474	4.355	4.542	4.045	3.900
3	4.922	4.283	3.683	3.349	4.074	3.809

Table 3 explains that acrylic thickness can affect the decrease in power, cutting speed, and lens focal distance. For 3 mm acrylic specimens, the most influential surface roughness response is power at level 1, cutting speed at level 2 and lens focal distance at level 3. For 5 mm acrylic specimens, the most influential surface roughness response is power at level 2, cutting speed at level 1 and lens focal distance at level 3. The improved cut parameters affect the quality of roughness, which tends to decrease. This can be seen with the S/N value indicating a significant decrease for a thickness of 3 mm to 5 mm. The decrease is not a decrease in the cut parameters but a decrease in the roughness rate due to the increased cut parameters. Visually, the effect of S/N in the response of roughness to the cut parameter is presented in Figure 3 and Figure 4.

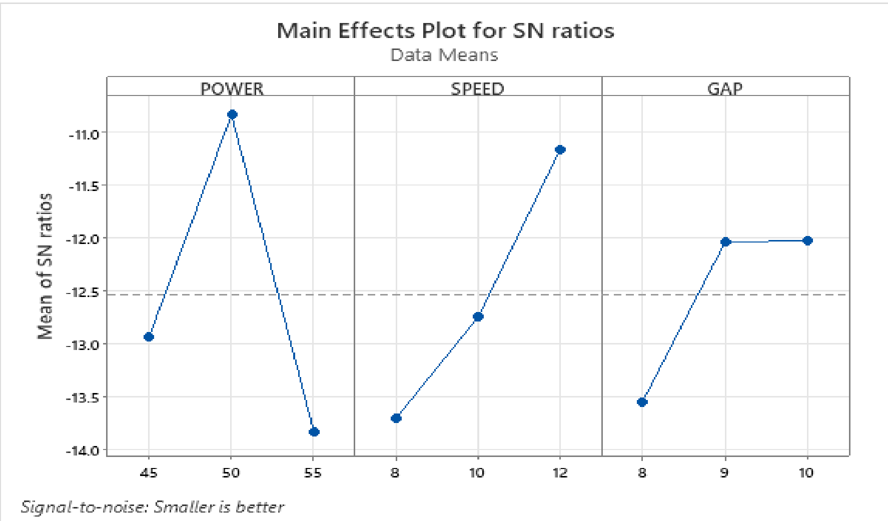


Figure 3. The main effect Plot for the SN ratio smaller is better acrylics 3 mm

Based on Table 3 and Figure 3, the effect of the surface roughness response on a 3 mm acrylic specimen is most optimal if the power used is 50%, the cutting speed is 12 mm/s, and the lens focal distance is 10 mm.

These results recommend using CNC laser cutting machines with cuts for acrylics up to 3 mm thick.

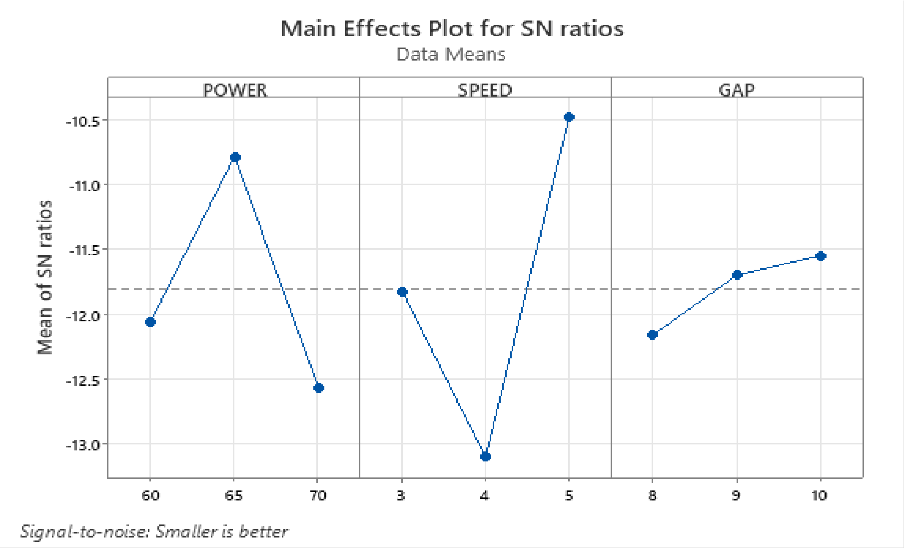


Figure 4. The main effect plot for the SN ratio smaller is better acrylics 5 mm

Based on Table 3 and Figure 4, the effect of the surface roughness response on a 5 mm acrylic specimen is most optimal if the power used is 65%, the cutting speed is 5 mm/s, and the lens focal distance is 10 mm. The result is a thickness of 3 mm, where the lenses' focal distance is 10 mm. The results of this analysis can be a recommendation for using CNC laser cutting machines for acrylic cutting with a thickness of 5 mm.

3.4. Confirmation Experiment

Confirmation experiments are the last step that must be carried out in research on process optimization. This experiment was carried out by looking at the results of the analysis calculation from the previous stage, where the value of the S/N Ratio calculation was seen. Then factual confirmation is carried out by looking at the results of specimen cutting reviewed from the accuracy of the geometric size, where the accuracy value is taken from the percentage of the size between the design size and the factual size on the specimen object of each acrylic thickness. The geometry's accuracy level can be seen in Table 4 and Table 5 of the following calculation results.

Table 4. Geometric accuracy of acrylic specimens 3 mm

Samp.	Panjang	Wide	Average	Accuracy
1	69.92	15	42.46	99.906%
2	69.99	14.87	42.43	99.835%
3	69.97	14.86	42.415	99.800%
4	69.94	14.8	42.37	99.694%
5	69.93	14.88	42.405	99.776%
6	70	14.93	42.465	99.918%
7	69.9	14.85	42.375	99.706%
8	69.84	14.88	42.36	99.671%
9	70.01	14.85	42.43	99.835%

Table 5. Accuracy of acrylic specimen geometry 5 mm

Samp.	Panjang	Wide	Average	Accuracy
1	69.76	14.82	42.29	99.506%
2	69.81	14.93	42.37	99.694%
3	69.93	14.88	42.405	99.776%
4	69.7	14.79	42.245	99.400%
5	69.83	14.79	42.31	99.553%
6	69.96	15.02	42.49	99.976%
7	69.86	14.8	42.33	99.600%
8	69.84	14.79	42.315	99.565%
9	69.9	14.8	42.35	99.647%

The tabulation of the percentage of geometric measurements in Table 4 and Table 5 show that the measurement results are not more than 0.5%. These results indicate that there is no significant deviation from the design size. For the surface roughness results, the average roughness value was 0.80 μm – 6.3 μm. In addition, the experimental data confirming the optimal data produced on a 3 mm acrylic specimen was 99.918%, and the optimal data produced on a 5 mm acrylic specimen was 99.976%.

4. Discussion

The cutting parameters for acrylic require correct precision to increase production efficiency. This study has proven the optimum data in acrylic at 3 mm and 5 mm thickness in terms of power, cutting speed, and focal distance of the lens used. These three aspects have been recommended for the cutting variable [11].

The 40-watt CNC laser cutting machine has a light working capacity for the MSME scale. This business is widely found in Indonesia, especially in helping customers cut and shape acrylic.

Data identified by the Taguchi method [23], [24] can be an option for business runners who have a 40 watt CNC laser cutting machine for cutting acrylics, for example, a thickness of 3 mm by setting a power of up to 50%, a cutting speed of 12 mm/s, and a lens focal distance of 10 mm. The test results for ten samples can be used as a reference in optimizing the use of the 40-watt CNC laser cutting machine.

This cutting test is focused on the optimal parameters. Of course, this still requires a more comprehensive study by referring to other factors. Visually, acrylic almost resembles glass but has a differentiator with elastic properties [9]. The properties of acrylic that are not easily broken, lightweight, easy to cut, file, and paint, make acrylic a substitute for glass materials [12], [25]. These malleable properties are combined with thermal bending techniques. The development of acrylic materials has made their functions and uses more varied. The material properties of acrylic can affect the quality and speed of laser cutting. Conditions like this need to be considered in research development so that the optimization of 40-watt CNC laser cutting machines is increasingly diverse in value and dosage of use.

5. Conclusion

Based on the comprehensive research and assessment results, several research conclusions were obtained that provided recommendations. The optimization of the 40-watt CNC laser cutting machine parameters was carried out using the Taguchi method by calculating the S/N ratio to research the noise factors that arise. The calculation for the S/N ratio and geometric accuracy on the 3 mm acrylic specimen with surface roughness response was found to be the optimal value for the power parameters of 50%, cutting speed of 12 mm/s, lens focal distance of 10 mm, and geometric accuracy of 99.918%. For acrylic specimens with a 5 mm surface roughness response, optimal values were found in power parameters of 65%, cutting speed of 5 mm/s, lens focal distance of 10 mm, and geometric accuracy of 99.976%. The data from this research can be a reference for operators of 40-watt CNC laser cutting machines when processing acrylic cutting with 3 mm and 5 mm thicknesses.

The results of this study prove that when it produces smoother acrylic cuts, the cutting speed needs to be reduced. Conversely, the cutting speed can be increased if the thickness is smaller. It is necessary for CNC laser cutting machine operators to pay attention to this so that the cutting process can produce better quality with higher process efficiency.

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