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Effect of Working Table and Bandsaw Speed on the VZ 400-SA Machine in Obtaining the Optimal Width of Steel Plate

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A B S T R A C T

The size of the material test specimen determines the accuracy of the material characteristics. This research was conducted to obtain the optimal tensile test specimen size by optimizing the cut parameters on the VZ-400 SA cutting machine. The material used is SNI 07-2054-2007 standard angled steel with a thickness of 5 mm. Optimization of machine parameters was carried out using the Taguchi method to measure the effect of work table speed (mm/s) and saw blade speed (m/min) on the response to the width of the rectangular cutting product. Cut width limit between 34-36 mm. Data was collected by conducting experiments 9 times with 3 replications. The results showed that the factor that most influenced the size of the width of the cut was the speed of the work table with a contribution of 86.49%, while the speed of the saw blade was 1.64% with an error of 11.87%. The optimal size of the test specimen is produced from the table speed parameter of 2 mm/s and the saw cutting speed of 90 m/min. Cutting validation was conducted in triplicate, and the result showed an average plate width of 34.7 mm with an error of 0.02.

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1. INTRODUCTION

The steel products manufactured by industry are required to comply with the specifications as labelled on the products. each product must undergo material mechanical tests to obtain product specifications that describe accurate characteristics. These characteristics are useful for determining the conditions of use of the product so that it can be relied upon according to its function. Accurate product specifications are very important for application of the materials when it is used appropriate, functions properly. Construction and manufacturing sectors are common users of steel products that require the assurance of safe and reliable products (Hartati, 2018).

The Indonesian Standardization Body (BSN) regulates the standardization of products marketed in Indonesia (Herjanto, 2011). BSN is a governmental body that protect consumers through issuing technical regulations in the form of Indonesian National Standards or SNI (Kusumah & Andriawan, 2019). In our case, the steel manufacturing company produces the SNI 07-2054-2007 angle bar steel products with the thickness of 4 mm - 12 mm. This product can be found, among others, in machinery (Kriswanto et al., 2021).

In order to test the material, the test specimens need to be prepared according to the standards used. The mechanical characteristics of the SNI 07-2054-2007 products could employ a tensile test procedure such as ASTM E8 standard. For this purpose, the SNI 07-2054-2007 product which is in the form of an L-shaped profile must be cut first. The tensile test specimens are prepared in two stages: (1) cutting the angle bar steel into the rectangular form, and followed by (2) making the gauge part of the test specimens from the rectangular plates using a milling machine.

In the first phase, the rectangular steel plates are cut by using a bandsaw cutting machine VZ 400-SA (YS Koki Ltd., Japan) with the size of 363 mm (length) and 35±1 mm (width), followed by a milling process to form the specimen gauge. The final gauge width is 31 mm. The first procedure is critical for the second process, i.e.: the milling process. The rectangular steel plates should be cut 3 – 4 mm surpassed the specimen's nominal width size of 31 mm, or between 34 - 36 mm. The length of the rectangular steel is kept as same as prescribed in the testing standard. The common problem occurred during the first stage is that the width size is out of the 34 – 36 mm. In a case that the width size is less than 34 mm, it is not usable in the milling process to form the exact gauge width. In the other case that the width size greater than 36 mm, the milling process will take in a longer time and it will result in too many scraps. In the current situation, the operators are usually use the cutting machine without a certain standard procedure which result in more inaccurate size of the rectangular steel plates. This phenomenon inevitably results in suboptimal cutting outcomes and damage to cutting machine components, including rapidly worn blade edges and bending during the cutting process, leading to inaccurate cutting results. Consequently, this research holds significance in determining optimal cutting machine settings on the VZ-400 SA cutting machine for the preparation of test specimens of steel material.

This study aims to optimize the cutting parameters setting for the cutting machine used in producing the rectangular steel plates for the preparation of the tensile test specimens. As described in the previous studies that the Taguchi method was useful in obtaining a better optimization value on a factor composition and to plan product and process designs to match predetermined targets (Genichi et al., 2005).

2. LITERATURE REVIEW

A number of studies have been carried out to find optimal machine setting parameters. The studies used varied optimization methods as well based on the design of experiment (DoE) that were applied in obtaining optimal operating results. Chetan et al. (2019) selected the optimal parameters of the cutting operation of a lathe machine. The effects of spindle speed, depth of cutting and feed were evaluated on their influence on acoustic, tool wear and vision signals. The study employed L27 array of Taguchi method. The optimal parameter settings for lowest acoustic, tool wear, and vision signals yields are 450 rpm of spindle speed, 0.07 mm/rev feed depth and 0.2 mm of cutting depth. The results found that method has measured optimal parameters for the cutting operation of the lathe machine.

Vu et al. (2019) evaluated the cutting parameters effects of a grinding machine. The study was focused in obtaining efficient process of grinding while enhancing parts quality. The study has successfully found the optimal operation parameters of the feed rate, cutting depth and the wheel speed by employing Taguchi method. Their findings showed that the cutting depth influenced the most on the grinding time, followed by the feed rate. The wheel speed parameter was the least influencing factor that affected the grinding time. The optimal cutting parameters were set by 0.03 mm of the cutting depth, 5000 m/min of the wheel speed and 3500 mm/min of the feed rate of. Those factors were the most optimal parameters setting for efficient grinding time. Modi et al. (2019) study the effects of lathe machine parameters, consists of three independent parameters, i.e.: speed, cut-feed and cut-depth on the rate of material removal. The Taguchi method was used to find the influencing parameters on metal removal rate. The result shows that the material removal rate increases with increase the speed parameter (rpm).

In the Gao's study (2022), fused deposition modeling (FDM) 3D printer was optimized its operating parameters. The study compared two optimization approaches: Taguchi method and Response Surface Method (RSM). The study evaluated parameters setting consist of layer thickness, extrusion temperature, print speed and raster width. The factors were set in three levels. The measured responses were tensile and compressive strength. Although both methods showed slightly different results, but successfully optimized the parameters setting of FDM 3D printer process.

Borra and Neigapula (2023) have applied Taguchi method to optimize the processing parameters of a stereolithography 3D printer. L-9 orthogonal array and ANOVA were performed in Minitab software to determine the most influencing factors of the 3D printing process. A regression equation was proposed to predict the best potential outcomes for the given set of parameters and levels. The results found that exposure time played an important role in most of the measurements.

Another study conducted by Ozcelik et al.(2012) investigated traverse velocity, nozzle diameter, pump pressure and standoff distance parameters of water jet cutting. In their work, various operational parameters, including. The cut depth and width were the responses variables that determine the efficient cutting process. The results of the study found that ideal cutting circumstances were determined by 5 mm for the standoff distance, 0.8 mm diameter of the pump nozzle, 90 MPa of the pump pressure, and 4 m/min for the traverse velocity. Those parameters setting resulted a cutting depth of 7.694 mm and 1.986 mm of cutting width.

The previous research studies reported different machine parameters setting to be optimized. Similar methods have been employed in experiment design of Taguchi method and Response Surface Method. These methods are proved to be effective to find the influencing factors on the response variable and the interaction among the operative parameters. The selection of the Taguchi method was driven by its well-established effectiveness in optimizing settings and identifying significant factors in experimental investigations (Gao, Xu, & Xu, 2022). Taguchi experiments utilize orthogonal arrays, facilitating the simultaneous study of multiple factors with a reduced number of experimental runs (Zhang et al., 2021). This proves advantageous in situations where resources are constrained or experimentation involves substantial costs. Furthermore, the Taguchi method is known for its simplicity and efficiency, requiring fewer experimental runs compared to the Response Surface Method (Mohd et al., 2020).

The literature review also reveals that several studies have investigated the optimization of machine setting parameters using various methods. While the studies by Chetan et al. (2019), Vu et al. (2019), Modi et al. (2019), Gao (2022), and Borra and Neigapula (2023) focused on different machining processes and optimization techniques, there is a research gap in the specific application of the Taguchi method to optimize the cutting parameters of a bandsaw cutting machine. The existing gap suggests a need for further exploration of the Taguchi method's application in optimizing cutting parameters for enhanced efficiency and precision in bandsaw cutting machines. This study aims to address this gap by systematically applying the Taguchi method to optimize the cutting parameters of a bandsaw cutting machine and contribute valuable insights to the existing body of knowledge in machining optimization.

3. RESEARCH METHOD

3.1 Materials

The material employed in this study is the SNI 07-2054-2007 angle bar steel profile. The material has dimension of . Vertical bandsaw cutting machine VZ 400 SA (YS Koki Ltd., Japan) was used to produce the rectangular steel plates cut from the bar angle steel profile SNI 07-2054-2007. The cutting machine uses an Eberle 13X0.9X6/10X3340 cutting blade (Eberle, Germany). The technical specifications of the bandsaw cutting machine are shown in Table 1.

Table 1. Technical specifications of the cutting machine

Descriptions	Specifications
Cutting size	400 mm (width), 300 mm (height)
Grip circumference	3340 mm
Electricity	3 Phase 200V 1.5kW
Weight	400 Kg

The machine is operated by setting up the following parameters: (1) working table speed, and (2) blade rotation speed. The operating interface of the machine is shown in Figure **1**.

Figure 1. The interface of the cutting machine

Digital calliper was used to confirm the measurement results as displayed in the cutting machine after the experiment was performed. The material used for the specimens' preparation is the SNI 07-2054-2007 angle bar steel products with the thickness of 5 mm.

3.2 Experiment Procedure

The SNI 07-2054-2007 angle bar steel profile is clamped on the working table and cut to produce a rectangular plate with the width dimension of 34 – 36 mm. The plates are prepared to form the tensile test specimens according to ASTM E8 standard. As the rectangular plates are produced, it is further processed to form gauge indentation by milling process. In order to obtain correct dimension of the gauge, the rectangular plates width should be between 34 – 36 mm. Due to this requirement, the cutting process is crucial for the following operation in the tensile testing specimens' preparation. The configuration of the machine and the specimen's material is shown in Figure **2**. We examine 2 factors of the operating parameters setting of the bandsaw cutting machine, i.e.: (1) working table speed, coded as table speed (mm/s) and (2) bandsaw blade speed, coded as blade speed (m/min). Both parameters determine the accuracy of the cutting operation. 3 levels are applied for each factor.

Figure 2. Cutting operation

The table speed levels are 2, 3, and 4 mm/s. The blade speed levels are 65, 90, and 120 m/min. The levels are determined based on the previous experience of the machine operators with trial-and-error approach. Since the parameters applied in the cutting operation are not certain for each cutting specimens, the results often fail or do not meet the specified size. In this study Taguchi design of experiment method was employed to find optimal parameter settings of the bandsaw cutting machine. The Taguchi method is employed to to determine the influence of factors on response variables. On top of this, optimal conditions can be obtained (Terzioğlu, 2020). It is a cost-effective experimental method that is able to provide optimal conditions with minimum number of experiments using orthogonal arrays (Shojaei et al., 2021). The factors and levels employed in this study are shown in Table 2.

Table 2. Factors and levels adopted in design experiment

Factor	Level		
	I	II	III
Table speed (mm/s)	2	3	4
Blade speed (m/min)	65	90	120

3.3 Data Analysis

The Taguchi L9 design of experiment is applied and followed by the analysis of variance

(ANOVA) of the collecting measurement data. The analysis works to analyse the effect of each parameter and their interaction on the response variable, i.e., steel plate width dimension of 34-36 mm. Mathematical formula is further developed which covers the relationship of the measured parameters and the response. The signal-to-noise ratios (SN Ratio) are calculated by using the smaller the better condition as the deviations from the nominal value should be kept minimum. SN Ratio is to determine the control factor configurations that reduce the variability brought on by the noise factors (Salur et al., 2019). The optimal levels for each factor were determined by the mean plots.

4. RESULT AND DISCUSSION

4.1 The specimens' width

The measurements of 9 runs of experiment in triplicate resulting in 27-dimensional data. The mean for each run experiments are calculated. Table 3 shows the experiment results of the width dimension of the rectangular steel plates using the VZ 400 SA (YS Koki Ltd., Japan) bandsaw cutting machine. In this study, we conducted 9 runs experiment with 3 replications at each level and factor. The response of the study is the width size of the steel plate that should be between 34-36 mm. The results shows that all the specimens have dimension above 34 mm, while 6 measurements showed the dimension greater than 36 mm as exhibits in experiment run #7, #8, and #9. As exhibited in Table 3, those experiment runs applied the table speed of 4 mm/s.

Table 3. The results of experiment

Run	Speed		Width (mm)			Mean
	Table (mm/s)	Blade (m/min)	I	II	III	
1	2	65	35.27	35.60	35.39	35.42
2	2	90	34.75	34.55	34.77	34.69
3	2	120	34.86	35.12	35.21	35.06
4	3	65	35.10	35.24	35.13	35.16
5	3	90	35.07	35.42	35.01	35.17
6	3	120	35.17	34.99	35.12	35.09
7	4	65	35.96	36.11	35.80	35.96
8	4	90	36.23	36.20	36.33	36.25
9	4	120	36.31	36.44	36.54	36.43

The rectangular steel plates resulted from the cutting process are shown in Figure 2. The dimensions of the results are shown in the machine display during the operation. Afterward, it was verified by manual measurements using a digital calliper.

Figure 3. Rectangular steel plates measurement

The results were analysed according to the 'small is better' condition in Taguchi method. Table 3 shows that the smallest width dimensions are found in the parameter experiment #2, namely 34.75 mm, 34.55 mm, 34.77 mm, for each replication. However, these results cannot be ascertained as optimal, so the data must be processed according to the Signal to Noise Ratio (SNR) and ANOVA test.

4.2 SN Ratio

Experimental data for the width response as the results of the SN Ratio and means are shown in Table 4.

Table 4. SN ratios and means for the response width dimension

Run	Speed		SNR	Mean
	Table (mm/s)	Blade (m/min)		
1	2	65	-30.985	35.420
2	2	90	-30.804	34.690
3	2	120	-30.897	35.063
4	3	65	-30.920	35.157
5	3	90	-30.923	35.167
6	3	120	-30.905	35.093
7	4	65	-31.116	35.957
8	4	90	-31.187	36.253
9	4	120	-31.229	36.430

The response effect for the SN Ratio for the cutting parameters was carried out by using Minitab software. The response means of the specimens' width dimension are exhibited in Table 5.

Table 5. Main effects for means response

Level	**Table speed (mm/s)**	**Blade speed (m/min)**
1	35.06	35.51
2	35.14	35.37
3	36.21	35.53
Delta	1.16	0.16
Rank	1	2

As exhibited in Table 5, table speed factor (delta 1.16, rank 1) has the largest effect on the means of the width response measurements, followed by blade speed parameter. The blade speed has lower effect with delta value of 0.16. The main effects plot for means of the width response is shown in Figure 4. Figure 4 shows the main effects plot for means as table speed and blade speed parameters influencing the response. The highest point of the means is achieved by the table speed of 4 mm/s. while the table speeds of 2 mm/s and 4 mm/s show the lower means of 35.06 mm and 35.14 mm respectively. The blade speed factor shows relatively stable means of the width response. From the three levels of the blade speed factor, the mean values are between 35.37 – 35.53 mm.

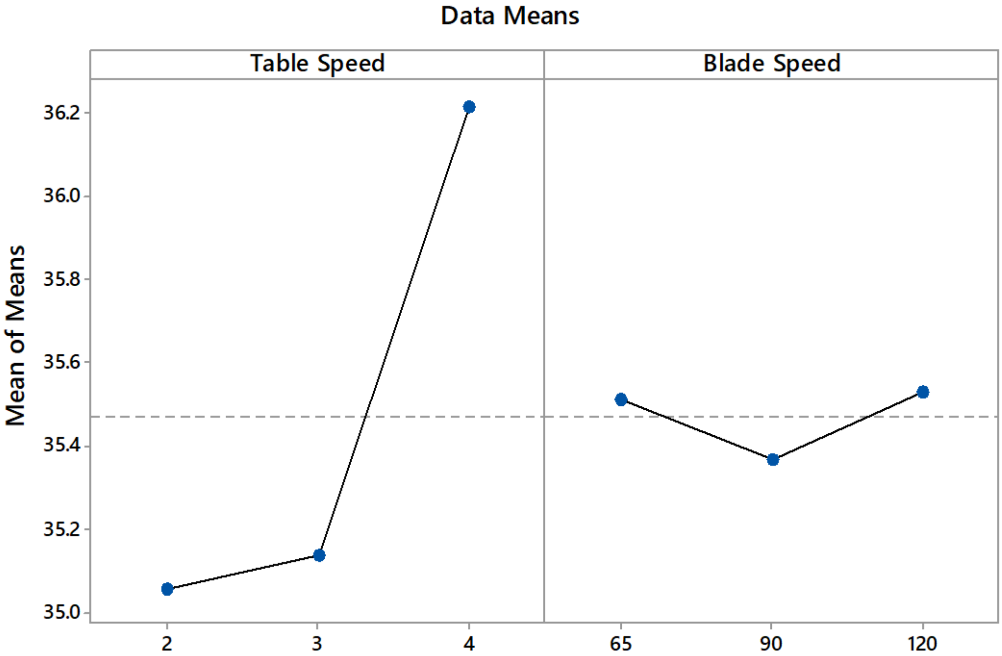

Figure 4. Influence of table – and blade speed on the means of the width response

The higher the signal value, the smaller the noise. For the table speed of 2 mm/s and the blade speed of 90 m/min exhibit the highest point of SN Ratio. The response effect for the SN Ratio for the cropping yield parameter is displayed in Table 6.

Table 6. SN Ratio – smaller is better

Level	**Table Speed**	**Blade Speed**
1	-30.90	-31.01
2	-30.92	-30.97
3	-31.18	-31.01
Delta	0.28	0.04
Rank	1	2

The optimum level for each factor is found in the response value of the largest SN ratio. Table 6 shows that the largest value is found at the level 1 for the table speed: -30.90 SN Ratio and the level 2 for the blade speed: -30.97 SN Ratio. Table speed factor (delta 0.28, rank 1) has the largest effect on the SN Ratio, followed by the blade speed. The main effects plot for the SN Ratio of the table speed and the blade speed are shown in Figure 5.

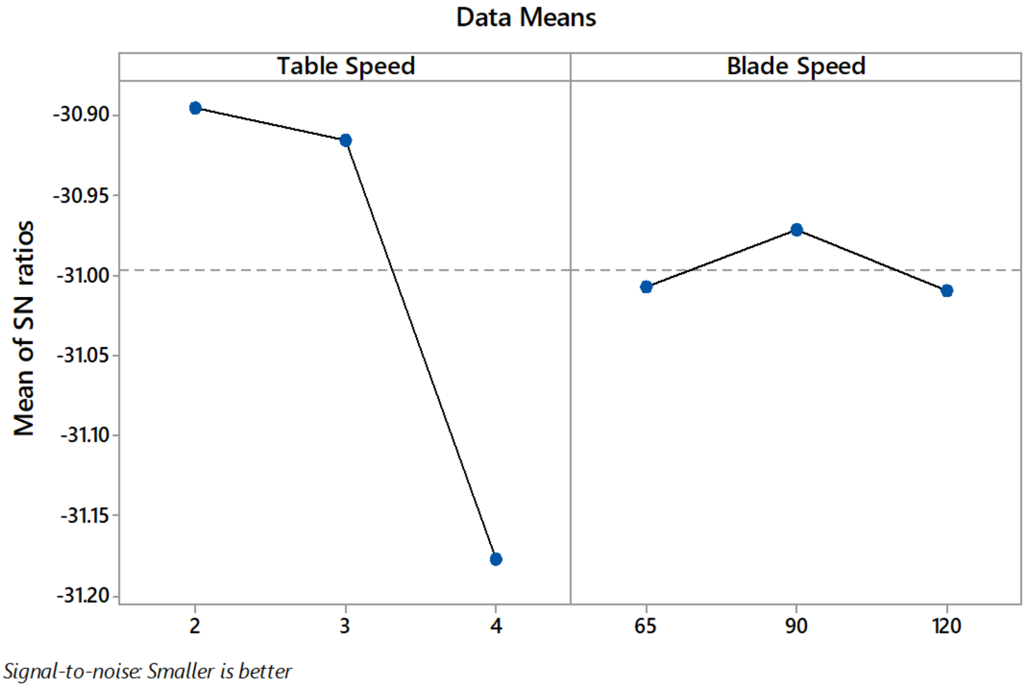

Figure 5. Influence of the table and blade speeds on the SN Ratio of the width response

Figure 5 shows that that the higher the signal value, the smaller the noise. The highest point is at level 1 for table speed with speed 2 and level 2 for blade speed with a speed of 90 m/min.

4.3 ANOVA Test

ANOVA tests compare the response variable means at the various factor levels to determine the relative relevance of one or more factors (Lakens & Caldwell, 2021). The ANOVA test and model summary results are summarized in Table 7. Regression equation predicting the width response is shown in equation (1).

Table 7. Analysis of variance and model summary

Analysis of Variance							
Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Table speed	2	0.148216	86.49%	0.148216	0.074108	14.57	0.015
Blade speed	2	0.002806	1.64%	0.002806	0.001403	0.58	0.772
Error	4	0.020348	11.87%	0.020348	0.005087		
Total	8	0.171370	100%				
Model Summary							
S	R-sq	R-sq(adj)					
0.290950	88.24%	76.49%					

$$Width = 35.4700 - 0.412T_2 - 0.331T_3 + 0.743T_4 + 0.041B_{65} - 0.100B_{90} + 0.059B_{120} \quad (1)$$

Table 3. Validation of optimal setting parameters

Run	Table speed (mm/s)	Blade speed (M/MIN)	Replications (mm)			Mean
			I	II	III	
1	2	90	34.7	34.78	34.63	34.70

Table 7 shows that the largest F-Value of the two factors tested. The table speed factor has a F-value of 14.57 which has the greatest influence on the width dimension of the cutting materials. The P values of the table speed and the blade speed are 0.015 and 0.772 respectively. Meaning that the table speed is significant factor in determining accurate width dimension of the cutting materials ($P<0.05$). While the blade speed is not significantly affecting the accuracy of the cutting materials ($P>0.05$).

The model is considered as significantly represent the actual results with R-sq value of 88.24% (adjusted R-sq = 76.49%). Furthermore, the regression equation for predicting the width response is shown in equation (1), where T is table speed variable, followed by the speed level (T2 = table speed 2 mm/s), and B is blade speed variable, followed by the blade speed level (B65 = blade speed 65 m/min). As shown in the equation (1) that table speed factor of 2 (T2) has the highest constant value (0.412) among the other factors. Meaning that the table speed factor has the most influence in determining the width response accurately. And the blade speed factor of 120 m/min (B120) has the lowest constant value (0.059) among others.

4.4 Validation

As found in the obtained results for optimal setting parameters for bandsaw cutting machine VZ-400 SA, validation has been performed by cutting the specimens material. The parameters were set for the table speed 2 mm/s and the blade speed 90 m/min. The cutting operations were conducted in triplicate. The same procedure as the previous experiment was followed, and the results are shown in Table 3. It is clearly exhibited Table 3 that the results are within the range of 34 – 36 mm. The mean value of the width plate dimension is 34.70 mm. the results confirm the recommended setting parameters of the bandsaw cutting machine VZ-400 SA for the preparation of the tensile test specimens for the SNI 07-2054-2007 angle bar steel products. By applying the Taguchi method, it is proved to obtain optimal parameters setting of the machine which results in optimal cutting results. On top of this, by applying design of experiment, the Taguchi method in particular, the operation has been improved to be more effective and efficient. It is also found that the table speed has a clearly significant effect on the precision of the cut materials dimension. Before conducting the experiment using Taguchi Method, the blade was often broken and obtained uneven results.

The industry can leverage the outcomes of this research in several ways. Firstly, the application of the Taguchi method has demonstrated its effectiveness in obtaining optimal parameter settings for bandsaw cutting machines, leading to improved cutting results. Additionally, the incorporation of design of experiments, specifically the Taguchi method, has enhanced overall operational efficiency and effectiveness. The research findings highlight the significant impact of table speed on the precision of cut material dimensions. Prior to the implementation of the Taguchi Method, the industry experienced challenges such as frequent blade breakage and inconsistent results. By adopting the optimal parameter settings identified through this research, the industry can minimize these issues, ensuring smoother operations, reduced equipment wear, and more precise cutting outcomes. This can ultimately result in increased productivity, cost savings, and improved product quality for the industry.

5. CONCLUSION

The optimization of the setting parameters of the bandsaw cutting machine VZ-400 SA have been successfully caried out by applying Taguchi Method as design of experiment tool. Two factors were investigated in the experiment, namely the table speed factor (mm/s) and the knife rotation speed factor (m/min) on the response of the cutting width of the cut materials. It is concluded that the table speed plays important role to obtain accurate dimension of the cut materials. Contribution factor of the table speed was 86.49 %, while the blade speed was 1.64 % (error 11.87 %). The optimal setting parameters was obtained by considering the largest S/N Ratio at the level 1 for table speed (2 mm/s), namely -30.90 and level 2 for blade speed (90 m/min), namely -30.97. Since the table speed of the machine has a greater contribution to the accuracy of the cut material, it is relied on the pressure between the blade and cut material. The faster blade speed, the more pressure between cutting blade and cutting material occurs. As a result, the cutting blade become more vulnerable and getting broken, and the cutting materials become inaccurate in dimension. In the case that the table speed is slower, then too many materials are scrapped by the cutting blade which results in inaccurate dimension. The operation time is getting longer as well. The setting parameters of the machine for different cutting materials might be adjusted for optimal result.

The study indicates a significant opportunity for future research in the field of optimizing bandsaw cutting machine parameters. While the Taguchi Method has proven effective in this study, there is potential to explore and compare the results with other design of experiment tools, such as the response surface method. Future research could focus on the adjustment of machine settings for different cutting materials to achieve optimal results. This entails a comprehensive exploration of how varying materials interact with the machine's parameters and how adjustments can be made to enhance precision and efficiency. The study suggests that different cutting materials may require specific machine settings for optimal outcomes, and further investigation can provide insights into these material-specific adjustments.

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