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Multi–Objective Optimization of Machining Conditions on Surface Roughness and MRR during CNC End Milling of Aluminium Alloy 7075 Using Taguchi Design of Experiments

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In this research, an experimental investigation of the machining characteristics of Aluminium Alloy 7075 T6 in CNC milling machine using High Speed Steel (HSS) cutting tool had been carried out. In machining operation, the quality of surface finish is an important requirement for milled work pieces. Thus, the choice of optimized cutting parameters is very important for controlling the required quality. The purpose of this research is focused on the analysis of optimum cutting conditions for minimum surface roughness and maximum material removal rate in CNC milling of Aluminium Alloy 7075 T6 by Taguchi method. Experiment have been carried out based on L16 standard orthogonal array design with three process parameters namely Spindle Speed, Feed rate, Depth of Cut. The results of the machining experiments were used to characterize the main factors affecting surface finishing and material removal rate by signal to noise ratio and analysis of variance method. Feed rate is the most significant process parameters for surface roughness and depth of cut is the most significant process parameters for material removal rate.

Keywords: Aluminium Alloy 7075, CNC End milling, Surface Roughness, Metal Removal Rate, Taguchi method, ANOVA.

1. Introduction

End milling is the most important milling operation and it is widely used in most of the manufacturing industries due to its capability of producing complex geometric surfaces with reasonable accuracy. In end milling, surface finish and material removal rate are two important aspects, which require attention both from industry personnel as well as in Research & Development, because these two factors greatly influence machining performances. CNC machines are capable of achieving reasonable accuracy and surface finish. Processing time is also very low as compared to some of the conventional machining process.

Aluminium alloys contains the typical alloying elements, such as copper, magnesium, manganese, silicon and zinc and in which Aluminium (Al) is the predominant metal. Here Aluminium 7075 T6 alloy is taken as workpiece material and HSS as cutting tool. The main properties of Aluminium are lightweight, strength, recyclability, corrosion resistance, durability, ductility, formability and conductivity, which make them valuable material.

J. Pradeep Kumar, K. Thirumurugan [1]: This paper describes a comprehensive study of end milling of titanium alloys. The study investigated the optimum parameters that could produce significant good surface roughness whereby reducing tooling cost. The control parameters were spindle speed, feed rate, depth of cut and type of end milling tool. Then, an orthogonal array of L27 (313) and analysis of variance (ANOVA) were carried out to identify the significant factors affecting the surface roughness.

Mr. Dhole N. S., Prof. Naik G. R., Mr. Prabhawalkar M. S. [2]: The overall objective of the method is to produce high quality product at low cost to the manufacturer. Taguchi developed a method for designing experiments to investigate how different parameters affect the mean and variance of a process performance characteristic that defines how well the process is functioning. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and their appropriate levels. The experiments are conducted using L-18 orthogonal array on EN 33 material as suggested by Taguchi. Signal–to–Noise (S/N) ratio and Pareto Analysis of Variance (ANOVA) will be employed to analyze the effect of milling parameters on cutting force. Main effects of process parameters on the quality characteristics can be analyzed.

Sanjit Moshat, Saurav Datta, Asish U. D. Gulhane, M. P. Bhagwat, M. S. Chavan, S. A. Dhatkar, S. U. Mayekar [3]: This study involves the investigation of optimum cutting parameters in CNC end milling process. Design of experiments is performed to analyse the effect of spindle speed, feed rate and depth of cut on the surface roughness of 6061 Aluminium alloy. The results of the machining experiments were used to characterise the main factors affecting surface roughness by the Analysis of Variance (ANOVA) method. The feed rate was found to be the most significant parameter influencing the surface roughness in the end milling process.

2. Taguchi's method

Taguchi defines as the quality of a product, in terms of the loss imparted by the product to the society from the time the product is shipped to the customer. Some of these losses are due to deviation of the products functional characteristic from its desired target value, and these are called losses due to functional variation. The uncontrollable factors,which cause the functional characteristics of a product to deviate from their target values, are called noise factors, which can be classified as external factors and product deterioration. The overall aim of quality engineering is to make products that are robust with respect to all noise factors. Taguchi has empirically found that the two stage optimization procedure involving S/N ratios, indeed gives the parameter level combination, where the standard deviation is minimum while keeping the mean on target.

The effects of the process machining parameters are very essential. The present method of selection of parameters on desired surface roughness, and material removal rate (MRR) has been accomplished using Taguchi's parameter design approach. In this paper our objective is to minimize surface roughness and maximize the MRR. The experimental results (or data) are further transformed into a signal–to–noise (S/N) ratio. There are several S/N ratios available depending on the type of characteristic; lower is better (LB), Nominal is best (NB) and higher is better (HB) The characteristic that higher value represents better machining performance, such as MRR, is called Higher is better (HB). The characteristic that lower value represents better machining performance such as surface roughness, is called Lower is better (LB). Therefore, "HB" for MRR and "LB" for SF were selected for obtaining optimum machining performance characteristics.
For MRR (Larger is Better),

$$\text{S/N Ratio} = 10 \log \frac{1}{n} \int_{i=1}^{n} \frac{1}{y^2}$$

For Ra (Smaller is Better),

$$\text{S/N Ratio} = 10 \log \int_{i=1}^{n} y^2$$

where y is the observed data at i-th trial and n is the number of trials. From the S/N ratio, the effective parameters having influence on process results can be seen and the optimal sets of process parameters can be determined.

3. Materials and method

3.1. *Work piece material*

The Rectangular $35 \times 35 \times 20$ mmm Aluminium Alloy 7075 T6 were used for experimentation. Tab. 1 and Tab. 2 shows composition and properties of AA 7075 T6 used for the study. Milling operation was carried out on universal milling machine by using HSS tool.

3.2. *Design of experiments using Taguchi method*

Design of experiments using Taguchi method is employed here in order to find the optimum number of runs required to conduct the experiment with the combination of parameters. A of total three factors namely cutting speed, feed and depth of cut were considered for the experimental design. Each factors has four levels. L l6 orthogonal array was formed based on the three factors–four level design. The various factors and their levels are listed in the Tab. 3.

3.3. *Experimental setup*

Work piece was inserted in the jaw on the work bed and tightened in the jaws until they fixed the work piece such that top surface of the work piece will be perfectly perpendicular to the tool axis. The milling was carried out for 16 different work pieces.

Table 1 Composition of AA 7075 elements

Elements	Composition [%]
Aluminium	87.1-91.4
Zinc	5.1-6.1
Magnesium	2.1-2.9
Copper	1.2-2
Ferrous	0.5
silicon	0.4
Manganese	0.3
Titanium	0.2
Chromium	0.18-0.28

Table 2 Properties of AA 7075

Density	2.8 [g/cm^3]
Tensile Strength	276 [MPa]
Yield Strength	146 [MPa]
Elongation	9-10%
Machinability	70%
Brinell Hardness	150

Table 3 Properties of AA 7075

S. No	Process parameters	Levels			
		1	2	3	4
1	Cutting speed [rpm]	1000	1500	2000	2500
2	Feed rate [mm/rev]	40	50	60	70
3	Depth of cut [mm]	0.2	0.4	0.6	0.8

3.4. *MRR and surface roughness measurement*

Material removal rate (MRR) has been calculated from the difference of weight of work piece before and after the experiment.

$$\text{MRR} = \frac{w_i - w_f}{\rho\, T}$$

where:

w_i – initial weight of the work piece [g],
w_f – final weight of the work piece [g],
ρ – density of material [g/cm3],
T – machining time [min].

The surface roughness of each specimen was tested on the surface roughness tester SJ-201(MITUTOYO Model) shown in Fig. 1. The surface roughness value is measured with 4mm cut-off distance and average value is taken.

Figure 1 Surface roughness tester SJ-201

4. Results and discussion

The main objective of the experiment is to optimize the milling parameters (spindle speed, feed rate and depth of cut) to achieve low value of the surface roughness and high material removal rate. The experimental data for the surface roughness values and the calculated signal-to-noise ratio are shown in Tab 4. Taguchi recommends to analyze data using the S/N ratio that will offer two advantages; it provides guidance for selection the optimum level based on-least variation around on the average value, which closest to target, and also it offers objective comparison of two sets of experimental data with respect to deviation of the average from the target.

Response table for Signal to Noise ratio of both responses are shown in Tab. 5 and Tab. 6. Significance of machining parameters (difference between maximum and minimum values) of surface roughness indicates that cutting speed is contributing towards the machining performance for lower surface roughness. Plot for S/N ratio shown in Fig. 2 explains there is less variation for change in Depth of cut where as there is more variation for change in cutting speed. Plot for S/N ratio shown in Fig. 3 explains there is less variation for change in Cutting Speed where as there is more variation for change in feed.

But, in case of MRR, variation in depth of cut is more significant as compared to cutting speed and feed. Also there is less variation in MRR for change in cutting speed.

Table 4 Experimental results for surface roughness and MRR

Test No.	Cutting Speed [rpm]	Feed rate [mm/rev]	Depth of cut [mm]	MRR [mm^3/min]	Ra [μm]	S/N ratio for Ra	S/N ratio for MRR
1	1000	30	0.2	67.3623	1.23	-1.7981	36.5683381
2	1500	30	0.4	122.47	1.42	-3.0458	41.76059436
3	2000	30	0.6	220.913	0.76	2.3837	46.88442547
4	2500	30	0.8	269.449	1.02	-0.1720	48.60953152
5	1000	40	0.4	187.9699	0.83	1.6184	45.48176621
6	1500	40	0.2	70.181	1.26	-2.0074	36.92439104
7	2000	40	0.8	311.915	1.93	-5.7111	49.88072521
8	2500	40	0.6	234.4996	1.44	-3.1672	47.40284212
9	1000	50	0.6	335.775	2.85	-9.0969	50.52096716
10	1500	50	0.8	408.163	4.11	-12.2768	52.21667267
11	2000	50	0.2	102.041	2.03	-6.1499	40.17549412
12	2500	50	0.4	224.489	1.41	-2.9844	47.02390131
13	1000	60	0.8	538.899	2.34	-7.3843	54.63014755
14	1500	60	0.6	367.431	1.88	-5.4832	51.3035159
15	2000	60	0.4	244.954	1.72	-4.7106	47.78169071
16	2500	60	0.2	147.023	2.33	-7.3471	43.34770561

Table 5 Response table for signal to noise ratios smaller is better

Level	Cutting speed	Feed	Depth of cut
1	-4.1652	-0.6580	-4.3256
2	-5.7033	-2.3168	-2.2806
3	-3.5470	-7.6270	-3.8409
4	-3.4177	-7.6270	-6.3861
Delta	2.2856	6.9690	4.1055
Rank	3	1	2

Table 6 Response table for signal to noise ratios larger is better

Level	Cutting Speed	Feed	Depth of cut
1	46.80	43.46	39.25
2	45.55	44.92	45.51
3	46.18	47.48	49.03
4	46.60	49.27	51.33
Delta	1.25	5.81	12.08
Rank	3	2	1

4.1. *Analysis of variance (ANOVA)*

Taguchi method cannot judge and determine effect of individual parameters on entire process. Contribution of individual parameters of process can be determined using ANOVA. Minitab 17 software of ANOVA module was employed to investigate the effect of machining parameters feed, cutting speed and depth of cut.

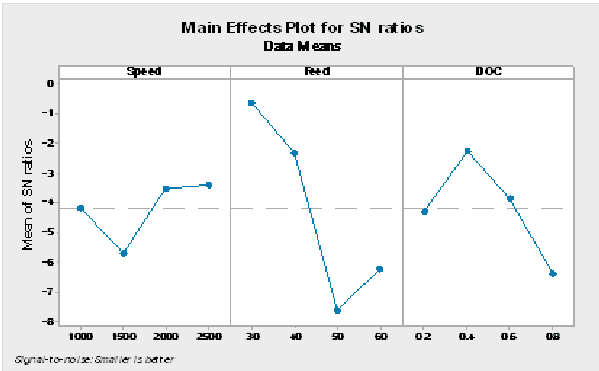

Figure 2 Main effect plots for Ra

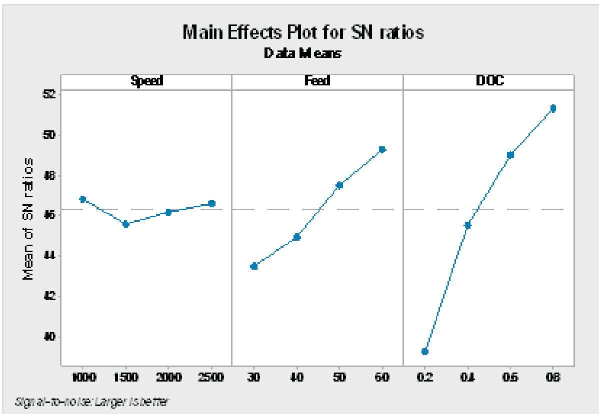

Figure 3 Main effect Plot for MRR

From surface roughness analysis ANOVA (Tab. 7), F value (4.95) and contribution % (51.26%) indicates that feed rate is contributing more for minimum surface roughness. F value (0.84) of parameter indicates that cutting speed is contributing less for minimum surface roughness. Test No: 3 has the lowest surface finish value (Ra = 0.76 μm). Whereas, Test No: 10 has the highest surface roughness value (Ra = 4.11 μm).

Table 7 ANOVA for surface roughness

Source	DF	SS	MS	F value	P value	Contribution %
Speed	3	0.9317	0.3106	0.84	0.522	8.66
Feed	3	5.5178	1.8393	4.95	0.046	51.26
DOC	3	2.0834	0.6945	1.87	0.236	19.36
Error	6	2.2308	0.3718			20.72
Total	15	10.7637				100.00

Table 8 ANOVA for MRR

Source	DF	SS	MS	F value	P value	Contribution %
Speed	3	10625	3541.6	5.69	0.035	4.21
Feed	3	57265	19088.3	30.66	0.000	22.67
DOC	3	180933	60311.1	96.88	0.000	71.64
Error	6	3735	622.5			1.48
Total	15	252558				100.00

From MRR analysis ANOVA table (Tab. 8), F value (96.88) and contribution % (71.64%) indicates that depth of cut is contributing more for material removal rate. F value (5.69) of parameter indicates that cutting speed is contributing less for material removal rate. Test no: 13 has the highest material removal rate (MRR = 538.899 mm^3/min). Whereas, Test No: 1 has the lowest material removal rate (MRR = 67.3623 mm^3/min).

5. Conclusion

1. Taguchi method of experimental design has been applied for optimizing multi–response process parameters for CNC End Milling Al 7075 T6 Alloy with L16 orthogonal array.

2. Results obtained from Taguchi method exactly matches with ANOVA.

3. From Tab. 5 and Tab. 7, Feed is the most influencing parameter for minimum surface finish which is followed by depth of cut and cutting speed.

4. From Tab. 6 and Tab. 8, Depth of cut is the most influencing parameter for material removal rate which is followed by feed and cutting speed.

5. From Tab. 4, optimal parameters for minimum surface roughness (Ra = 0.76 μm) are feed rate = 30 mm/rev, cutting speed = 2000 rpm and depth of cut = 0.6 mm and for maximum MRR (MRR = 538.899 mm^3/min) are feed rate = 60 mm/rev, cutting speed = 1000 rpm and depth of cut = 0.8 mm were obtained, which produced very close to the results during the confirmation experiments.

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