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Optimization of CNC Turning Parameters for cutting Al6061 to Achieve Good Surface Roughness Based on Taguchi Method

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ABSTRACT

In the machining process of manufacturing sector, surface quality is critical factor in evaluating output of product. One of the machining processes is by CNC turning. The excellent surface finish ensures that the product is in the high quality. The industries are in the requirement of producing more parts with acceptable quality with the shortest period and the least resources. Some materials used for manufacturing parts have various kinds. This study applied Al6061 as workpiece and used Taguchi method to optimize the CNC turning parameter for cutting it. The Taguchi L9 orthogonal array experimental design was used in this research. In the CNC turning process, spindle speed, feed rate, and depth of cut were chosen as controllable process parameters, and surface roughness was utilized to assess performance as a response. The result will be analyzed by main effect plot, ANOVA, and the residual normal probability plot. In this research, 1000 rpm as a spindle speed, 0.08 mm/min as a feed rate, and 0.25 mm as a depth of cut were found to be the optimal parameters for achieving lower $R_a = 0.459\ \mu m$. The primary effect plot provides considerable data to support the experiment's principal goal. Furthermore, according to the ANOVA table, feed rate was the cutting parameter with the largest percent contribution to achieve better surface roughness, and the residual normal probability plot revealed that the coefficient model was significant.

Keywords:
Optimization, CNC turning, Surface roughness, Taguchi method

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1. Introduction

In the industries, turning is an important part of machining[1][2]. One of machining parameters is surface roughness[3]. Surface roughness is one of the most common ways to assess a product's quality[4][5]. Surface roughness improvement has long been a priority for every business. The choice of material for workpieces will also be considered based on what product or part that will be manufactured[6][7].

Evolved from a numerical control (NC) machining process that uses punched tape cards, CNC machining is a manufacturing process that uses computerized controls to operate and manipulate cutting machines and tools to shape workpieces for example, metal, plastic, wood, foam, etc[8]. Although there are so many types and processes in CNC machining, the basic principles of the processes remain largely the same. The basic CNC machining process includes the following stages,

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namely Designing a CAD model, Converting a CAD file to a CNC program, Preparing the machine, Executing machining operations on the machine[9].

In the present day, the requirement of Al6061 is widely used as the material for workpiece in the industries because it is relatively high strength, good workability, and high resistance to corrosion[10]. This study applied Al6061 as workpiece and used Taguchi method to optimize the CNC turning parameter for cutting[11].

2. Experimental Procedure

2.1 Cutting Parameters

In this research, three different parameters of cutting in machining were applied. Those were spindle speed, feed rate, and depth of cut. Those cutting parameters referred to some previous research conducted and those were modified to gain the optimal best data that can represent the real application in the industry. Table 1 shows the detail of cutting parameters and their levels.

Table 1
Cutting parameters of Turning and Their Levels

The Parameters of Cutting	Levels		
	1	2	3
Spindle speed	1000 rpm	1400 rpm	1800 rpm
Feed rate	0.08 mm/rev	0.12 mm/rev	0.16 mm/rev
Depth of cut	0.15 mm	0.2 mm	0.25mm

2.2 Tools and Workpiece

The tools and workpieces for this research are commonly used for application in the manufacturing industry. The detail information of tools and workpiece for this research can be seen in Table 2.

Table 2
The detail information of Tools and Workpiece Used for This Research

Tools	Specification
Three-axis CNC turning	FANUC 0i-TF (LEADWELL)
Turning insert	DCMT070204HQ VP15TF carbide inserts with a blade angle of 55 degrees
Machining tool holder	BMT-45 of DW220-C20-35-W77
Machining arbor	SDJCR-2020K-07 alloy arbor with an angle of 55 degrees
Workpiece material and dimension	Aluminum (Al6061), tensile strength-yield (276 MPa), density (2.70 g/cc), tensile strength-ultimate (310 MPa), elasticity modulus (68.9 GPa), conductivity of thermal (167 W/m-k), Hardness-brinell (95), $\emptyset 30\ mm\ x\ 150\ mm$

2.3 Cutting Process

The cutting process is turning process. It means the cutting tool removes material from the outer diameter of the workpiece. The primary purpose of turning is to decrease the workpiece diameter to the appropriate size. For the illustration of turning process can be seen in Figure 1.

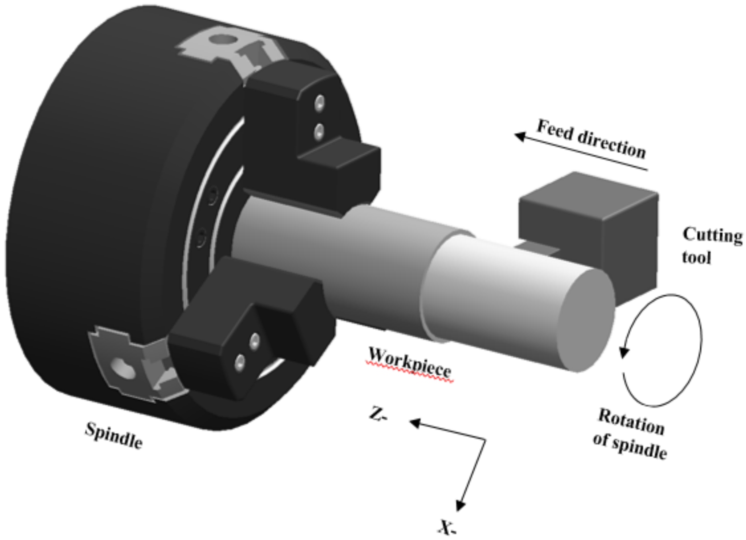

Fig. 1. The Illustration of Cutting Process in Turning Process

2.4 Surface Roughness Tester

Measurement of surface roughness used a portable roughness meter (SURFTEST SJ-210). The measurement unit is μm. Figure 2 illustrates the measurement process.

Fig. 2. The Measurement Process of Surface Roughness

After machining process, the workpiece will be placed like the figure above. The surface roughness meter will be set to touch the surface that has already been cut. The start button will be pressed, and let the tool start measuring until the process is completed, and the actual value of surface roughness will appear on the screen. The surface roughness parameter that we use is R_a (Roughness Average). R_a is the most extensively used and popular roughness measurement in the world. For the equation, can be seen in Eq. 1.

$$R_a = \frac{1}{L}\int_0^1 |Y(x)|dx \qquad (1)$$

where R_a is the deviation of arithmetic mean from the average line, L is the length of sample, and Y is the curve coordinate of the profile. It is the arithmetic mean of the roughness profile's divergence from the center line.

3. Result and Discussion

3.1 Taguchi Method

Genichi Taguchi applied a loss function, which is the difference between experimental and target values, and then turned into the S/N ratio. The mean to standard deviation ratio is known as the S/N ratio. The terms "signal" and "noise" were introduced by Taguchi to describe the response's desired (mean) and undesirable (standard deviation) values, respectively. In this research, the trials were set up in a L9 orthogonal array, and the S/N ratio and ANOVA were used to optimize the results. Taguchi classified the S/N ratio into three groups based on reaction requirements. Those are lower-the-better, medium-the-better, and higher-the-better.

To improve machinability, the quality attribute of R_a in this research is the lower-the-better. As a consequence, Eq. (2) was used to compute the S/N ratio. The result of means of data mean, the mean of S/N ratio, and analysis of variance (ANOVA) were produced and presented using the Minitab 17 software tool.

The signal to noise ratio for the smaller the better $= -10log\frac{1}{n}\sum(R)^2$ (2)

where *n* is observation number. *R* is each response in observed data.

Table 3
Experimental Design, Surface Roughness Measurement Result and S/N Ratio Result

Experimental number	The Parameters of Cutting			Surface roughness (μm)	Result of S/N ratios (dB)
	Spindle speed (rpm)	Feed rate (mm/min)	Depth of cut (mm)		
1	1000	0.08	0.15	0.518	5.713
2	1000	0.12	0.2	1.186	-1.484
3	1000	0.16	0.25	1.861	-5.396
4	1400	0.08	0.2	0.538	5.390
5	1400	0.12	0.25	1.236	-1.840
6	1400	0.16	0.15	1.903	-5.590
7	1800	0.08	0.25	0.489	6.220
8	1800	0.12	0.15	1.320	-2.414
9	1800	0.16	0.2	1.793	-5.070

3.2 Effect of Cutting Parameters on Surface Roughness (R_a)

Figure 3 shows how process factors affect surface roughness. From effect of spindle speed to R_a, 1400 rpm is the highest level that has effect in the highest R_a, followed by 1800 rpm and 1000 rpm respectively. From effect of feed rate to R_a, 0.16 mm/min is the highest level that has effect in the highest R_a, followed by 0.12 mm/min and 0.08 mm/min respectively. From effect of depth of cut to R_a, 0.15 mm is the highest level that has effect in the highest R_a, followed by 0.25 mm and 0.20 mm respectively. For the specific value of means of every parameter plot, it can be seen in Table 4. This result can be verified in the some previous researches such as the application of brass63/37 using Taguchi approach to improve CNC settings (C27400), application of Taguchi L9 orthogonal array to investigate the turning process of EN8 steel, and so on.

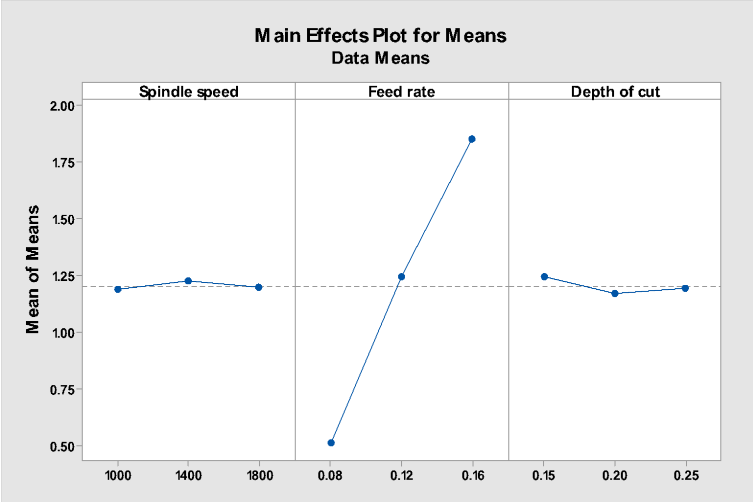

Fig. 3. Main Effect Plot of Surface Roughness Means

Table 4
Response Table for Means

Level	The Parameters of Cutting		
	Spindle speed	Feed rate	Depth of cut
1	1.1886	0.5148	1.2472
2	1.2257	1.2476	1.1722
3	1.2006	1.8524	1.1953
Delta	0.0371	1.3377	0.0750
Rank	3	1	2

3.3 Selection of Optimum Cutting Conditions for R_a

Table 5 shows the obtained S/N ratio response table in the R_a. The mean S/N ratio graph computed using the Minitab software tool is shown in Figure 4. From each S/N ratio mean of level, we have to choose the highest value. Based on taguchi method, the higher S/N ratio reflects the smallest possible deviation between the desired and measured outputs. The greatest mean S/N ratio of R_a was found for spindle speed at 1000 rpm, feed rate at 0.08 mm/rev, and depth of cut at 0.25 mm, as shown in Fig. 4. As a result, the predicted optimum cutting parameters for obtaining low surface roughness using the Taguchi method were determined to be spindle speed = 1000 rpm, feed rate = 0.08 mm/rev, and depth of cut = 0.25 mm, with the corresponding level values underlined in Table 5 for easy understanding from the response table.

Table 5
Response Table for Signal to Noise RatiosSmaller is better

Level	The Parameters of Cutting		
	Spindle speed	Feed rate	Depth of cut
1	-0.3891	5.7743	-0.7635
2	-0.6803	-1.9127	-0.3881
3	-0.4213	-5.3523	-0.3390
Delta	0.2912	11.1266	0.4245
Rank	3	1	2

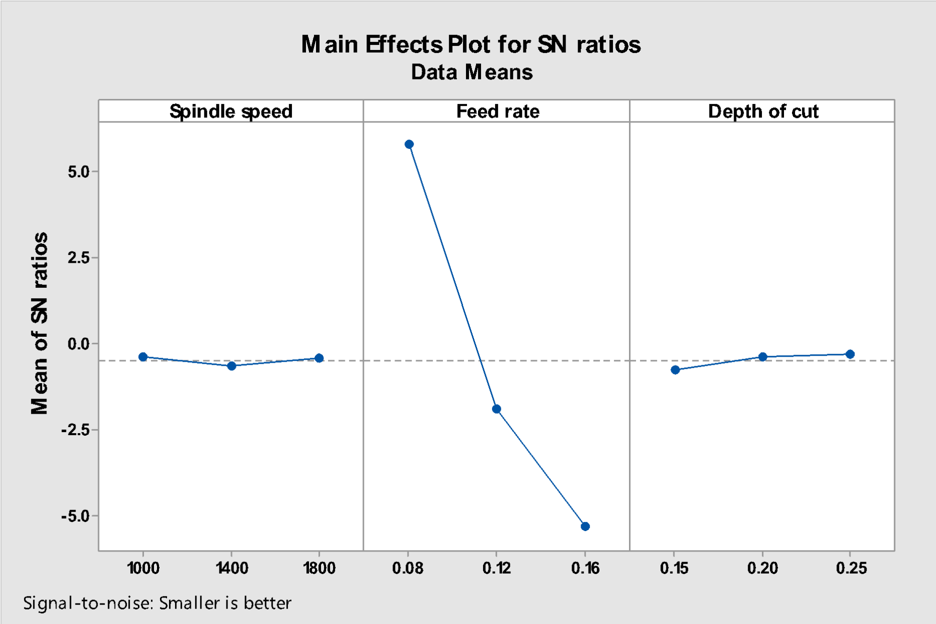

Fig. 4. Main Effect Plot for Surface Roughness S/N Ratios

3.4 Confirmation Test

Conformation experiments are required to validate the Taguchi predicted optimal conditions. The expected S/N ratio (ε) was determined using Eq. 3 to calculate and verify the response under predicted optimum cutting process condition.

$$\varepsilon_{predicted} = \varepsilon_l + \sum_{i=1}^{x}(\varepsilon_0 - \varepsilon_l) \quad (3)$$

Where ε_l is the total mean of S/N ratio, ε_0 is the mean of S/N ratio at optimal level, and *x* is number of input process parameters. Table 6. displayed the predicted optimal cutting parameters of R_a, which resulted in improved performance. Tables indicate that the S/N ratios of the predicted and optimal cutting conditions were nearly identical. At the optimum cutting condition, the S/N ratio improvement was 1.379. The Taguchi predicted optimum cutting conditions produce better outcomes than the initial parameter settings, according to the conformation experiments. Based on previous research, to know our experiment getting improvement result, we conducted the initial experiment by choosing random of middle cutting parameter design. When comparing the Taguchi projected optimal cutting conditions to the original parameter values, R_a reduction was determined to be 17.21%. As a result, the Taguchi predicted optimal cutting condition was chosen as the best cutting condition for machining Al6061 with the lowest R_a under the specified circumstances.

Table 6
Conformation Experimental Result

	Initial chosen cutting parameter	Optimum cutting parameter	
		Prediction	Experiment
Level	1400-0.08-0.2	1000-0.08-0.25	1000-0.08-0.25
Surface roughness	0.538 μm	0.488 μm	0.459 μm
S/N ratio	5.384 dB	6.039 dB	6.763 dB
Improvement in S/N ratio	1.379 dB		
Percentage reduction of surface roughness	17.21%		

3.5 ANOVA

An ANOVA test is used to determine whether or not the findings of a survey or experiment are significant. By ANOVA, the strain number that is affected by the independent variable can be presented. ANOVA has a table that represents the value of the survey. By comparing the p-value for each term in the model to our significance threshold to examine the null hypothesis, we can establish if the relationship between the response and each term in the model is statistically significant. The null hypothesis is that there is no association between the term and the response. A significance level is denoted by α (alpha). The significance level is 0.05. It shows that there is a 5% chance of determining that an association exists when there isn't one.

From this research conducted by applying the cutting parameters designed by L9 orthogonal array of Taguchi method, Ra is greatly impacted by feed rate, followed by depth of cut, and spindle speed respectively, as shown in Table 7. Feed rate, spindle speed, and depth of cut all contributed 99.526 percent, 0.166 percent, and 0.078 percent to Ra, respectively, as shown in Table 7.

Table 7
Analysis of Variance

Source	DF	Adj SS	Adj MS	F	P	% Contribution
Spindle speed	2	0.153	0.0765	0.34	0.747	0.078
Feed rate	2	194.721	97.3603	431.06	0.002	99.526
Depth of cut	2	0.324	0.1618	0.72	0.583	0.166
Residual error	2	0.452	0.2259			0.231
Total	8	195.649				100

3.6 Modelling

In this research, the dependent variables of Ra as a function of spindle speed, feed rate, and depth of cut were developed using linear regression analysis in the Minitab 17.0 software tool. On each response, no modification has been applied. The Eq. (4) indicate the prediction equations derived from the regression analysis. The ability of created models was evaluated using the R-squared coefficient of determination. The value of the coefficient of determination ranges from zero to one. If it is near to one, it suggests that the dependent and independent variables are well-matched. The constructed regression models for Ra in this study have a high R-squared value of 0.9924 or 99.24 percent. It means closed to one. The coefficients in the projected model were checked for significance using the residual plot. If the residual plot is a straight line, the model's residual errors are normally distributed and the coefficients are significant. Figure 5. shows that the residuals are close to the straight line, indicating that the coefficient models are significant.

$$\text{Surface roughness} = -0.719 + 0.000015\ \text{Cutting speed} + 16.721\ \text{Feed rate} - 0.519\ \text{Depth of cut}\ (R^2 = 99.24\%). \quad (4)$$

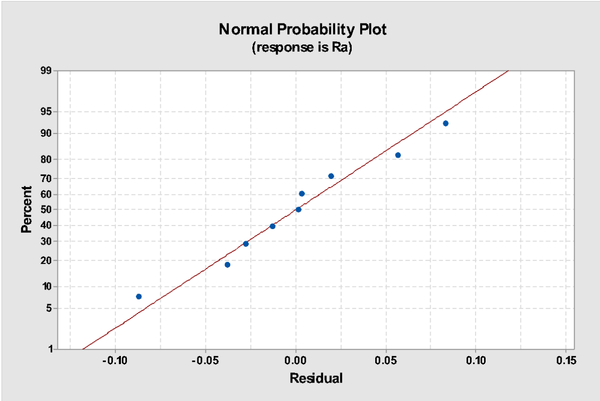

Fig. 5. The Residual Normal Probability Plot of Surface Roughness

4. Conclusion

The findings of this research led to the following conclusion:

1. In this research, The Taguchi technique was used to discover the best cutting condition combination for obtaining low surface roughness, which was found to be spindle speed= 1000 rpm, feed rate = 0.08 mm/rev, and d = 0.25 mm, with a 17.21 percent decrease in surface roughness.
2. Surface roughness was considerably impacted by the feed rate with a contribution of 99.526 percent, followed by depth of cut, and spindle speed, according to the ANOVA for the cutting process in Al6061.
3. The coefficients in the experimental model was checked for significance by the residual normal probability plot, and the result of the coefficient model is significant.
4. According to the findings, Taguchi found optimum cutting settings that greatly decreased surface roughness during Al6061 machining. As a result, metal cutting companies were recommended to employ these optimum cutting conditions to improve the machinability of Al6061 within the specified range.

5. Future Research

In the future research, the principal impacts of heat treatment on surface roughness can be studied. It may also have contribution in the surface roughness. In addition, the cutting tool will also be considered to do machining process. The different composition of cutting tool material may have impact in the result of cutting process.

References

[1] Gadekula, Rajesh Kumar, Mallikarjuna Potta, Diwakar Kamisetty, Uday Kumar Yarava, Priyanka Anand, and Raja Sekhar Dondapati. "Investigation on parametric process optimization of HCHCR in CNC turning machine using Taguchi technique." *Materials today: proceedings* 5, no. 14 (2018): 28446-28453.

[2] Pang, J. S., M. N. M. Ansari, Omar S. Zaroog, Moaz H. Ali, and S. M. Sapuan. "Taguchi design optimization of machining parameters on the CNC end milling process of halloysite nanotube with aluminium reinforced epoxy matrix (HNT/Al/Ep) hybrid composite." *HBRC Journal* 10, no. 2 (2014): 138-144.

[3] Irfan, S. Syed, M. Vijay Kumar, and N. Rudresha. "Optimization of machining parameters in CNC turning of EN45 by Taguchi's orthogonal array experiments." *Materials Today: Proceedings*18 (2019): 2952-2961.

[4] Rahman, Md Zishanur, Alok Kumar Das, Somnath Chattopadhyaya, Md Reyaz, Md Taslim Raza, and Saima Farzeen. "Regression modeling and comparative analysis on CNC wet-turning of AISI-1055 & AISI-4340 steels." *Materials Today: Proceedings* 24 (2020): 841-850.

[5] Shagwira, Harrison, T. O. Mbuya, Esther T. Akinlabi, F. M. Mwema, and B. Tanya. "Optimization of material removal rate in the CNC milling of polypropylene+ 60 wt% quarry dust composites using the Taguchi technique." *Materials Today: Proceedings* 44 (2021): 1130-1132.

[6] Kolappan, S., K. Subramani, and A. Vasudevan. "Taguchi optimization of advanced machining process parameters on AA2014/TiC composite." *Materials Today: Proceedings* (2021).

[7] Kittali, Praveen, Vijaykumar Kalwa, D. Athith, K. P. Prashanth, and B. K. Venkatesh. "Optimization of machining parameters in turning operation to minimize the surface roughness using Taguchi technique for EN1A alloy steel." *Materials Today: Proceedings* 54 (2022): 463-467.

[8] Yadav, Deepak Kumar, Nitesh Kumar Dixit, Deepak Agarwal, and Sanchit Kumar Khare. "Optimization of surface roughness by design of experiment techniques during CNC milling machining." *Materials Today: Proceedings* 52 (2022): 1919-1923.

[9] Gurugubelli, Sasidhar, Rama Bhadri Raju Chekuri, and Ravi Varma Penmetsa. "Experimental investigation and optimization of turning process of EN8 steel using Taguchi L9 orthogonal array." *Materials Today: Proceedings* 58 (2022): 233-237.

[10] Kanaujia, Neetu, Jitendra Kumar Behera, Sambit Kumar Mohapatra, Asit Behera, Pushkar Jha, Kamal Kishore Joshi, and Bharat Chandra Routara. "Process parameters optimization in CNC turning of aluminum 7075 alloy using TOPSIS method coupled with Taguchi philosophy." *Materials Today: Proceedings* 56 (2022): 989-994.

[11] Cimbala, John M. "Taguchi orthogonal arrays." *Pennsylvania State University* (2014).