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Optimization of Surface Roughness on 6061-T6 Aluminium Alloy in CNC Milling Machine Using Response Surface Methodology

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ABSTRACT

This paper presents an experimental study of optimization of controllable cutting parameter in CNC (VMC-1000) milling machine. RSM utilized to create an optimization plot for surface roughness regarding cutting parameters: cutting speed, depth of cut and feed rate. For this purpose, A 20 experiments based on statistical three-level full central composite design (CCD) in Minitab-16 software carried out to come out with the best surface roughness value of 6061-T6 AL. The cutting tool that used was (HSS-4 flute) high-speed steel. The optimization plot generated to show the parameter reaction to achieve a better value of surface roughness. The final optimal parameters setting were (cutting speed 1400 rpm, depth of cut 0.5818 mm and feed rate 120 mm/min). By testing the final optimal parameters five times, the result verified to be 0.3 µm. The outcome witnesses that cutting speed has significant effect on the surface roughness while depth of cut and feed rate have less effect within the range of experimental values.

Keywords:
Surface roughness, response surface methodology, cutting parameters, CNC milling machine, minitab-16 software, optimization process

1. Introduction

Surface finished quality play an important role in the industrial world todays. From customer's perspective, product quality affects its satisfaction degree of consumers while they are using it. It also improves the company reputation[1, 2]. End-milling operation done on CNC milling machine. Surface roughness effects on some functional attributes of parts, such as contact causing surface friction, wearing, light reflection, the ability to distribute and also holding a lubricant, load-bearing capacity, coating and resisting fatigue[3–5].

The problem that faces industry is there is no constant best surface roughness value for specific material at a specific process. Because have uncontrollable factors that affect the process. Moreover,

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traditional trials and error method are time consuming, inaccurate, very expensive, and it depends on the technician experience [6, 7].

The various research studied on the effects of various parameters of end milling process on aluminium alloy. Most of them are using the parameters of spindle speed (800-1200) rpm, depth of cut (0.2-0.4) mm and feed rate (60-100) mm/min [8–13]. By using Taguchi Methodology the output characteristic, surface finish analysed by software Minitab and ANOVA. They approved experimentally significant factors affect the response which is

Feed rate has the highest effect on the response spindle speed has the second highest effect on response and depth of cut has least. The L50 orthogonal array adopted for the present investigation. So 50 experiments conducted and the average surface roughness of all these components measured and used to build a mathematical model using (RSM) and controllable parameter (axial depth of cut, radial depth of cut, feed rate and cutting speed nose radius). Study on optimization of machining parameters in turning of AISI 202 austenitic stainless steel is done by using (DOE- full factorial design) [14]. The result analysed by using Minitab 14 software. Moreover, he concluded in his research that in order to obtain a good surface finish on AISI 202 steel, higher cutting speed, lower feed rate, lower depth of cut and higher nose radius are preferred. Speed has the highest effect on the response; feed has second highest effect on response and depth of cut has least effect on output response[15].

This paper aims to analyse the effect of CNC milling parameters to the surface roughness of 6061-T6 Aluminium Alloy and selecting the optimum parameters level setting to achieve better surface roughness.

2. Experimental Setup and Procedure

By using the design of experiment method (DOE), a central composite design has been adapted to follow up. The minimum and maximum values of parameters setting selected according to the past researches in literature review [15–18]. Workers and technician experience also are being considered as well as machine capability, the cutting tool (HSS, 4-Flute) and cutting condition (dry machining); shown in Table 1.

Table 1
Parameters setting and levels

Parameters	Levels		
	Min (-1)	Avg (0)	Max (1)
Cutting speed (rpm)	400	900	1400
Depth of cut (mm)	0.10	0.55	1.00
Feed rate (mm/min)	120	160	200

CNC machine programmed by G&M code (shown in Figure 1). All of the measurement done by using surface roughness tester as shown in Figure 2.

2.1 RSM Design

The purpose of response surface methodology is to determine the factors level that will simultaneously satisfy a set of desired specifications, to select the optimum combination of factors that yield a desired response and describes the response near the optimum, to determine how a specific response is affected by changes in the level of the factors over the specified levels of interest, and achieve a quantitative understanding of the system behavior over the region tested [19].

Fig. 1. CNC Milling Machine

Fig. 2. MITUTOYO (CS-5000 CNC)

By using Minitab-16 software the design has been conducted, choosing central composite design (CCD) with three number of factors and the value of alpha is a standard for (CCD) equal to one.

Alpha (α is the distance from the center of the design space to a star point and the value of (α allows simultaneous rotatable. Alpha (α equal to one given by Minitab-16 software as default in central composite design. The axial points placed on the “cube” portion of the design. This is an appropriate choice when the “cube” points of the design are at the operational limits [20]. The design generated by Minitab-16 shown in Table 2.

Table 2
Central composite design

Run order	p. type	Blocks	Parameters		
			Cutting speed (rpm)	Depth of cut (mm)	Feedrate (mm/min)
1	0	1	0	0	0
2	1	1	-1	-1	1
3	1	1	1	-1	-1
4	1	1	1	1	-1
5	1	1	1	1	1
6	0	1	0	0	0
7	0	1	0	0	0
8	1	1	-1	1	-1
9	1	1	-1	1	1
10	1	1	1	-1	1
11	0	1	0	0	0
12	1	1	-1	-1	-1
13	-1	2	-1	0	0
14	0	2	0	0	0
15	0	2	0	0	0
16	-1	2	0	1	0
17	-1	2	1	0	0
18	-1	2	0	0	1
19	-1	2	0	0	-1
20	-1	2	0	-1	0

2.2 Experimental Details

A three rectangular cubic 6061-T6AL length 200mm, width 50mm and thickness 40 mm. There are 20 trails conducted with no defects occur. The whole process is done by using CNC -VMC 5000 milling machine (end-mill process). The cutting tool was (HSS-4 flute) and dry machining condition.

There are 20 experiments has been conducted. The specimen divided into three groups, each specimen length, width and thickness are (200, 50, 40) mm respectively. The whole process conducted by using fully control CNC milling machine.

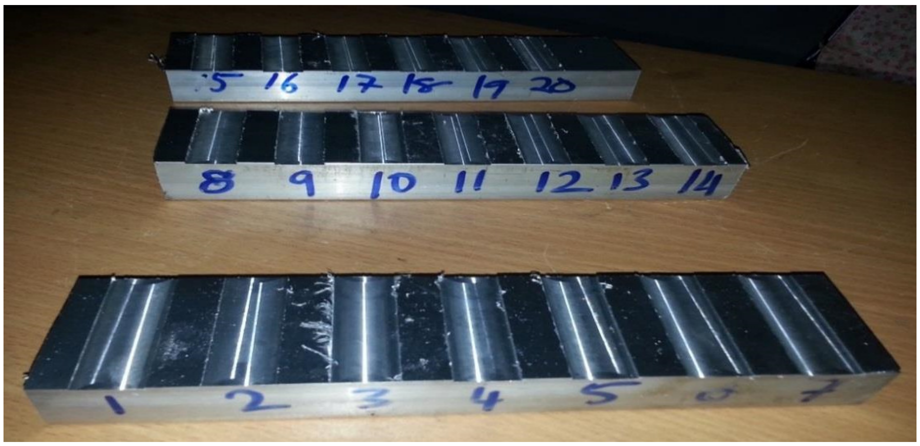

Fig. 3. Tested Material (6061-T6 AL)

Figure 3 shows the 20 trails conducted by using fully control CNC milling machine (end-mill process). The experiment shows that the number of cutting tool teeth engaged in cutting process affects the surface roughness profile

3. Results and Discussion

The data collection includes surface roughness as the output response. The analysis divided into three major parts, which is RSM analysis, conformation analysis and measurement device analysis.

RSM analysis includes contour plot of surface roughness for the three factors among three cases, where it is done by showing the reaction of two factors with surface roughness profile and setting the third factor at the lowest factor analysis (lowest value). RSM analysis also includes the surface plot for three cases. The purpose of surface plot is to investigate the effect of the parameter to get the optimal surface roughness value. Lastly, the process of optimization is carried out to find the optimal surface roughness value for the finishing case.

Table 3 shows the experiments control factors. The experimental data collected to use for response surface methodology analysis.

Table 3
Experiment Control Factor

Control factors	Values			Unit
Cutting speed	400	900	1400	rpm
Depth of cut	0.1	0.55	1	mm
Feed rate	120	160	200	mm/min

Table 4 shows the surface roughness values for all experiments. The best surface roughness value is (0.492μm) as shown in experiment 17.

Table 4
Experiment Result

NO	Parameters			Response
	v_c (rpm)	a_p (mm)	v_f (mm/min)	R_a (μm)
1	900	0.55	160	2.207
2	400	0.10	200	2.599
3	1400	0.10	120	1.594
4	1400	1.00	120	1.563
5	1400	1.00	200	2.057
6	900	0.55	160	2.427
7	900	0.55	160	2.287
8	400	1.00	120	2.241
9	400	1.00	200	2.209
10	1400	0.10	200	2.052
11	900	0.55	160	2.388
12	400	0.10	120	1.927
13	400	0.55	160	2.699
14	900	0.55	160	2.330
15	900	0.55	160	1.620
16	900	1.00	160	1.478
17	1400	0.55	160	0.492
18	900	0.55	200	2.009
19	900	0.55	120	1.142
20	900	0.10	160	2.562

The parameters were set to achieve best surface roughness using normal trials method found to be the maximum value of cutting speed (1400rpm), middle level of depth of cut (0.55mm), and middle level of feed rate (160mm/min). The problem for this method is the feed rate value significantly affects the cutting tool life because the highest value may cause failure.

3.1 RSM Analysis

RSM analysis divided into three cases to construct contour and surface plots for two factors and one response. The contour plot shows the reaction of two factor to achieve better surface finish quality, which represented by the light green area. The contour plot and the surface plot generated by selecting the lower factor analysis, which is to set the hold value equal to minimum value of the third parameter for each case.

3.1.1 First case

For the first case, the parameters were selected to be feed rate and cutting speed. The hold value of the depth of cut was 0.1mm. Table 5 shows the involvement trails to come out with contour and surface plots. Surface plot represent the surface response of two factor in order to get the optimal surface roughness value as shown in Figure 4 and 5.

Table 5
Surface roughness versus cutting speed & feed rate

No	Cutting speed (rpm)	Feed rate (mm/min)	Ra (μm)
2	400	200	2.599
3	1400	120	1.594
10	1400	200	2.052
12	400	120	1.927
20	900	160	2.562

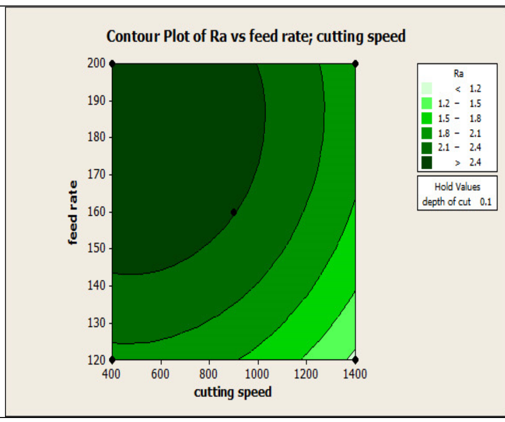

Figure 4: Contour plot

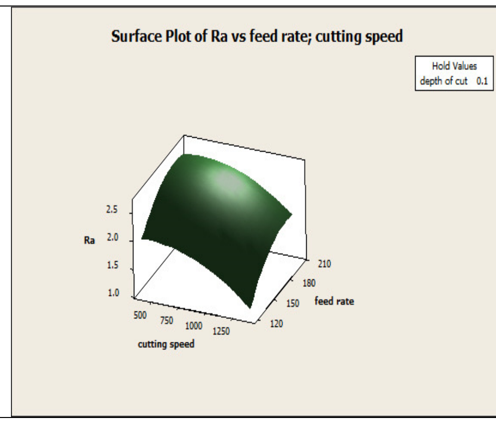

Figure 5: Surface plot

3.1.2 Second case

The contour and surface plots were generated for depth of cut and ctting speed while the feed rate hold value was (120 mm/min). All of the trails involve were shown in Table 6**.**

Table 6
Surface roughness versus cutting speed & depth of cut

No	Cutting speed (rpm)	Depth of cut (mm)	Ra(μm)
3	1400	0.10	1.594
4	1400	1.00	1.563
8	400	1.00	2.241
12	400	0.10	1.927
19	900	0.55	1.142

3.1.3 Third case

For the third case the hold value was (400 rpm). The contour and surface plot have been constructed. Table 7 represents the surface roughness values for the third case.

Table 7
Surface roughness versus depth of cut & feed rate

No	Depth of cut (mm)	Feed rate (mm/min)	Ra(µm)
2	0.10	200	2.599
8	1.00	120	2.241
9	1.00	200	2.209
12	0.10	120	1.927
13	0.55	160	2.699

3.2 RSM Findings

By applying response surface methodology analysis in Minitab-16 software, the counter & surface plots shows the best range of surface finishing quality accomplished by highest value of cutting speed (1400 rpm), the middle value of depth of cut (0.5-0.6) mm and lower value of feed rate (120 mm/min). The result has matched the hypothesis because the high level of cutting speed allow the cutting tool to process faster while a lower level of feed rate allows the cutting tool to cover all of the necessary areas.

3.3 Process Optimization

The result verification was done by testing the parameter setting from optimization plot five times which is, feed rate (120 mm/min), depth of cut (0.5818 mm) and cutting speed (1400 rpm) as shown in Figure 6. The optimal surface roughness values were measured to be (0.331, 0.344, 0.305, 0.362, and 0.277) µm and the average value was taken to be 0.3238 µm as shown in Table 8.

Table 8
Optimization summary

Response	Parameters			Ra (µm)
	Vc (m/min)	ap (mm)	Vf (mm/min)	
Experiment 17	1400	0.55	160	0.4920
Optimal result	1400	0.5818	120	0.3238

Figure 6 shows cutting speed drastically affect surface roughness followed by the depth of cut and feed rate. The curves represent the effect to surface roughness while the red line indicates the optimal value of the parameter.

4. Conclusion

The effect of cutting speed, depth of cut and feed rate on the surface roughness have been studied and analysed by using response surface methodology technique. The parameters were measured using the experimental design. According to the analysis, cutting speed affect the most on the surface roughness. The surface roughness changes drastically with the increasing of cutting speed regardless of the change of depth of cut. Feed rate, cutting speed and depth of cut are very crucial factors that need to be controlled and chosen carefully. The optimization plot has been developed by using Response Surface Methodology for prediction of surface roughness in milling. By testing, the parameters level from optimization plot five times the surface roughness values have been decreased to the optimal value which is 0.3µm. An optimization of material removable rate (MRR) for this research its recommended because some company cares about material removable in term of the price after achieving 70% of the best surface roughness value.

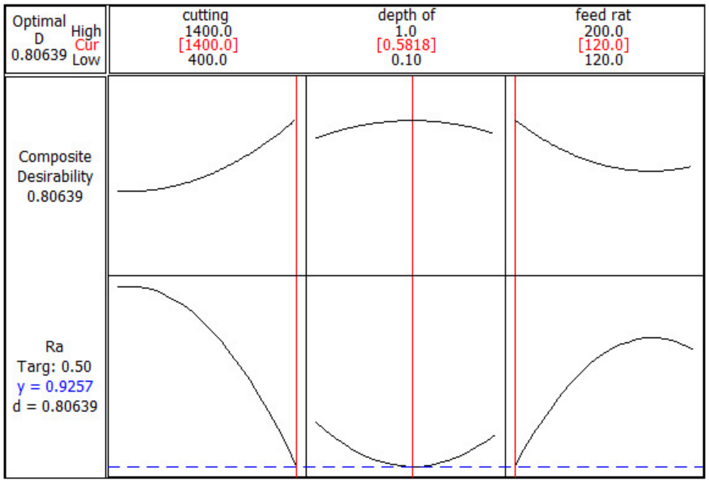

Fig. 6. Optimization plot

Reference

[1] Sharma, Manisha, Geoffrey IN Waterhouse, Samuel WC Loader, Sanjay Garg, and Darren Svirskis. "High surface area polypyrrole scaffolds for tunable drug delivery." *International journal of pharmaceutics* 443, no. 1-2 (2013): 163-168.

[2] Reddy, B. Sidda, J. Suresh Kumar, and K. Vijaya Kumar Reddy. "Optimization of surface roughness in CNC end milling using response surface methodology and genetic algorithm." *International Journal of Engineering, Science and Technology* 3, no. 8 (2011): 102-109.

[3] Prajina, N. V. "Multi-response optimisation of CNC end milling using response surface methodology and desirability function." *International Journal of Engineering Research and Technology* 6, no. 6 (2013): 739-746.

[4] Kuram, Emel, and Babur Ozcelik. "Multi-objective optimization using Taguchi based grey relational analysis for micro-milling of Al 7075 material with ball nose end mill." *Measurement* 46, no. 6 (2013): 1849-1864

[5] Benardos, P. G., and G. Cl Vosniakos. "Prediction of surface roughness in CNC face milling using neural networks and Taguchi's design of experiments." *Robotics and Computer-Integrated Manufacturing* 18, no. 5-6 (2002): 343-354.

[6] Al Hazza, Muataz Hazza F., Erry YT Adesta, M. Y. Superianto, and Muhammad Riza. "Cutting temperature and surface roughness optimization in cnc end milling using multi objective genetic algorithm." In Advanced Computer Science Applications and Technologies (ACSAT), 2012 International Conference on, pp. 275-278. IEEE, 2012.

[7] Raju, Kantheti Venkata Murali Krishnam, Gink Ranga Janardhana, Podaralla Nanda Kumar, and Vanapalli Durga Prasada Rao. "Optimization of cutting conditions for surface roughness in CNC end milling." *International journal of precision engineering and manufacturing* 12, no. 3 (2011): 383-391.

[8] Routara, B. C., A. Bandyopadhyay, and P. Sahoo. "Roughness modeling and optimization in CNC end milling using response surface method: effect of workpiece material variation." *The International Journal of Advanced Manufacturing Technology* 40, no. 11-12 (2009): 1166-1180.

[9] Zhang, Julie Z., Joseph C. Chen, and E. Daniel Kirby. "Surface roughness optimization in an end-milling operation using the Taguchi design method." *Journal of materials processing technology* 184, no. 1-3 (2007): 233-239.

[10] Patel, Bharat S., and Hiren Pal. "Optimization of machining parameters for surface roughness in milling operation." *International Journal of Applied Engineering Research* 7, no. 11 (2012): 2012.

[11] Kumar, Harish, Mohd Abbas, Aas Mohammad, and Hasan Zakir Jafri. "Optimization of cutting parameters in CNC Turning." *Optimization* 3, no. 3 (2013): 331-334.

[12] P. Sahoo, "OPTIMIZATION OF TURNING PARAMETERS FOR SURFACE ROUGHNESS USING RSM AND GA," *Adv. Prod. Eng. Manag*., vol. 6, no. 3, pp. 197–208, 2011.

[13] Abdallah, Ali, Bhuvenesh Rajamony, and Abdulnasser Embark. "Optimization of cutting parameters for surface roughness in CNC turning machining with aluminum alloy 6061 material." *Optimization* 4, no. 10 (2014).

[14] Kadirgama, K., M. M. Noor, M. M. Rahman, M. R. M. Rejab, Che Hassan Che Haron, and K. A. Abou-El-Hossein. "Surface roughness prediction model of 6061-T6 aluminium alloy machining using statistical method." *European Journal of Scientific Research* 25, no. 2 (2009): 250-256.

[15] Qasim, Arsalan, Salman Nisar, Aqueel Shah, Muhammad Saeed Khalid, and Mohammed A. Sheikh. "Optimization of process parameters for machining of AISI-1045 steel using Taguchi design and ANOVA." *Simulation Modelling Practice and Theory* 59 (2015): 36-51.

[16] Yang, WH P., and Y. S. Tarng. "Design optimization of cutting parameters for turning operations based on the Taguchi method." *Journal of materials processing technology* 84, no. 1-3 (1998): 122-129.

[17] Youssef, Helmi A., and Hassan A. El-Hofy. Machining technology: machine tools and operations. CRC Press, 2008.

[18] 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.

[19] Sematech, N. I. S. T. "Engineering statistics handbook." NIST SEMATECH (2006).

[20] Gopalsamy, Bala Murugan, Biswanath Mondal, and Sukamal Ghosh. "Taguchi method and ANOVA: An approach for process parameters optimization ofhard machining while machining hardened steel." (2009).