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Optimization of aluminum 6061 surface integrity on dry-running machining CNC milling using Taguchi methods

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Abstract

Aluminum 6061 is an aluminum alloy, which contains aluminum as main entails, then magnesium and silicon are mixed as alloying elements. It had a good capability for corrosion resistance, heat treatable, formed, and welded. Computerized Numerical Control had excellent capability to process mass-production products. Unsubstantial machining parameter setting will lead to a lack of surface roughness or even worse damage on tool steel. The aim of this research is to arrange data about surface integrity conducted by Dry-running machining CNC Milling. Surface integrity included surface roughness and micro-cracks. Aluminum 6061 is chosen as the material. The observed parameter machining in this research is cutting speed 3 is levels 60, 70, 80 mm/minute, then depth of cut is 3 levels 300, 380, 450 mm/minute and depth of cut is 3 levels 0.5, 0.75, 1.0mm. Taguchi L9 (33) was used as a design experiment to find optimum parameters. Based on the result of the experiment in this research, the optimum surface roughness founded on the machining parameter combination of cutting speed was 80 m/min, feed rate 300 mm/min, and depth of cut was 0.5 mm.

***Keywords**: Aluminum 6061, CNC milling, dry-running machining, surface integrity, Taguchi*

1. Introduction

Computer Numerical Control (CNC) became the main option in machining manufacturing, their present shifting conventional milling machine. CNC Milling CNC can produce complex shape because it working on three-axis, some of them can operate in five or more axis (1). CNC milling had the capability to process high precision mass scale quickly and had low energy consumption compared to non-conventional machining. CNC controlled by numerical number series that containing alphanumeric who standardized on ISO 14649-121:2005 (2). Surface roughness is one of criteria that must been met by CNC milling to prove their cutting performance. During producing precision part, surface roughness is a key role (3).

Robust design on research applied to minimizing error and achieve optimum parameter. Taguchi is one of robust design to minimize error during experiment research by eliminate uncontrolled noise factor and obtain improvement process capability by reduce the causes of variability process (4). Applied Taguchi as design experiment allow optimal variable to obtained through the optimal number specimen as well (5).Beside optimization on milling machine parameter, Taguchi was applied in related research and retrieved optimum combination of machining parameters such as; turning machine (6), hot press forming (7), even welding (8), so as to provide an overview for related industries and develop similar research.

The research conducted face milling on EN-31 steel material by combining cutting speed with variables associated with minimum quantity lubrication employing Taguchi

Grey Relational Analysis L18 array. Optimum parameter facing tool wear and surface finish is 110 m/min as cutting speed, 150 ml/hour as lubricant flow rate, 50 mm as spraying distance, and 45° as nozzle elevation angle (9). Another research about optimization using carbide and polycrystalline diamond tool to achieve 1.6 µm surface roughness through depth of cut, Feed Rate, and Cutting speed with tools configuration (10). One research conducted to observe surface roughness, surface strain, micro hardness, and material removal of SS-304 material performed by end. Taguchi grey relational analysis used to optimize coolant, feed rate, depth of cut and cutting speed. Show that contribution of feed rate 36.1038%, followed depth of cut 20.811 %, cutting speed 16.759% and coolant 13.5409% (11). Based on a research lowest surface roughness (0.31µm) on Aluminum 6061 achieved on spindle speed 3500 rpm and feed rate 200 mm/minute (12). Higher rotation of spindle higher chatter generated during metal cutting process, thereby increasing the surface roughness value cut metal (13). Reported drilling operation on Inconel 718 superalloy by using cryogenic treated, show feed rate is most contributing factor for trust cutting force, while spindle speed is the most contributing significant factor for torque, and tool condition is the most contributing factor for surface roughness (14).

Based on current research, there is a lack of research that has discussed optimization about surface integrity on aluminum 6061 dry running machining using Taguchi methods. The purpose of this study is to provide feedback for some data for industries, especially the medium-capitalization tool industry that deals with similar material and machining process.

2. METHODS

2.1 Material and Machine

This research uses aluminum 6061, its density 2.7 g/cm^3. 6061 aluminum alloy is heat treatable, easily formed, weld-able, and is good at resisting corrosion. The milling machine uses RICHON XK-7132A with accuracy 0.0053mm. The tool using 5 mm HSS tool steel. Surface roughness measuring by Mitutoyo SJ-412. The material properties of aluminum 6061 are shown on table 1.

Table 1. Material properties of Aluminum 6061

Element	Content
Aluminum	97.9%
Silica	0.60%
Mangan	1.00%
Chrome	0,20%
Cooper	0,28%

2.2 Research Variable

Determining the level value of each parameter used can be the main component to form a raw workpiece into the final workpiece. The value of each parameter used can be determined through the type of material on the workpiece and the type of tool that will be used when machining. determination of machining parameters based on restrictions on CNC machines, materials, tools and previous research. research variables shown in table 1 below.

Table 2. Research variable

No	Factor	Level		
		1	2	3
1	Cutting speed (m/minute)	60	70	80
2	Feed rate (mm/minute)	300	380	450
3	Depth of cut (mm)	0.5	0.75	1.0

2.3 Surface Roughness Measurement

Measurement of surface roughness of CNC milling dry running cutting results twice on each specimen. One at the end of the feeding and the rest at the end of the feeding, this aims to know the roughness value of the cutting surface at each point. The direction of surface roughness measurement is taken perpendicular to the feeding direction, to obtain accurate roughness results due to the circular CNC cutting profile. It was similar to this research (15). The specimen measurement scheme is shown in Figure 1.

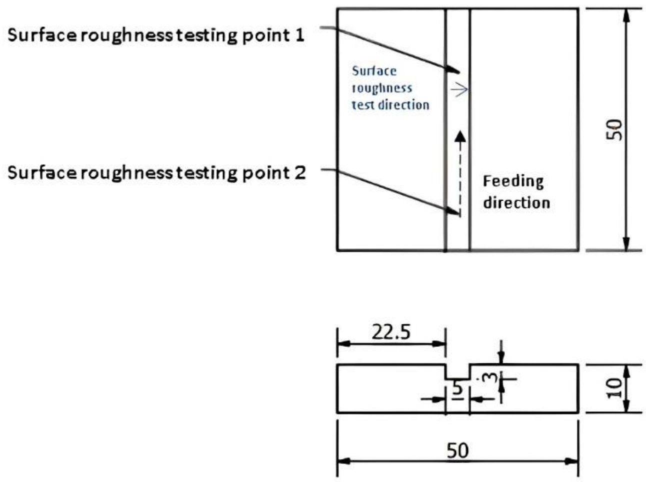

Figure 1. specimen measurement scheme

2.4 Determining Optimal Parameter

It was used to determine and calculate how many experiments or trials in this research. In this research there are two factors, each of which has three levels. The following is a calculation in determining the degrees of freedom for each factor as follows: Cutting speed has 3 levels, Feed rate: 3 level and Depth of cut has 3 so total degrees of freedom are 6. Next step is Calculation for Li degree of freedom used equation on this research (16). Based on those, this research uses an orthogonal matrix L_9 (3^3). After determining the orthogonal matrix, processing the surface roughness data of the experimental results begins by calculating the Sum of Squares which follows the number of squares of the S / N ratio, followed by calculations to obtain the square error of the Sum of Squares so that the Analysis of Variance value of the S / N ratio is obtained. The final step is to determine the optimal parameters using Minitab software, to obtain the optimal CNC Milling dry running cutting with parameters cutting speed, feed rate and depth of cut through to surface roughness. This is similar to the following research (17). Table 2 shows orthogonal matrix L_9 (3^3) design on this research.

Table 3. Orthogonal matrix L_9 (3^3) design

Experiment order	Variable		
	Cutting speed	Feed rate	Depth of cut
1st	60	300	0,5
2nd	60	380	0,75
3rd	60	450	1,0
4th	70	300	0,75
5th	70	380	1,0
6th	70	450	0,5
7th	80	300	1,0
8th	80	380	0,5
9th	80	450	0,75

3. Result and Discussion

This research was conducted according to the procedure in the methods chapter by combining the parameters of cutting speed, feed rate and depth of cut. The variable observed was surface roughness. Each variable has three levels, and each level has three replications. The purpose of replication is to minimize errors during the experiment. From the data, we will find the optimal combination of machining parameters through surface roughness. Surface roughness result and S/N Ratio result are shown on Table 4.

Table 4. Surface roughness test result

Specimen	Variable			Surface Roughness Result (µm)			Average	S/N Ratio
	Cutting speed	Feed rate	Depth of cut	Replication 1	Replication 2	Replication 3		
1	60	300	0.5	0.4127	0.5283	0.3898	0.4436	6,9789
2	60	380	0.75	0.6680	0.6108	0.4648	0.5812	4,6198
3	60	450	1.0	0.5829	0.6807	0.6743	0.6460	3,7745
4	70	300	0.75	0.5549	0.4762	0.3898	0.4737	6,4026
5	70	380	1.0	0.4521	0.5524	0.5626	0.5223	5,6007
6	70	450	0.5	0.5156	0.5930	0.2692	0.4593	6,3820
7	80	300	1.0	0.1993	0.1714	0.2184	0.1964	14,0943
8	80	380	0.5	0.2844	0.3263	0.2374	0.2827	10,8998
9	80	450	0.75	0.3810	0.1981	0.5105	0.3632	8,2870

Data of table 3 shows the lowest surface roughness is 0.1981µm, achieved at cutting speed 80 m/minute, feed rate 450 mm/minute and depth of cut 0.75mm on second replication. The highest surface roughness is 0.6807µm, achieved at cutting speed 60 m/minute, feed rate 450 mm/minute and depth of cut 1.0 mm. This is different compared to the average in each combination. Based on average the lowest surface roughness is 0.1964µm achieved cutting speed 80 m/minute, feed rate 300m/minute and depth of cut 1.0 mm. While the highest surface roughness is 0.6460µm achieved on cutting speed 60 m/minute, feed rate 450 mm/minute and depth of cut 1.0mm. This shows the importance of replicating an experiment in research, so as to reducing data discrepancies and can be reconfirmed on replication with the same parameters such like this research (18) and (19).

3.1 ANOVA Test on the Parameter

S/N ratio conducting to determine which factors that have impact to experiment on this research is surface roughness measurement. Table 5 shows model estimation of S/N ratio coefficient on surface roughness.

Table 5. Model Estimation Mean Coefficient

Term	Coef	SE Coef	T	P
Constant	7.4488	0.4587	16.239	0.004
Cutting speed 60	-2.3244	0.6487	-3.583	0.070
Cutting speed 70	-1.3204	0.6487	-2.035	0.179
Feed rate 300	1.7097	0.6487	2.636	0.119
Feed rate 380	-0.4088	0.6487	-0.630	0.593
Depth of cut 0.5	0.6380	0.6487	0.984	0.429
Depth of cut 0.75	-1.0124	0.6487	-1.561	0.259

Table 6. ANOVA means

Term	DF	Seq SS	Adj SS	Adj MS	F	P
Cutting speed	2	61.294	61.294	30.647	16.18	0.058
Feed rate	2	14.349	14.349	7.174	3.79	0.209
Depth of cut	2	4.716	4.716	2.358	1.25	0.445
Residual error	2	3.788	3.788	1.894		
Total	8	84.146				

Based on table 6 the largest F value in order cutting speed (16,18) followed by feed rate (3.79) and depth of cut (1.25). This is inversely proportional to the P value on the three variables P value for cutting speed is 0.058, P value for feed rate is 0.209 and P value depth of cut is 0.445. The conclusion that can be drawn based on hypothesis testing is that the value of F count < F Table (0.05 versus 2.6) H_0 is accepted for feed rate and depth of cut. The F Table value is 5.14. Based on the ANOVA test, it can be concluded that the feed rate and depth of cut factors have no significant effect on surface roughness. While the value of F count > F Table (0.05,2,6) (Accept H_1) for cutting speed. The F Table value is 5.14. Based on the ANOVA test, it can be concluded that the cutting speed factor has a significant effect on surface roughness. The specimen image of the dry running cutting results is shown in Figure 2.

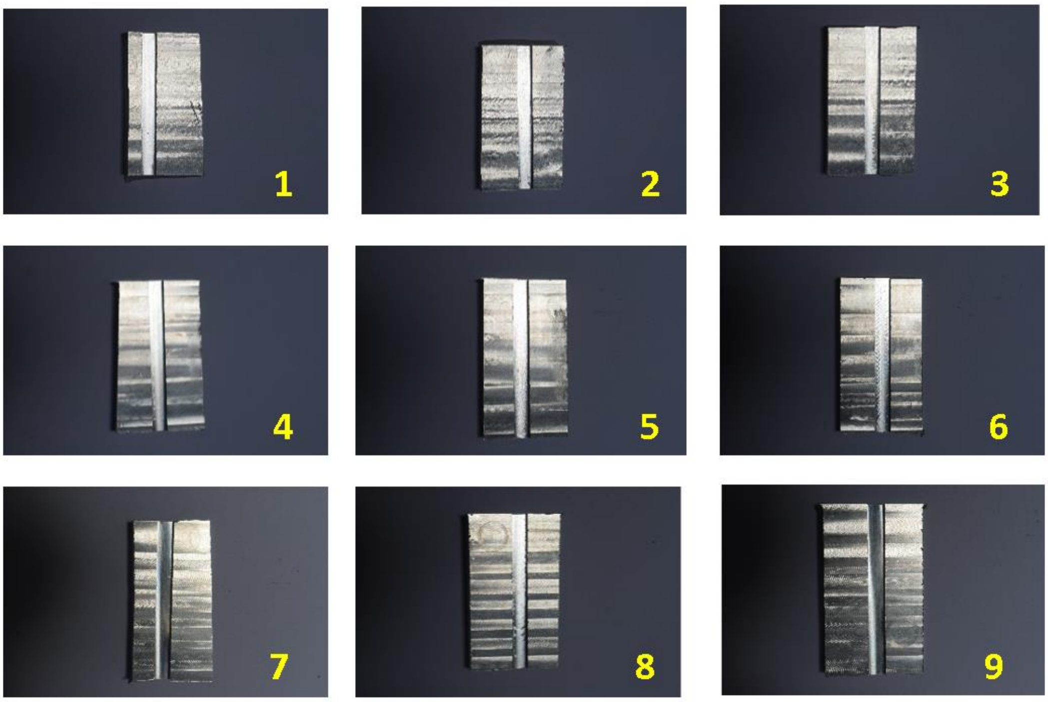

Figure 1. specimens of dry running cutting on aluminum 6061

Table 7 shows the results of the response to the S/N ratio which has an influence from the largest value to the smallest value on surface roughness, where in order the largest value is the cutting speed parameter with a delta value of 5.969 then at the feed rate with a delta value of 3.011 then at the depth of cut with a delta value of 1.650. The delta s/n ratio of both cutting speed and feed rate parameters have identical ranges, but the distance between the delta s/n ratio of cutting speed and feed rate is slightly greater than the difference in the delta s/n ratio values between feed rate and depth of cut parameters.

Table 7. S/N Ratio ranks

Level	Cutting Speed	Feed rate	Depth of cut
1	5.1 24	9.159	8.087
2	6.128	7.040	6.436
3	11.094	6.148	7.823
Delta	5.969	3.011	1.650
Rank	1	2	3

Table 8 shows the results of the response on average which has an influence from the largest value to the smallest value on surface roughness, where in order the largest value is on the cutting speed parameter with a delta value of 0.2762 then at the feed rate with a delta value of 0.1183 then at the depth of cut with a delta value of 0.0775. Based on S/N Ratio and means rank on table 7 and 8 confirmed that cutting speed is the most influenced parameter through to surface roughness performed by dry run cutting on aluminum 6061, followed by feed rate and depth of cut.

Table 8. Means ranks

Level	Cutting Speed	Feed rate	Depth of cut
1	0.5570	0.3713	0.3953
2	0.4851	0.4621	0.4727
3	0.2808	0.4895	0.4549
Delta	0.2762	0.1183	0.0775
Rank	1	2	3

The data in tables 7 and 8 reveal that based on the S/N ratio and mean analysis, the cutting speed parameter has a more significant influence when compared to the feed rate and depth of cut parameters. This can be seen from the difference in delta values between the cutting speed parameter and the feed rate and depth of cut parameters. the order of influence of the three parameters is cutting speed, followed by the feed rate and depth of cut parameters.

3.2 Optimal Factor Level based on Means and S/N Ratio of Surface Roughness

This optimal combination of factor levels can be determined and seen from the mean graph of the effect of factor levels on surface roughness. The optimal combination of factor levels can be determined and seen from the Means graph of the effect of factor levels on surface roughness. Based on figure 3 is a graph of the average effect, namely Determination of the optimal level used in this Taguchi analysis based on the quality characteristics of the smaller the better which has the smaller the value the better it is used because if the smaller the surface roughness value, the better the workpiece produced. Based on Figure 3, it is known that the optimal conditions based on the average surface roughness value are cutting speed at level 3, feeding rate at level 1 and depth cut at level 1.

Figure 3 Optimum parameter based on Means plot

The optimal combination of factor levels can be determined and seen from the graph of the S/N ratio value of the effect of factor levels on surface roughness. Based on Figure 4 is a graph of the effect of the S/N ratio, namely Determination of the optimal level used in this Taguchi analysis based on the quality characteristics of the smaller the better which has the smaller the value the better this is used because if the smaller the surface roughness value, the better the workpiece produced. Based on the figure above, it is known that the optimal condition based on the S/N ratio value of surface roughness is cutting speed at level 3, feed rate at level 1 and depth of cut at level 1.

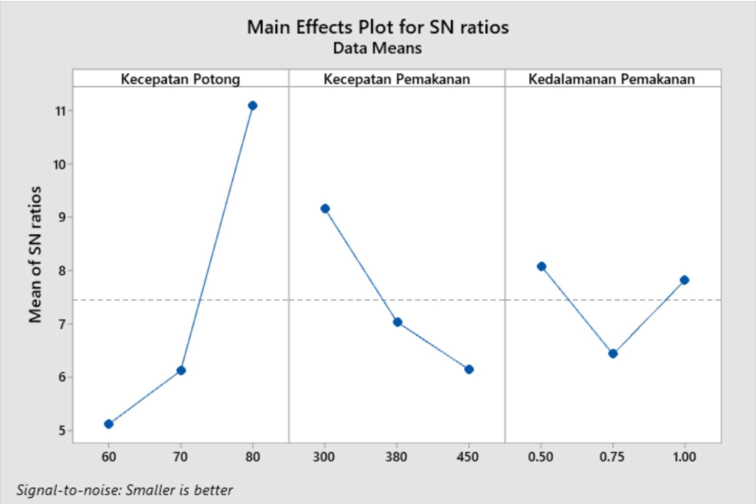

Figure 4. Optimum parameter based on S/N Ratio plot

Figures 3 and 4 reveal the optimized data based on the S/N ratio and mean plot using the Taguchi L_9 method. in both figures, the cutting speed parameters at speeds 60 m/min and 70 m/min have a sloping line pattern, while from 70 m/min to 80 m/min have a steep line pattern. This indicates that speed 80 has low surface roughness results. Similar to occurs in the plot results of the S/N ratio and the mean on the feed rate parameter. at feed rates 450 mm/min and 380 mm/min tend to have a sloping line pattern when compared to 380 mm/min to 300 mm/min. this indicates that the 300 mm/min feed rate has low surface roughness results when compared to 380 mm/min and 450 mm/min on 6061 aluminum material on dry running machining. the similar happens to the S/N ratio plot results and the mean on the depth of cut parameter. in the depth of cut on the polled line pattern 0.5mm to 0.75mm up, but still has a sloping tendency. It is also identical at 0.75mm to 1mm, only it's decreasing. This indicates a depth of cut of 0.75 mm tends to produce poor roughness. at a depth of cut of 0.5mm and 1mm they are identical but based on the Taguchi L_9 analysis the depth of cut of 0.5mm is slightly better than 1mm. based on the results of Taguchi L_9 the optimum parameter combination to get lowest surface roughness on CNC milling dry running condition is 80 m/min cutting speed, 300 mm/min feed rate and 0.50 depth of cut.

3.3 Analysis of the Effect of Significance Level of Surface Roughness

Based on the results of data processing with the Taguchi method in this study with variations in cutting speed parameters of 60, 70, 80 m/min, feeding speed parameters of 300, 380, 450 mm/min and feeding depth parameters of 0.5, 0.75, 1.0 mm. Data processing results in cutting speed parameters have a significant effect on surface roughness due to the value of F count> F table. The parameter of feeding speed does not have a significant effect on surface roughness because F count < F table and the parameter of depth of feed does not have a significant effect on surface roughness because F count < F table.

The cutting speed parameter on surface roughness has a significant effect on spindle rotation speed, the higher the cutting speed, the higher the spindle speed. Based on the research conducted, the higher the cutting speed parameter, the lower the roughness value produced, resulting in a workpiece with a smoother surface. The higher the cutting speed makes the tool rotate faster, the faster the tool rotates resulting in friction between the tool and the workpiece more often. Frequent friction produces instantaneous heat so that it makes the cut material easier to follow the cutting results, because there is heat generated during friction between work piece and tool steel following research (20) and reported that the heat achieved 540°C on dry running operation (21). The higher the rotation at the cutting speed, the higher the generated heat gets, then cut and melted more material in work piece then deposit while the tool steel left behind. Those making cutting process workpiece have a low surface roughness, it can be concluded that the surface roughness value is directly proportional to the cutting speed parameter. This phenomenon also appear in turning machine operation, but reported that will affected to low roundness cutting profile on work piece (22). The feeding speed parameter to surface roughness is the rotation speed of the tool movement when eating the workpiece or material. Based on the research conducted, the higher the feeding speed parameter, the higher the roughness value produced, which means the rougher the surface roughness value. This shows that the surface roughness value is inversely proportional to the feed speed parameter. The higher the feed rate results in cutting contact from the tool to the material getting shorter, resulting in the tool not cutting the workpiece optimally. This is exacerbated by dry running conditions, thus making the cut workpiece have high surface roughness.

The parameter of depth of feed to surface roughness is the depth of tool movement when eating the workpiece or material. Based on the research conducted, the higher the depth of feed parameter, the higher the roughness value produced, which means the rougher the surface roughness value. This shows that the surface roughness value is inversely proportional (rougher) to the depth of feed parameter. The parameters of feeding speed and depth of feed have an insignificant effect on surface roughness due to the vulnerable level that is too close.

4. Conclusion

Based on the research conducted using the Taguchi method analysis, it can be seen that the effect of CNC milling machining parameters, such as cutting speed, feeding speed and depth of feed on surface roughness, has different effects. The effect of cutting speed on surface roughness is significant because the value of F count> F table. The higher the cutting speed value, the smaller the surface roughness value. The effect of feeding speed on surface roughness is insignificant due to the value of F count < F table. The higher the feed speed value, the higher the surface roughness value (rough). The effect of depth of feed on surface roughness is insignificant due to the F value < F table. The higher the depth of the feed value, the higher the surface roughness value. In this research, the lowest surface roughness in the combination of 0.1993µm is achieved in the combination of cutting speed 80, cutting speed 300 and depth of feed 1.0 on first replication. While the highest surface roughness result is 0.6907µm obtained in the combination of cutting speed 60 feeding speed 450, and depth of feed 1.0 on second replication. Based on the research conducted using the Taguchi method analysis, the combination of machining parameter levels obtained cutting speed at level 3 of 80 m/min, feeding speed at level 1 of 300 mm/min, and depth of feed at level 1 of 0.5 mm. cutting on aluminum 6061 using 5 mm HSS tool steel under dry running cutting conditions on a CNC milling machine, the cutting speed parameter is directly proportional to the surface roughness, while the feed rate and depth of cut parameters are inversely proportional. Further research can be directed at analyzing the surface roughness of the results of cutting using different materials of tools.

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