Advances and Applications in Mathematical Sciences
Volume 21, Issue 9, July 2022, Pages 5299-5307
© 2022 Mili Publications, India

DESIRABILITY FUNCTION INTEGRATED RESPONSE SURFACE FOR CNC MILLING PROCESS VARIABLES OPTIMIZATION

RAM KRISHNA RATHORE*, RITIK LAXMIKANT UDAWANT, PRANSHU BASAK, BISHNU PRASAD ADHIKARI, PAPPU KUMAR and A. J. PRINSON

Department of Mechanical Engineering
Rungta College of Engineering and Technology
Bhilai, CG,-490024, India

Abstract

The impact of machining factors such as spindle speed, depth of cut, and feed rate on the surface quality achieved in CNC end milling is explored. In this study, the Taguchi, and response surface method (RSM), techniques were combined to predict optimal machining settings for AL6061 Aluminium alloy with the lowest surface roughness and high material removal rate (MRR) values. The effectiveness of computer numerical control processing parameters which include spindle speed, feed rate, and depth of cut on arithmetic average roughness (Ra) and MRR was investigated using a design of experiment. A stylus was used to measure the average surface roughness values of the samples. Using Taguchi L27 orthogonal array Design of experiment was generated then a second-order response surface regression mathematical model was generated and finally optimized using box-bohen design response optimizer using desirability function. In three steps, the best machining conditions for reducing Ra and MRR were determined. The proposed strategy provides an efficient way for minimising surface roughness and maximising material removal rate, according to experimental data for AL6061 Aluminium alloy.

1. Introduction

Milling machine is a type of machine where rotating multi point cutting tool is used, cutting tool is also known as milling tool. Surface quality, surface roughness, production time, and productivity are all affected by this

2020 Mathematics Subject Classification: 65.
Keywords: Milling, RSM, Taguchi, optimization, CNC.
*Corresponding author; Email: krish.rathore@gmail.com
Received February 24, 2022; Accepted May 7, 2022

procedure [1, 2]. As a result, judging the condition of the aluminium surface is a challenging task. Many researchers proposed methods for determining cutting parameters, such as using a handbook or the operator's prior experience from earlier studies [3, 4]. Researchers used a CNC machine to conduct studies to establish the structure of the CNC processing variables on surface roughness [5]. To achieve higher surface quality, the best machining parameters must be used. Furthermore, the significant elements for processing parameters should be used in a systematic manner [6]. To reduce the number of experiments, sophisticated experimental design is required. The design of experiment approach is a useful tool for reducing the number of duplicates in a study. In engineering, the central composite design (CCD), Taguchi, and Box-Bohen (BBD) designs have all been frequently employed [7 - 10]. From the above literature we can see that there are many types of optimization techniques available and the optimised result can be still optimised by the new available techniques [10]. The different types of optimization had performed on different machining operation with different machining parameter consideration, but still there are probabilities to get better optimization result [10]. For the machining of any material proper selection of cutting parameters are most important. There are many types of research are conducted for finding and selection of cutting parameter. But still some work is still required for optimize the end result. The motivation behind my research work is to minimise the research gap for modelling and optimization of milling process parameters i.e. velocity, Depth of cut and Feed, using Taguchi method and also optimize the milling parameter by using RSM algorithm for end milling on AL6061 Aluminium alloy with selected ranges of parameters on alloy.

2. Work Material

Table 1. Chemical composition of Al6061 [20].

Al	Mg	Si	Fe	Cu	Cr	Zn	Ti	Mn	Remainder
95.85-98.56	0.8-1.2	0.40-0.8	0.0-0.7	0.15-0.40	0.04-0.35	0.0-0.25	0.0-0.25	0.0-0.15	0.05 each, 0.15 total

This research work is carried on aluminium alloy 6061. For the milling process parameter optimization of AL6061 aluminium alloy 3 aluminium

6061 alloy plate have been taken, milling process is done on this workpiece material with the CNC milling machine. Chemical composition and mechanical properties of AL6061 are shown in table1. Figure 1 shows the AL6061 workpiece sample for the experimentation.

Figure 1. AL6061 Work Piece.

3. Experimental Setup

This research work is deals with the optimization of end milling process parameters for AL6061 Aluminium, alloy. For that milling machine is required to perform the milling with the input variables. Proper selection of cutting tool is also a big task, because the process is affected by the tool material also. The CNC milling machine used is from MCV-350 from Ace Micromatic utilizes FANUC Series oi-MF controller. For weight of the work piece before and after the machining a weight measurement device is needed. An electronic weight measurement device is used. For surface roughness calculations Mitutoyo surface roughness tester sj-210 is used after studying different published articles and research paper the cobalt bonded cemented carbide tool for end milling operation is selected. Tool is having 4 flutes with 16 mm diameter and made of ASPHALT with square end. Cutting fluid or coolant is play a major role in any machining operation, the cutting fluid minimises friction generated at the contact surface, and also minimises the heat generated at that portion. Removal of the chips is also a major process, this process decreases failure of work piece and cutting tool, this work is also done by the cutting fluid or coolant. In this process the servo way – 68 lubricating oil is used. For the optimization of the milling output responses three input parameters for end milling operations as feed, depth of cut and cutting velocity are selected. These are taken in a 3 level of input parameters as shown in table 2.

Table 2. Three level of input parameters.

parameter	1 level	2 level	3 level
speed RPM	580	920	1700
feed mm/min	26	41	55
depth of cut mm	1.2	1.8	2.6

4. Modelling and Optimization

Design of experiment (DOE): For the optimization purpose three input parameters and two output responses have been selected. The design of experiment (DOE) is conducted by Taguchi's L27 Orthogonal Array by using Minitab software ®19. Based on the 27 cases generated using Taguchi the experimentation is carried out on the CNC machine for the output response observation. The input parameters and output responses are shown in table 3. The input and output parameters are abbreviated as S, F, D, MRR, Ra for cutting speed, feed, depth of cut, material removal rate, and surface roughness respectively.

Table 3. Design of experiment and out Responses.

S. No.	Cutting Speed (RPM)	Feed (mm/min)	Depth of Cut (mm)	MRR (mm3/min)	Surface Roughness (μa)
1	580	26	1.2	408.424443	0.283
2	580	26	1.2	408.499202	0.193
3	580	26	1.2	412.650093	0.155
4	580	41	1.8	1291.64851	0.174
5	580	41	1.8	1288.94653	0.25
6	580	41	1.8	1298.4413	0.2
7	580	55	2.6	2039.73391	0.136
8	580	55	2.6	2040.86845	0.14

9	580	55	2.6	2047.20407	0.156
10	920	26	1.8	710.713049	0.175
11	920	26	1.8	706.207373	0.235
12	920	26	1.8	708.920188	0.214
13	920	41	2.6	1730.20056	0.195
14	920	41	2.6	1734.69087	0.15
15	920	41	2.6	1749.11817	0.192
16	920	55	1.2	1160.13072	0.187
17	920	55	1.2	1162.01423	0.217
18	920	55	1.2	1170.98166	0.273
19	1700	26	2.6	958.549671	0.198
20	1700	26	2.6	954.616588	0.238
21	1700	26	2.6	953.004892	0.281
22	1700	41	1.2	710.222222	0.176
23	1700	41	1.2	715.352449	0.166
24	1700	41	1.2	720.082632	0.189
25	1700	55	1.8	1469.02042	0.197
26	1700	55	1.8	1471.49009	0.194
27	1700	55	1.8	1472.13727	0.223

Regression Modelling using Response Surface Methodology (RSM): The results obtained from the Taguchi and the 27 experiments are used for the regression mathematical modelling using Response surface methodology. This Regression is relating the process parameters to the response and generates a Mathematical equation. By this Mathematical equation all constraints can be formulated and further optimization can be performed by using Evolutionary algorithms. Table 4 shows the RSM full quadratic regression model summary for the MRR, which shows a high curve fitting capability as the value of R square is 99.99%. P-Value tells about the significance of parameters it should be ≤0.05 and the Rsq(adj) value should be ≥ 70%, here the values are 99.99% for MRR that is far better the required limit. Here the value of R-sq is 96.03% for Ra represents a good curve fitting model for further calculation of optimum response variables.

Table 4. Model Summary.

S	R-sq	R-sq(adj)	R-sq(pred)	
4.91718	99.99%	99.99%	99.99%	MRR
0.0357476	96.03%	95.05%	96.00%	Ra

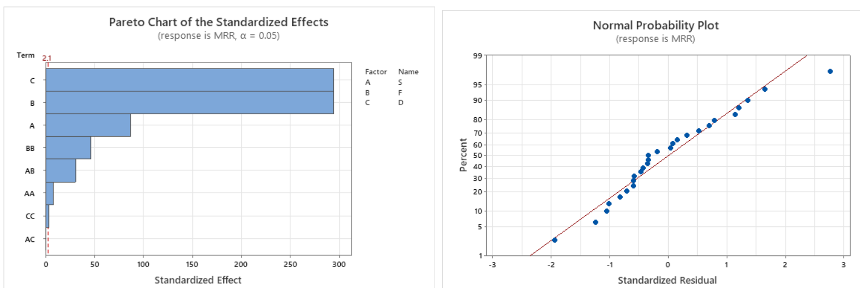

Figure 2. Residual Plot for MRR.

Figure 2 and 3 represents the 2 Residual plots for pareto standardized effect and normal probability plot graphs for MRR and Ra respectively. We can conclude that in Normal probability plot are experimental result lie nearer to the probability line drown, which shows the readings are linear.

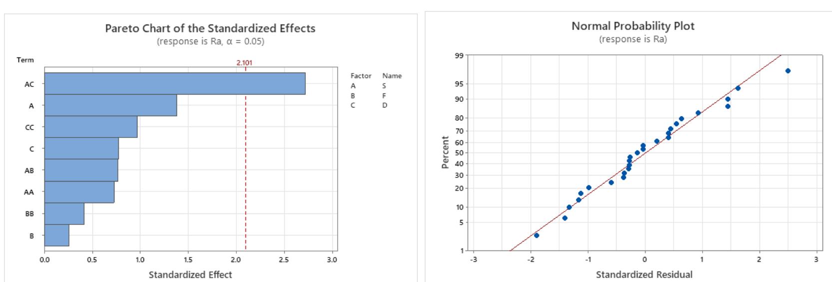

Figure 3. Residual plot For Ra.

The regression equation generated for MRR through the RSM is shown in equation 1.

$$MRR = -1589.1 - 0.3377\, S + 63.703\, F + 683.0\, D - 0.000061\, S*S - 0.5147\, F*F - 15.98\, D*D + 0.007405\, S*F - 0.00166\, S*D \quad (1)$$

The regression equation generated for Ra through the RSM is shown in equation 2.

$$Ra = 0.134 - 0.000018\, S + 0.00445\, F + 0.007\, D - 0.000000\, S*S - 0.000034\, F*F - 0.0346\, D*D - 0.000001\, S*F + 0.000098\, S*D \quad (2)$$

Optimization by Surface Response Optimizer: The RSM regression equations for MRR and Ra responses will be utilized to optimized the output responses. The MRR is required to be high whereas the surface roughness needs to lower. For the required condition the setting parameters are defined and shown in table 5.

Table 5. Goal setting Parameters.

Response	Goal	Lower	Target	Upper	Weight	Importance
Ra	Minimum		0.14	0.283	1	1
MRR	Maximum	408.424	2047.20		1	1

Table 6 shows the feasible candidate of optimum results for multi-objective optimization with the help of response surface optimizer with desirability function. Also, the table 6 depicts the composite desirability value as 0.971 for the solution 1 which shows a very good optimum values for the output responses MRR and RA.

Table 6. Optimum Result.

Solution		F	D	Ra (Fit)	MRR (Fit)	Composite Desirability
1	80	55.0000	2.60000	0.144000	2042.60	0.971042

Table 6 shows the optimum value of Ra and MRR as 0.1440 μa and 2042.60 mm3/min respectively for the input parameter combination as 580 rpm spindle speed, 55 mm/min feed rate, and 2.6 mm depth of cut.

Figure 4 shows the result obtained for Output parameters with respect to optimum input parameter with the desirability function for response surface optimizer. This input and output parameters are further tested in the CNC machine experimentally and the result shows in agreement with predicted optimum values with 2% variations.

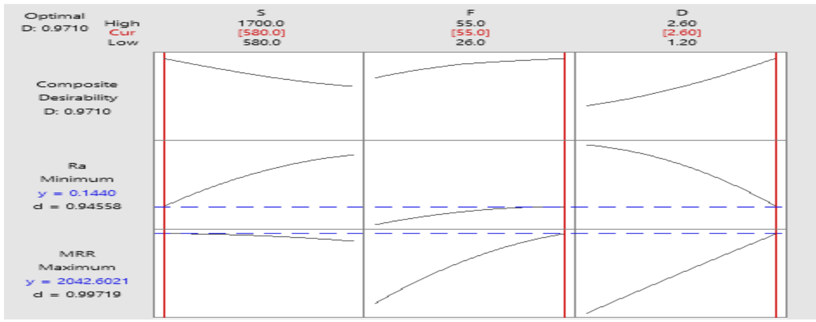

Figure 4. Variation of Output response vs. Input parameters.

5. Conclusion

This research work is basically working on optimization of milling process parameters on End milling process. Here 3 input variable and 2 output response were selected. Input variables are cutting speed, Feed rate, and Depth of cut and Output responses are Material removal rate and Surface roughness. The research work is carried out for Aluminium 6061-T6 alloy material, to provides the best output result, which can be used in milling process of the material. The Aluminium is the most used alloy in the present day in daily life as well as in industry. Aluminium is used due to its light weight due to less density as well as due to its oxidization resistance property. End milling process is vastly used process in the industry now these days. The output response MRR and Ra are extremely important parameters for milling process. In this work the design of experiment is done by using Taguchi L27 method to get the combination of input parameter to explore the proper design space. Regression analysis has also been performed on using RSM and the optimization of the responses were carried out using multi-objective response surface optimizer to enhance MRR and reduce the Ra values. This research work provides a very important method the perform the milling operation for the AL6061 material.

References

[1] M. Pooernesh, N. Harish and K. Aithal, Study of mechanical properties of aluminium alloy composites, American Journal of Materials Science 6(4) (2016), 72-76.

[2] K. B. Girisha and H. C. Chittappa, Preparation, characterization and wear study of aluminium alloy (Al 356.1) reinforced with zirconium nano particles, Int. J. Innova. Res Sci Eng. Techno. 2 (2013), 3627-3637.

[3] R. Dasgupta, Aluminium alloy-based metal matrix composites: a potential material for wear resistant applications, International Scholarly Research Notices, 2012.

[4] G. Zhou, C. Zhang, F. Lu and J. Zhang, Integrated optimization of cutting parameters and tool path for cavity milling considering carbon emissions, Journal of Cleaner Production 250 (2020), 119454.

[5] T. H. Hou, K. Y. Lin and C. Lin, Application of a revised multi-objective genetic algorithm to parameters optimization of a solar cell manufacturing process, In 2013 Ninth International Conference on Natural Computation (ICNC) IEEE (2013), 412-417.

[6] M. K. Pradhan and A. Tiwari, Modelling and optimisation of end milling parameters on Ti-6Al-4V titanium alloy using TLBO algorithm and TOPSIS algorithm, International Journal of Machining and Machinability of Materials 20(6) (2018), 513-535.

[7] P. C. Chang, J. C. Hsieh and C. Y. Wang, Adaptive multi-objective genetic algorithms for scheduling of drilling operation in printed circuit board industry, Applied Soft Computing 7(3) (2007), 800-806.

[8] S. Dewangan and R. K. Rathore, Review on cutting process parameter for surface roughness during turning operation parameters, International Research Journal of Engineering and Technology (IRJET) 6(03) (2019).

[9] S. Dewangan and R. K. Rathore, Analysis of cutting process parameter during turning of EN 31 for minimum surface roughness using Taguchi method, International Research Journal of Engineering and Technology (IRJET) 6 (2019), 832-834.

[10] R. K. Rathore, A. Sarda and R. Chandrakar, An approach to optimize ANN meta model with multi objective genetic algorithm for multi-disciplinary shape optimization, International Journal of Soft Computing and Engineering (IJSCE) ISSN, 2231-2307 2(1) (2012).