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INTEGRATION OF TAGUCHI AND PROMETHEE FOR CNC MILLING MACHINING PARAMETER OPTIMIZATION ON AA6061

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Abstract

In the manufacturing industry, machining has developed quite rapidly from the use of conventional machines to unconventional machines. Unconventional machines that are often used today are optimize computer numerically controlled (CNC), the use of CNC in the manufacturing industry provides many benefits in product quality and productivity. One of them is CNC milling, this type is one of the main machines on the production floor. Machining optimization becomes the main goal to achieve the ideal response in order to produce products with good and consistent quality and productivity. Surface quality leads to surface roughness, while productivity leads to material removal rate. This study aims to optimize CNC milling machining parameters on AA6061 with Taguchi experimental design and preference ranking organization method for enrichment evaluation (PROMETHEE) method. Machining was controlled using wet machining conditions to maintain temperature during machining. Experiments were conducted nine times with three factors and levels. These factors included spindle speed, feed rate, and depth of cut. The result of this research is the ideal value of the combination of surface roughness and material burning rate which is 0.565 (experiment 3). This best experiment is influenced by spindle speed 2600 rpm, feed rate 65 mm/min, and depth of cut 2.5 mm. Feed rate has the largest contribution in influencing the response which is 43.23%, followed by depth of cut 25.24%, and spindle speed 15.91%.

Keywords: *Optimization, CNC Milling, Surface Roughness, Material Removal Rate, Taguchi, Promethee*

1. INTRODUCTION

One machining that is often used in the manufacturing industry is conventional machining. This machining uses specialized machines to achieve optimal productivity and quality. This special machine is a optimize computer numerically controlled (CNC) milling machine, a machine with many benefits with accurate results and fast processing. These benefits become a reference for use in industrial applications and many studies to analyze surface roughness and material removal rates. Surface roughness analysis to get the good and bad quality of a product, by looking at the level of smooth rough surface. So that roughness becomes a factor that can determine in terms of quality and performance of a product. The value of surface roughness must be monitored in the machining process so as not to produce poor surface roughness. Poor surface roughness can affect one of them, namely production costs. If there is a defect in finishing, it must be remanufactured which results in increased costs.

In addition to surface roughness, material removal rate is a factor that needs to be taken into account as well because it can affect productivity levels, tool life, and cutting forces in

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the production process [1]. Its high productivity is in line with the high value of material removal rate. Productivity leads to the ability of production to produce products, so that more products are produced, more profits will be obtained [2]. Therefore, many manufacturing industries are currently considering the material removal rate to be used as an important factor in their manufacturing process [3]. For example, manufacturing industries in aerospace, automotive parts, and structural

The basis of using these two parameters, namely surface roughness and material removal rate, is to get the ideal value so that it can be used in the industrial world to maintain and be consistent in terms of quality, productivity, and cost savings [4]. To get the ideal value, we must optimize the response of surface roughness and material surface rate. Optimization requires process parameters such as spindle rotational speed, feed speed, and depth of cut [5]. The test material in this research is aluminum alloy 6061, this material has good material properties for use in milling machining, because it has good strength and corrosion resistance. In addition, this aluminum alloy has high tensile strength and good formability [6]. This aluminum has been widely used in the manufacturing industry for the production of automotive and construction parts [7]. The benefits of this aluminum make the material used in research to see the results of variations in machining as well as being useful in other industries and further research [8].

Validation and evaluation of the optimization results using the design of experiment method. The methods used are various such as taguchi, response surface, gray analysis, etc. Researchers consider taking into account the cost and number of experiments, because of the high cost of experiments. Researchers consider taking into account the cost and number of experiments, because of the high cost of experiments Many researchers analyzed CNC milling machining optimization such as Shaik [9] aims to minimize the vibration rate and surface roughness (Ra) in the end milling process on AI6061 material. The experiment design uses RSM and Box Behnken methods to vary the parameters of spindle speed, axial depth of cut, and feed rate. Spindle speed and axial depth of cut contributed highly compared to feed rate. Viswanathan, et al. [10] analyzed multi-objective optimization with a combined design experiment method of Taguchi and Grey Relay Analysis. This research varies the parameters of cutting speed, feed rate, depth of cut, and cutting condition to get the ideal value on surface roughness (Ra) and tool life. The result is that feed rate is very influential on roughness and tool life followed by cutting condition, depth of cut, and cutting speed.

Khalilpourazari and Khalilpourazary [11] used the sine cosine whale algorithm for production time optimization with variations in feed rate, cutting speed and total production parameters. This research proves that the sine cosine whale used produces a more optimal time than previous research. Wojciechowski, et al. [12] analyzed baha material on the development of methods to minimize vibration and cutting force in the milling process. This study evaluates the optimization results using Taguchi. The results show that cutting force and vibration significantly affect the quality of the machined surface. Ali, et al. [13] analyzed the ideal values for surface roughness (Ra), cutting time, and material removal rate on AI2024 with the integration of taguchi and grey analysis methods. The tool path was also varied in this study in response to feed rate, cutting speed and depth of cut. As a result, cutting speed has a high contribution of 75%, followed by tool path strategy of 8%, depth of cut of 3%, and feed rate of 3%. Makhesana and Patel [14] evaluated lubricant variations in machining conditions with ranking processing from the preference ranking organization method for enrichment evaluation (PROMETHEE) method. The results will be used to select the most ideal combination of lubricants in machining conditions.

Muaz and Choudhury [15] conducted a study by applying minimum quantity lubrication with CNC milling on AISI 4340 steel alloy. Taguchi experimental design was used to obtain the ideal value in this study. The parameter variations tested were MQL type, spindle speed and feed rate. The result of this study is that the low viscosity MQL type contributes greatly in reducing waste and minimizing roughness (Ra). Lizzul, et al. [16] evaluated the surface quality (Ra) of Ti6AI4V titanium alloy by flexibility ball end milling. The variations used were surface topography, cutting force, and chip morphology. The results prove that the additive processed alloy has better machining than conventional. In addition, the material removal rate is more optimal in optimizing the response and significantly reduces the material resistance to cutting. Suresh, et al. [17] minimized surface roughness (Ra) and maximized material removal rate in green-based cnc milling. This research aims to reduce waste to a minimum in the manufacturing process in order to create green manufacturing in the surrounding environment. In addition to parameter optimization, researchers consider coolant in CNC milling machining. Kumar, et al. [18] optimized the surface roughness (Ra) and material removal rate by varying the factors of feed rate, cutting speed, and depth of cut. The result is that cutting speed has a large significance on the surface roughness response, besides the feeding rate and depth of cut significantly affect the material removal rate. SUR, et al. [19] evaluated cutting force and surface roughness (Ra) on Ti6Al4V alloy. Cutting speed, helix angel, and feed rate were the process parameters considered for variation. Feed rate was the most influential parameter on surface roughness. A high cutting speed results in a decreased cutting force, but increases when the feed rate value is high. Meanwhile, helix angle is the parameter that most significantly affects the cutting force response.

The above review explains that research on surface roughness only uses the surface roughness characteristic Ra. The use of surface roughness characteristics Ra, Rq, and Rz is still not examined. Therefore, the researcher discussed the three characteristics to be analyzed with the response to the material removal rate. Ra is a characteristic that has the average value of the center profile calculated by the deviation value. Rq is a characteristic that has the root mean square of the evaluation profile, Rq is more sensitive to values at peaks and valleys than Ra. While Rz is the average of the peak to valley values, the Rz value is also an illustration of the large offset in the evaluation profile. The review also explains that variations in spindle speed, feed rate, and depth of cut provide significant results on the surface roughness response and material removal rate so that researchers use variations in these parameters [20]. Researchers use taguchi experimental design then integrated with the PROMETHEE method, taguchi method is used to get the optimal value of each response and PROMETHEE is used to get the optimal combination value. The optimal value is the result of a combination of low surface roughness and high material removal rate. In addition, researchers also use both methods because there is still no research on machining optimization with the integration of the two methods. In this study, the researcher aims to optimize the surface roughness (Ra, Rq, Rz) and material removal rate in CNC milling machining with AI 6061 material. The researcher varied the factors and levels of process parameters spindle speed, feed rate, and depth of cut with the integration of Taguchi and PROMETHEE methods. This research can provide varied experimental results as well as ideal machining combinations. The results of this research are expected to be useful, among others, as a reference for further research or used in the manufacturing industry in the CNC milling machining process.

2. MATERIALS AND METHODS

2.1. Framework

This type of research is experimental research on CNC milling machines with research flow stages including experimental design, machining, data collection, to data processing. The conceptual framework is described in Figure 1, from the conceptual framework the response parameters on aluminum alloy 6061 material (Figure 2) are influenced by variations in spindle speed, feed rate, and depth of cut parameters. The machining temperature is maintained by liquid cooled wet machining and cutting tools with 8 mm diamter High Speed Steel (HSS) tools.

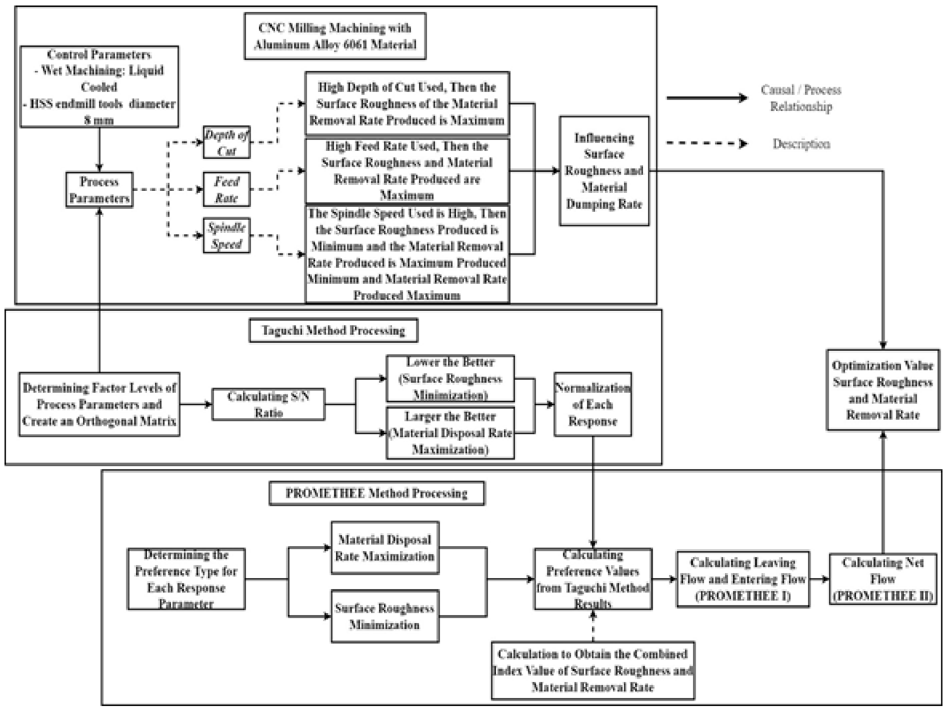

Figure 1. Framework

Machining data is processed by taguchi and PROMETHEE integration methods, taguchi is used to obtain the value of each response. Taguchi itself can create an experimental design with various levels of factors from spindle speed, feed rate, and depth of cut which will be made into an orthogonal matrix. After that, it produces a normalized s/n ratio value of each response parameter. The PROMETHEE method is used to get the optimum result from the combination of each response from the S/N ratio value. The PROMETHEE method is based on the type of preference for the taguchi ratio value, the type of preference will be processed to obtain combined indices with weights and S/N ratios. After that, ranking with PROMETHEE I by calculating the value of leaving flow and entering flow, PROMETHEE II calculates net flow. Net flow becomes the optimal value for the combination of the two response parameters.

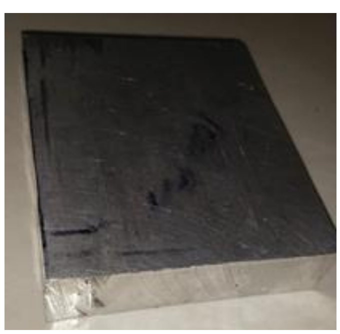

Figure 2. Aluminum Alloy 6061

2.2. Experimental Design

The research was conducted using a Taguchi experimental design with nine experiments, three factors and levels. The three factors including spindle speed, feed rate, and depth of cut were varied to obtain the optimal response. Each factor consists of three different levels as shown in Table 1. Figure 3 illustrates machining on a DAHLIH MCV vertical CNC milling machine. Roughness testing was performed with a Mitutoyo ISO 97 surface roughness tester with a cut off of 0.8 mm and an evaluation length of 5, while the material removal rate was obtained from calculations using a formula algorithm. Machining was carried out with controlled temperature in a wet state with flooding technique.

Figure 3. CNC Milling Machining

Table 1. Level and Factor

Factor	Unit	Level		
		1	**2**	**3**
Spindle Speed	rpm	1300	2600	4000
Feed Rate	mm/min	35	50	65
Depth of Cut	mm	0,5	1,5	2,5

3. RESULT AND DISCUSSION

The surface roughness characteristics type uses the analysis of three types of characteristics, namely, Ra, Rq, and Rz as shown in Table 2. Data collection was carried out with nine experiments on one specimen.

Table 2, Surface Roughness Test Results

	Process Parameters			Surface Roughness		
Experiment	**spindle speed (rpm)**	**feed rate (mm/min)**	**depth of cut (mm)**	**Ra (μm)**	**Rq (μm)**	**Rz (μm)**
1	1200	35	0,5	0,491	0,614	3,815
2	1200	50	1,5	0,369	0,459	2,906
3	1200	65	2,5	1,1	1,483	12,293
4	2600	35	1,5	0,513	0,635	3,752
5	2600	50	2,5	0,346	0,422	2,506
6	2600	65	0,5	0,533	0,666	4,536

	Process Parameters			Surface Roughness		
Experiment	spindle speed (rpm)	feed rate (mm/min)	depth of cut (mm)	Ra (µm)	Rq (µm)	Rz (µm)
7	4000	35	2,5	0,366	0,456	2,763
8	4000	50	0,5	0,859	1,124	8,205
9	4000	65	1,5	1,294	1,667	9,79

Table 3. Material Removal Rate Result

Experiment	Depth of Cut(mm)	Tool Width (mm)	Feed rate (mm/min)	Material Removal Rate (mm^3/min)
1	0,5	8	35	140
2	1,5	8	50	600
3	2,5	8	65	1300
4	1,5	8	35	420
5	2,5	8	50	1000
6	0,5	8	65	260
7	2,5	8	35	700
8	0,5	8	50	200
9	1,5	8	65	780

3.1. S/N Ratio (Taguchi)

The S/N ratio generated in the taguchi experimental design is processed to measure the value of characteristics that deviate from the desired value. The S/N ratio has three response objectives, namely large is best, normal is best, and small is best. The characteristic objective of the S/N ratio of surface roughness is small is best because it has a response objective for value minimization with the formula in Equation 1. The characteristic objective of the material removal rate is large is best because it has a value maximization response objective with the formula in Equation 2. Then normalization as in Equation 3 (surface roughness) and Equation 4 (material removal rate). The overall calculation results for each response can be seen in Table.4.

$$\text{S/N} = -10\ log \sum_{i=1}^{n} yi\text{^}2 \quad (1)$$

$$\text{S/N} = -10\ log \sum_{i=1}^{n} \frac{1}{n}\frac{1}{yi\text{^}2} \quad (2)$$

$$\text{Xi (k)} = \frac{\max Xi(k)\ (k) - Xi\ (k)}{\max Xi\ (k) - \min Xi(k)} \quad (3)$$

$$\text{Xi (k)} = \frac{Xi\ (k) - minXi\ (k)}{\max Xi\ (k) - \min Xi(k)} \quad (4)$$

Table 4. S/N Ratio and Normalization

	S/N Ratio				Normalization			
Experiment	S/N Ratio Ra	S/N Ratio Rq	S/N Ratio Rz	S/N Ratio MRR	S/N Ratio Ra	S/N Ratio Rq	S/N Ratio Rz	S/N Ratio MRR
1	6,178	4,237	-11,630	42,923	0,265	0,273	0,264	0,000
2	8,659	6,764	-9,266	55,563	0,049	0,061	0,093	0,653
3	-0,828	-3,423	-21,793	62,279	0,877	0,915	1,000	1,000
4	5,798	3,945	-11,485	52,465	0,299	0,297	0,254	0,493

	S/N Ratio				Normalization			
Experiment	S/N Ratio Ra	S/N Ratio Rq	S/N Ratio Rz	S/N Ratio MRR	S/N Ratio Ra	S/N Ratio Rq	S/N Ratio Rz	S/N Ratio MRR
5	9,218	7,494	-7,980	60,000	0,000	0,000	0,000	0,882
6	5,465	3,531	-13,133	48,299	0,328	0,332	0,373	0,278
7	8,730	6,821	-8,828	56,902	0,043	0,056	0,061	0,722
8	1,320	-1,015	-18,282	46,021	0,689	0,713	0,746	0,160
9	-2,239	-4,439	-19,816	57,842	1,000	1,000	0,857	0,771

The variation of the surface roughness response (Ra, Rq, and Rz) to the three factors is described in the main effect plot S/N ratio as shown in Figure 4. The graphs of spindle speed, feed rate, and depth of cut are not aligned in a horizontal straight line with respect to the X-axis. The graph states that it affects the surface roughness with different results. The optimal condition on the surface roughness graph is at the level of spindle speed 2600 rpm, feed rate 35 mm/min, and depth of cut 2.5 mm. The three main effect plots illustrate almost the same variation graph, only the mean (Y axis) at Ra is higher than the others. The optimal response combination results from a low feed rate level and a high depth of cut level. This combination is like the results of research by NGUYEN, et al. [21], DAS, et al. [22], and MUHAMMAD, et al. [23] also used a low feed rate and high depth of cut to provide an optimal response, namely surface roughness.

The variation of the material removal rate response to the three factors is described in the main effect plot S/Ratio as shown in Figure 5. The graphs of feed rate, and depth of cut are not parallel to a straight line on the X-axis. This graph states that each level of the fedd rate and depth of cut factors tested affects the response with different results. While the spindle speed factor level is parallel to the X axis, meaning it does not give different results. The optimal conditions on the graph for the material removal rate are spindle speed (1300, 2600, 4000) rpm, feed rate 65 mm/min, and depth of cut 2.5 mm. The optimal response combination is obtained from a high feed rate and depth of cut. Like the research results of VISWANATHAN, et al. [24], SHAGWIRA, et al. [25], and LU, et al. [26] also used a high feed rate and high depth of cut to provide an optimal response, namely the material removal rate.

3.2. Preference Ranking Organization Method For Enrichment Evaluation (PROMETHEE)

The preference ranking organization method for enrichment evaluation (PROMETHEE) is a ranking method with flexible and simple data processing for researchers to evaluate multicriteria problems [27]. The S/N ratio of each response from the taguchi results is used as input in the integration of the PROMETHEE method along with the preference type. The PROMETHEE method processing uses the PROMETHEE viasul application. The surface roughness response characteristic used is only Ra, because the characteristics Ra, Ra, Rz have linear values in the main effect plot. Therefore, the value to be processed will produce the same value to be integrated with PROMETHEE. So the researcher chose one of the criteria, namely Ra, besides that Ra is widely used as a standard in surface roughness [28] [29].

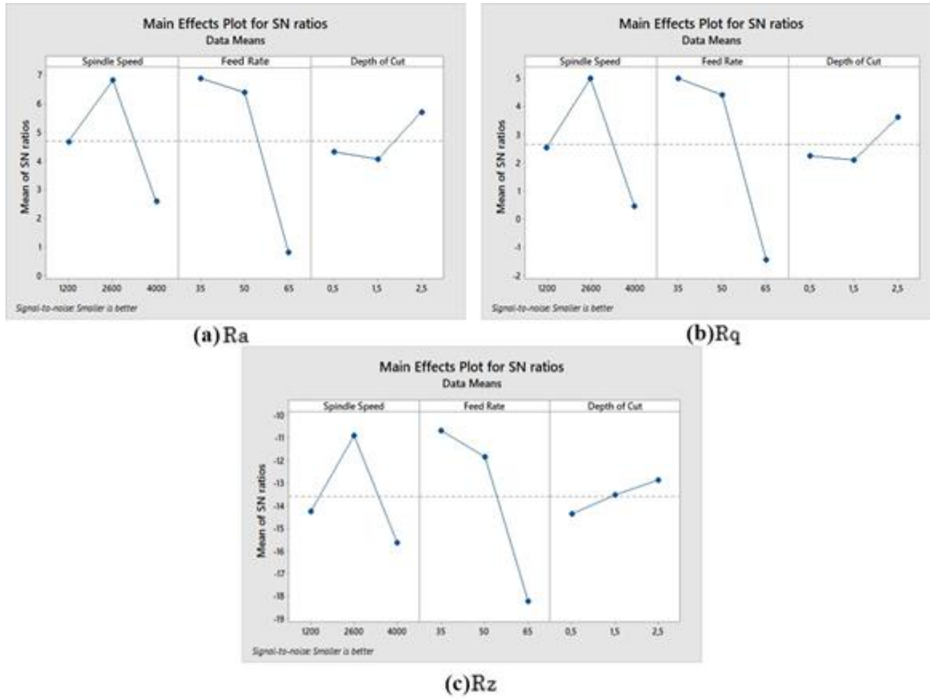

Figure 4. (a) Main Efect Plot for SN Rations Ra, (b) Main Efect Plot for SN Rations Rq, (c) Main Efect Plot for SN Rations Rz

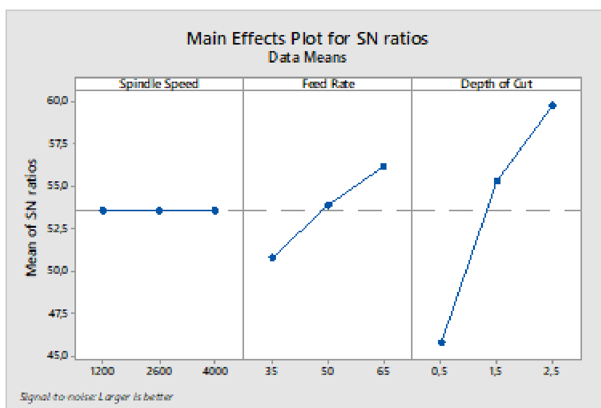

Figure 5. Main Effect Plot for SN Ratio Material Removal Rate

3.2.1. Preference Type

The two responses, surface roughness and material removal rate, use a linear preference type. This type is used because the data in this study is quantitative. And this type can produce consistent and accurate responses in the quality criteria of a product [30]. Table 5 is a table of preference types for each response parameter.

Table 5. Preference Type

	Experiment											
Response Parameters	1	2	3	4	5	6	7	8	9	Purpose	Preference Type	Unit
Surface Roughness	0,265	0,049	0,877	0,299	0,000	0,328	0,043	0,689	1,000	Min	Linear	µm
Material Removal Rate	0,000	0,653	1,000	0,493	0,882	0,278	0,722	0,160	0,771	Max	Linear	mm^3/min

3.2.2. PROMETHEE I and II

PROMETHEE I data processing produces a combination of high leaving flow and lowest entering flow, PROMETHEE II produces the highest net flow as the best experiment. PROMETHEE II produces com-plex and consistent values rather than PROMETHEE I which produces partial rankings. As per the ranking in Table 6, experiment 3 is the most ideal experiment as it has low surface roughness and high material removal rate. Therefore, the combination in experiment 3 can be applied to have optimum and consistent quality and productivity as the objective of this research.

Table 6. Experiment Ranking

Experiment	Leaving Flow	Entering Flow	Net Flow	Ranking
3	0,5651	0	0,5651	1
9	0,5611	0	0,5611	2
8	0,2344	0,2215	0,0129	3
5	0,1588	0,2226	-0,0638	4
7	0,1104	0,2127	-0,1023	5
2	0,0921	0,2201	-0,1280	6
4	0,0387	0,1832	-0,1445	7
6	0,0080	0,2775	-0,2696	8
1	0	0,4310	-0,4310	9

4. ANALYSIS OF VARIANCE

Variance analysis in research is used to statistically calculate the process parameters that affect the response parameters in Table 7. As well as the level of contribution of process parameters to the re-sponse parameters. The data generated by PROMETHEE II is used for variance analysis because it rep-resents the optimization results of surface roughness and material removal rate. The highest contribu-tion of process parameters to the response parameters is the feed rate of 43.235%, followed by depth of cut of 25.248%, and spindle speed of 15.911%.

Table 7. ANOVA

Source	Df	Adj SS	Adj MS	Contribution
Spindle Speed	2	0,1503	0,07515	15,911 %
Feed Rate	2	0,4084	0,20420	43,235 %
Depth of Cut	2	0,2385	0,11924	25,248 %
Error	2	0,1474	0,07370	
Total	8	0,9446		

5. CONCLUSION

This research focuses on multirespon optimization of CNC milling machining on AA6061 with the help of taguchi experimental design and PROMETHEE method. The following are the conclusions of the research objectives that can be accepted with confirmable values:

1. The combination of responses, namely surface roughness and material surface rate, resulted from the variation of experimental process parameters 3 including spindle speed 1200 rpm, feed rate 65 mm/min, and depth of cut 2.5 mm.
2. In the experimental results, the higher the spindle speed, the minimum surface roughness But the spindle speed itself has no effect on the material removal rate, so the speed speed has the last contribution in the multi-response optimization of this study
3. Feed rate has the highest contribution in influencing the response, low feed rate results in small surface roughness and material removal rate. A high feed rate produces a large surface roughness and material removal rate.
4. Depth of cut has a second contribution in influencing the response, low depth of cut results in surface roughness and a fairly small material removal rate. While a high depth of cut produces a large surface roughness and material removal rate.

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