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Taguchi and ANOVA-based Optimization of CNC Milling Parameters for Aluminium 7075 Alloy

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ABSTRACT

This study is aimed at optimizing the CNC milling parameters for Aluminium 7075 alloy, using Taguchi and Analysis of Variance (ANOVA) approaches. The high-strength alloy has applications in the automobile and aerospace industries. The cutting depth, speed of milling and rate of feed were adjusted to methodically enhance the machining performance and efficiency; surface roughness was studied in these metrics. Taguchi and ANOVA approaches were helpful in optimizing the parameters to lower cost, improve machining quality and enhance the productivity of Aluminium 7075 alloy.

Keywords: Al7075; Taguchi; ANOVA; Milling; Surface roughness.

1. INTRODUCTION

The optimized settings of CNC milling aids in machining high-strength aluminium alloys, which find applications in the defense, automobile and aerospace industries (Bhuvanesh *et al.* 2020; Shihab *et al.* 2021). To be accurate, efficient and repeatable, machining procedures for the alloy have to be optimized (Kumar *et al.* 2020; Țîțu *et al.* 2020). The three most important machining parameters are: Cutting depth, Speed of milling and Rate of feed, for quality and efficiency. Using Analysis of Variance (ANOVA) and Taguchi methodology, their interactions can be studied (Singh *et al.* 2023; Akhtar et al. 2021).

Zinc, aluminium and copper are made of 7075 alloys stronger than many steels (Pinarbaşi *et al.* 2020). Nevertheless, rapid tool wear, heat buildup and issues including work hardening may occur in high-strength aluminium alloy while cutting (Manjunath *et al.* 2022). To address these challenges systematic strategy and appropriate and optimized settings for CNC milling is required (Košarac *et al.* 2020).

The removal of material from a workpiece by a computer makes use of cutting tools controlled by milling computer numerically to a subtractive manufacturing technique (Sreenivasulu and Rao, 2020). The accuracy and process efficiency determine controlling and choosing the machine settings (Zhou *et al.* 2020). Optimizing these parameters is essential for optimal surface finish, material removal rates and tool life and hence for cost-effectiveness, high-quality components and higher productivity (Hussein *et al.* 2022; Singh *et al.* 2022).

Taguchi method constructs trials and optimizes systematically and successfully (Bharat *et al.* 2023). From a few trials, minimizing the effect of external factors, resilient design is possible by testing numerous parameters concurrently (Palaniappan *et al.* 2019).

In this work, ANOVA and Taguchi methods were used to optimize CNC milling settings for Aluminium 7075 alloy.

2. MATERIALS AND METHOD

Aluminium 7075 alloy, owing to its lightweight nature and high strength, has several industrial applications. It includes precise tools and superior controls in a CNC milling machine from the experimental setup for its broad usage chosen in the workpiece material. The three main parameters for CNC milling, cutting depth (d_c), speed of milling (s) and rate of feed (f) were selected. Tool wear, efficiency and quality of manufactured surfaces are affected significantly by these elements.

Taguchi's design uses a factorial design to examine the impact of several variables with a few experimental runs at once. An L9 orthogonal array was used at three distinct levels. Each component generated these levels by combining nine experimental runs. Table 1 shows the three levels of the three selected process parameters.

Table 1. Levels of process parameters

S. No.	Process Parameters	Level 1	Level 2	Level 3	Unit
1	Cutting depth (d_c)	0.3	0.6	0.9	mm
2	Speed of Milling (s)	40	60	80	m/min
3	Rate of feed (f)	0.08	0.11	0.14	mm/tooth

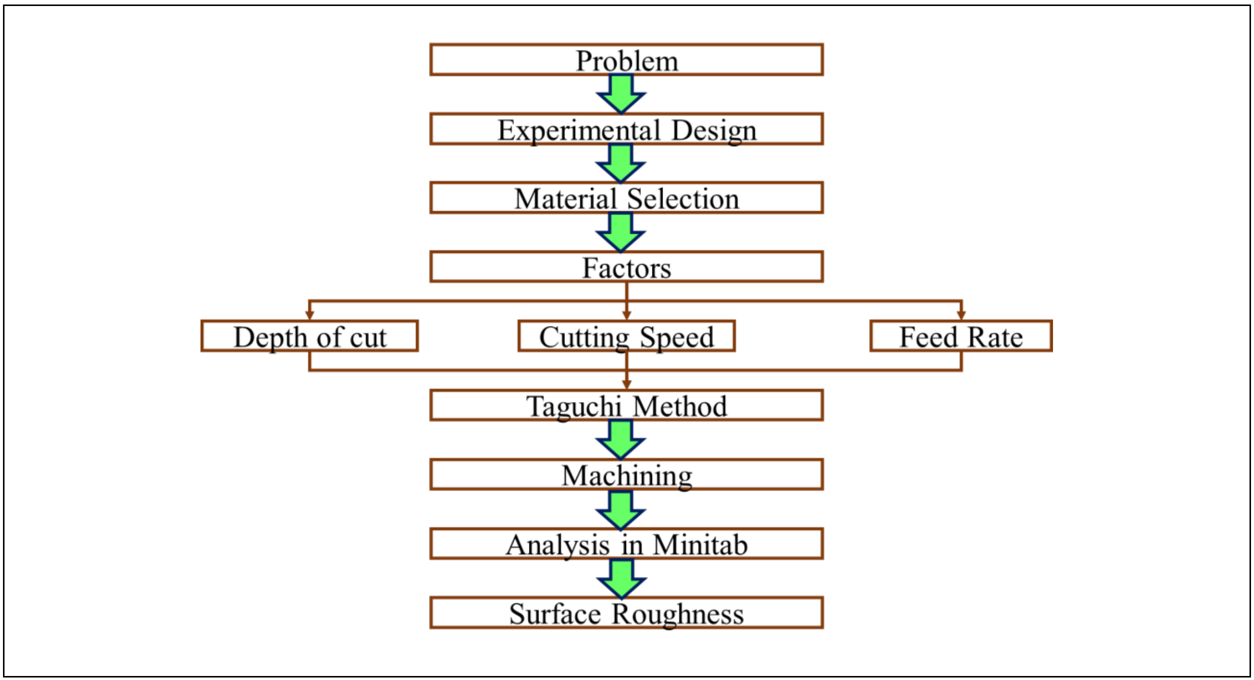

Fig. 1: Experimental set-up of CNC milling operation

CNC milling trials were performed in a controlled environment to keep things consistent. Each trial has to establish the cutting parameters and the cutting tool has to be positioned to be fastened to the CNC milling machine in the workpiece. The cutting tool wear throughout the trials was tracked for its capacity to cut aluminium. Fig. 1 shows the experimental setup of the CNC milling operation.

The surface quality and the tool wear were measured to see how the results affected the CNC milling settings..

The data was run through an ANOVA, to find out how they interacted and how each element was important. Varying the cutting depth, speed of milling and rate of feed to determine the ideal settings for machining Aluminium 7075 alloy was the study's objective. To guarantee reproducibility and validity, each experiment was done many times and the results were averaged out. An orthogonal array used in the Taguchi technique was additionally robust in the experimental design.

3. RESULTS AND DISCUSSION

3.1 Surface Roughness

The findings indicate that the speed of milling has a substantial effect on the surface roughness. The experimental design of the three factors: cutting depth, speed of milling and rate of feed by L9 array is shown in Table 2.

The experimental results obtained using Minitab software (based on Table 2) for analysis were presented in Table 3. The mean value, surface roughness, SN ratio, residual and surface residual values are listed in this table. Cutting depth of 0.6 mm, speed of milling of 40 m/min and rate of feed of 0.11 mm/tooth resulted in 0.22, 13.15154638, 0.22 as surface roughness, SN ratio and mean value, respectively; -0.008889 is the residual value and -1.41754 is the surface residual.

Table 2. Experimental design - L9 array

S. No.	Cutting depth (mm)	Speed of milling (m/min)	Rate of feed (mm/tooth)
1	0.3	40	0.08
2	0.3	60	0.11
3	0.3	80	0.14
4	0.6	40	0.11
5	0.6	60	0.14
6	0.6	80	0.08
7	0.9	40	0.14
8	0.9	60	0.08
9	0.9	80	0.11

Table 3. Experimental results of surface roughness

S. No.	Surface roughness	SN Ratio	MEAN	Residual	S Residual
1	0.23	12.76544328	0.23	-0.000556	-0.12074
2	0.26	11.70053304	0.26	0.0061111	0.974559
3	0.28	11.05683937	0.28	0.0027778	0.603682
4	0.22	13.15154638	0.22	-0.008889	-1.41754
5	0.25	12.04119983	0.25	-0.002222	-0.35438
6	0.25	12.04119983	0.25	-0.005556	-1.01015
7	0.23	12.76544328	0.23	0.0027778	0.603682
8	0.24	12.39577517	0.24	0.0094444	1.717259
9	0.25	12.04119983	0.25	-0.003889	-0.70711

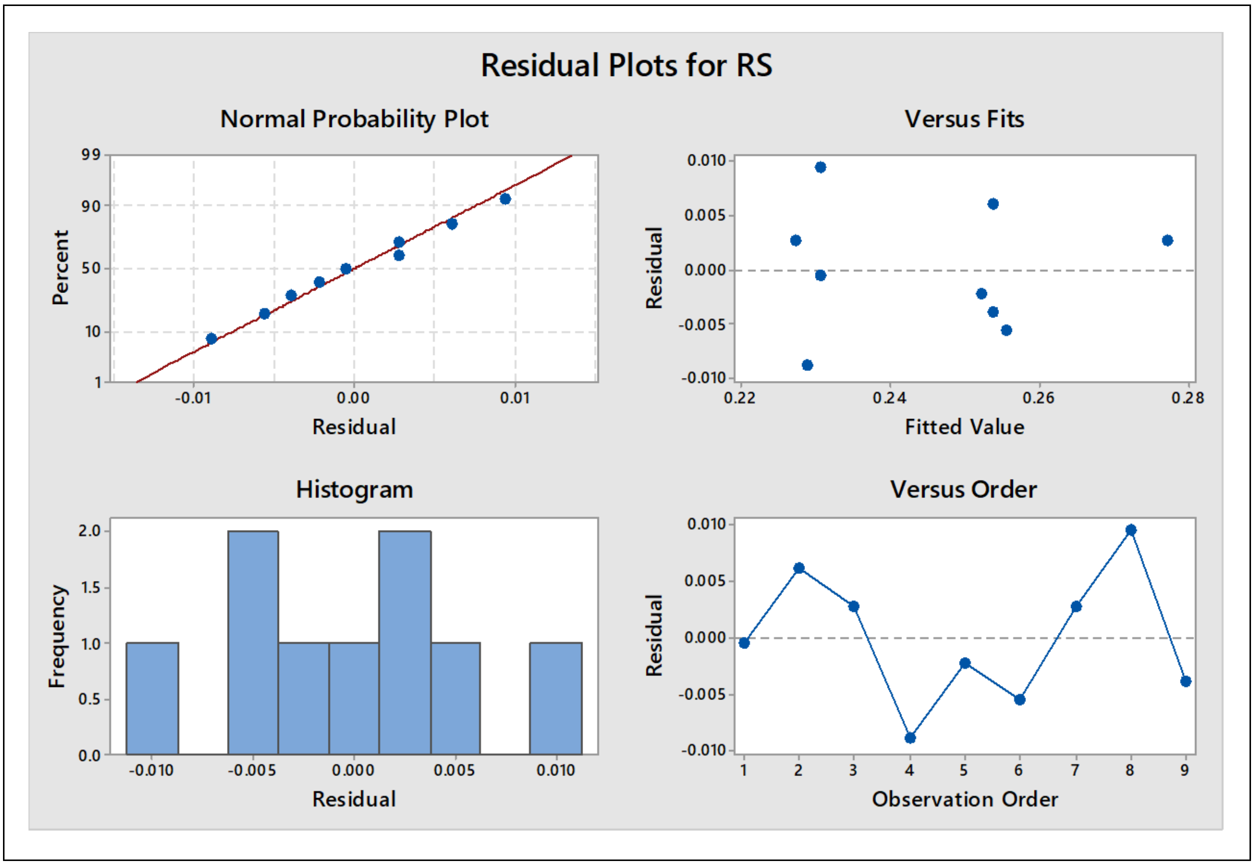

Fig. 2: Surface roughness in residual plots

The surface roughness variations are plotted in Fig. 2. The normal probability plot shows that surface roughness equally rises by residual and percent. The residual values with the fitted value are shown in the versus fits. From the histogram, the frequency has increased with the rise in the residual. The observation order plot reveals that the values are good for the surface roughness.

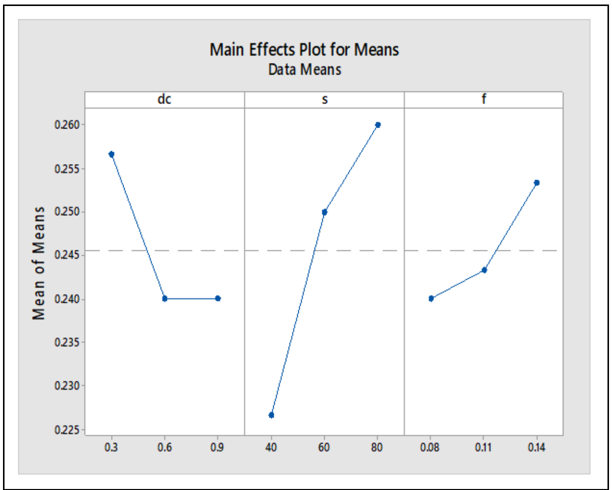

Fig. 3: Main effects for means of surface roughness

Table 4 shows the mean value of the response table from the three factors: cutting depth (d_c), speed of milling (s) and rate of feed (f), with rank based on the needs of the factors. The main effects for the mean are plotted based on the data from the three factors. From these, 0.9 mm, 40 m/min and 0.08 mm/tooth are the needed values for surface roughness, as shown in Fig. 3. Speed of milling values of 0.2267, 0.25, and 0.26 are from levels 1, 2 and 3, respectively; the delta value is 0.0333.

Table 4. Response table for means of surface roughness

Level	d_c	s	f
1	0.2567	0.2267	0.24
2	0.24	0.25	0.2433
3	0.24	0.26	0.2533
Delta	0.0167	0.0333	0.0133
Rank	2	1	3

Table 5. Response table for Signal-to-Noise ratios

Level	d_c	s	f
1	11.84	12.89	12.4
2	12.41	12.05	12.3
3	12.4	11.71	11.95
Delta	0.57	1.18	0.45
Rank	2	1	3

Signal-to-Noise ratios presented in Table 5 reveal that the smaller is better. The delta values of 1.18, 0.57 and 0.45 are shown in Table 5. The main effects of the S-N ratio are plotted in Fig. 4. The needed values of cutting depth, speed of milling and rate of feed are 0.3 mm, 80 m/min and 0.14 mm/tooth, respectively are the values we want. Speed of milling values of 12.89, 12.05, and 11.71 are from levels 1, 2 and 3, respectively; the delta value is 1.18.

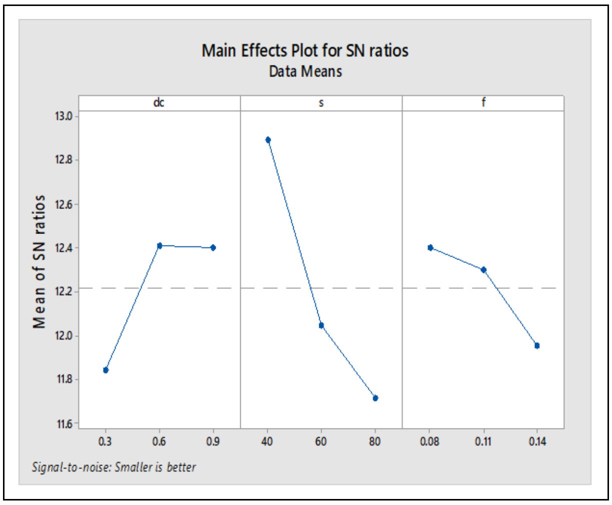

Fig. 4: Effects of S-N ratios of surface roughness

The coefficient values are presented in Table 6. P-values are 0.04, 0.003 and 0.075 for d_c, s and f, respectively. T-values are -2.77, 5.53 and 2.21. Significant coefficient values are 0.01, 0.00015 and 0.1. Table 7 delivers the analysis of the variance; F-values are 7.65, 30.61 and 4.9 and the regression value is 14.39. P-values are 0.04, 0.003, 0.078 for d_c, s and f, respectively and the regression value is 0.007.

Table 6. Coefficient values of surface roughness

Term	Coeff	SE Coeff	T-value	P-value	VIF
Constant	0.1878	0.0157	11.97	0	
dc	-0.0278	0.01	-2.77	0.04	1
s	0.00083	0.00015	5.53	0.003	1
f	0.222	0.1	2.21	0.078	1

Table 7. Analysis of variance

Source	DF	Adj SS	Adj MS	F-value	P-value
Regression	3	0.00235	0.00078	14.39	0.007
dc	1	0.00042	0.00042	7.65	0.04
s	1	0.00167	0.00167	30.61	0.003
f	1	0.00027	0.00027	4.9	0.078
Error	5	0.00027	0.000054		
Total	8	0.00262			

Contour plots are depicted in Fig. 5. The values of surface roughness based on the cutting depth are shown in Fig. 5 (a). It is evident that the cutting depth value of 0.6 and the rate of feed of 0.11 results in a highly smooth area. From Fig. 5 (b), the speed of milling of 42 and the rate of feed of 0.11 is the best. Fig. 5 (c), the speed of milling of 42 and the depth of cut of 0.6 is the best value. The values are segregated by the color in the figures between the surface roughness values of 0.22 and 0.28.

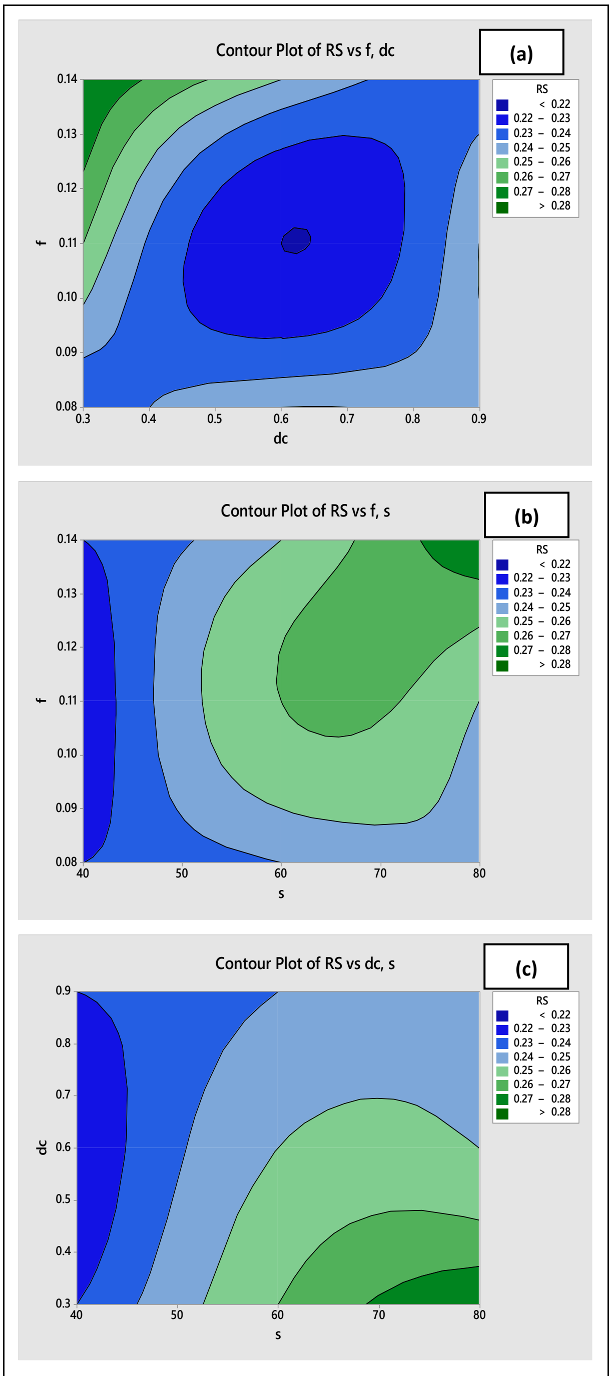

Fig. 5: Surface roughness based on: (a) Rate of feed and cutting depth (b) Rate of feed and speed of milling and (c) Cutting depth and speed of milling

The overall performance, fatigue life and corrosion resistance are better with smoother surfaces in the industries, where the components need to be accurate and aesthetically appealing. Surface imperfections might result from excessive material removal and forceful cutting.

4. CONCLUSION

- This study is aimed at optimizing the CNC milling parameters for machining Aluminium 7075 alloy has been carried out in this work, using Taguchi and Analysis of Variance (ANOVA) methodologies.
- Manufacturing efficiency, fatigue life and overall performance are all favorably affected by smoother components made possible by optimized cutting settings, which in turn decrease machining times and enhance the overall efficiency.
- Carrying out Tool wear analysis on Aluminium alloys will give more insights and better optimization of the selected parameters.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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