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Research Article

OPTIMIZATION OF THE CUTTING PARAMETERS AFFECTING THE SURFACE ROUGHNESS ON FREE FORM SURFACES

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ABSTRACT

This study aims to determine the optimal cutting parameters in order to achieve minimum surface roughness on free form surfaces. Frequently preferred Al 7075-T6 material was used. Free form surfaces on the material were machined in the CNC milling in order to determine the cutting conditions that provide the best surface roughness. An experiment list was created with the Taguchi L_{16} experiment design for cutting speed, feed rate, stepover and machining strategies. As a result of these experiments, the average surface roughness (Ra) values were measured. Signal-to-noise (S/N) ratios were determined in the Taguchi design, and the most important effect on the average surface roughness among the four factors was found to be the stepover according to the experimental results. In ANOVA analysis, step over was found the 95% confidence level in Ra value.
Keywords: Al 7075-T6, cutting parameters, milling, Taguchi Method, surface roghness.

1. INTRODUCTION

Manufacturing by machining is a commonly used method increasingly preferred in production day by day [1]. The reason why machining is used more is the possibility to produce parts that have better dimensional accuracy and surface quality by choosing optimal parameters in machining. Therefore, many scientific studies have been carried out on this subject [2]. Kurt et al. have performed optimization of the cutting parameters to minimize surface roughness and form error at the surface when processing free form surfaces [3]. The free form surfaces have been frequently used in different branches of the industry in recent years. For example, it's widespread in areas such as mold production, precision machinery manufacturing industries, space and aircraft industry, automotive industry, and production of biomedical devices [4,5]. The main aim of mass production is to produce high quality products in a short time with low cost [6]. Automation and manufacturing systems can be used for this purpose [7]. Computer-controlled (CNC) machines are used to achieve high surface quality while achieving production at low cost and in short time [8].

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In order to reduce production costs and ensure optimum surface quality, machining of the material using optimal parameters is important [9]. The selection of optimal machining parameters and investigating the interactions between parameters with experimental studies is of great importance in the field of manufacturing [10,11]. Parameters such as the machining strategy, selected fmaterial, type of cutting tool, physical, chemical and thermal factors, coolant used during machining, cutting tool, and mechanical movements between the workpiece affect surface quality [12]. A quality machined surface provides significant level of improvement in fatigue strength, corrosion resistance, and product life. Hence, it is important to calibrate the measuring instruments when performing measurements. Interpretation of the experiment results is as important as obtaining the results [13]. The aim of researchers is to find the ideal values in design, manufacturing or maintenance work. In studies conducted for this purpose, statistical methods are widely used to find the optimum value [14]. Methods such as Taguchi, regression models, surface response method, artificial neural networks help the researcher in the decision making stage. The Taguchi method is a problem-solving tool that has the ability to reduce production costs, increase production volume and save time [15].

So it helps to achieve efficient production. This method combines experimental and analytic concepts by choosing the most efficient parameters to optimize efficiency for reducing production costs and saving time [16,17]. To achieve this, the Taguchi method takes advantage of special orthogonal arrays to determine the most appropriate method by taking the entire process into account and reducing the number of experiments [18].

In this study, the average surface roughness values obtained in the machining on free form surfaces of AL 7075-T6 material were experimentally measured. The Taguchi L_{16} design was used as the experimental design. With Taguchi analysis, optimum cutting parameters were determined for obtained better surface roughness values.

2. MATERIAL AND METHOD

2.1 Workpiece Material and Cutting Tool

Al 7075-T6 series materials, which are light metals with very low density, resistant to corrosion due to an oxide film formed on the surface, have higher strength and machinability, are widely used in automotive industry as well as in aircraft, ships, and light armored vehicles for military purposes. The mechanical and chemical properties of the Al 7075-T6 material used in our experiments are shown in Table 1.

Table 1. Mechanical properties and chemical composition of the material

Mechanical properties		**Chemical Composition (%)**	
Tensile Strength (MPa)	570	Zn	0,50
Yield Strength (MPa)	505	Si	0,13
Density (Kg/m^3)	2800	Mn	0,30
Elongation (%)	11	Cr	0,28
Hardness (HRb)	102	Ti	0,20
		Cu	2
		Al	Base

Al 7075-T6 material of 253x148x60mm in size was used in the experiments. As shown in Figure 1, experiments were carried out by creating free form surfaces of 30x40 mm in size on the stock.

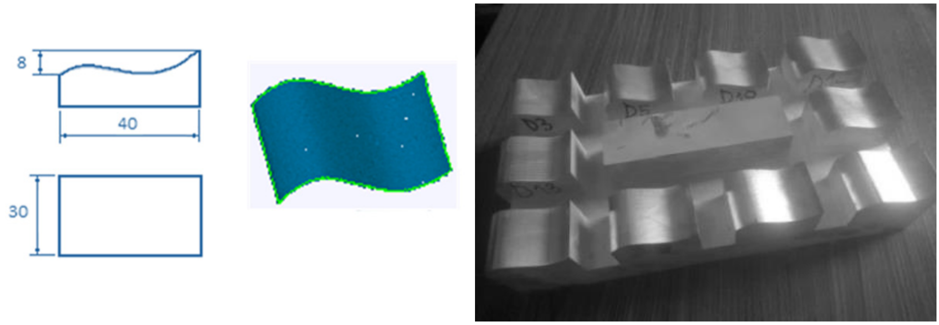

Figure 1. Experimental samples

TAKUMA JVH-710 CNC milling machine was used for machining the samples. No coolant was used in the experiments, and milling was performed under dry cutting conditions. In the experiments, BT40-ER40x80-PB tool holder, and ER40 clamp was used. In this system, the cutter is tightened circumferentially around the periphery. As a cutting tool, TaeguTec brand externally cooled carbide massive ball-end milling cutter, which is often used in the manufacture of free form surfaces, was preferred. Dimensions of the cutting tool are given in Figure 2.

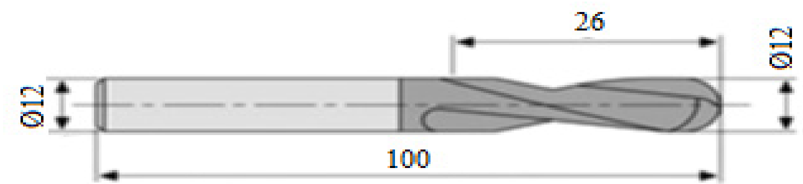

Figure 2. The ball-end milling tool

2.2 Method

The cutting parameters used in the experiments are determined at four different values and four different machining strategies according to the manufacturer's catalog. The cutting parameters and the chosen levels are shown in Table 2.

Table 2. Cutting parameters and levels

Symbol	Cutting Parameters	Level 1	Level 2	Level 3	Level 4
A	Cutting Speed (m/min)	100	140	180	220
B	Feed Rate (mm/min)	200	500	800	1100
C	Step Over(mm)	0,5	0,8	1,1	1,4
D	Machining Strategies	Parallel	Zig-Zag	Spiral	One Way

The surfaces obtained after applying the cutting parameters given in Table 2 were measured perpendicular to the machining directions at three points with the Mitutoyo Surftest SJ-210 surface roughness measuring instrument to determine the surface roughness Ra values. Averages of measurements were taken. The determined surface roughness values are given in Table 3. The experimental scheme of the Taguchi method used to optimize surface roughness is shown in Figure 3.

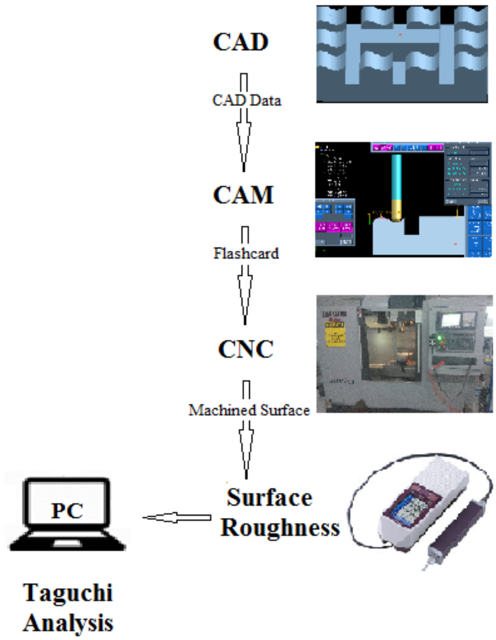

Figure 3. Experimental scheme

2.3 Evaluation of the results with the Taguchi method

In Taguchi method, optimum cutting conditions required for the best surface roughness are obtained by choosing the "smaller is better" signal to noise ratio. In the MINITAB 14 program, the S/N ratios and level values were calculated using the "smaller the better" equation. The S/N ratios obtained according to the result of this equation are given in Table 4.

Table 3. Generated experimental design and experimental results with using L_{16} orthogonal array

Experiment Number	Symbol				Average Surface Roughness (Ra) (µm)
	A	B	C	D	
1	1	1	1	1	1,69
2	1	2	2	2	1,78
3	1	3	3	3	1,84
4	1	4	4	4	2,14
5	2	1	2	3	1,49
6	2	2	1	4	1,38
7	2	3	4	1	2,28
8	2	4	3	2	2,30
9	3	1	3	4	2,03
10	3	2	4	3	1,75
11	3	3	1	2	1,56
12	3	4	2	1	1,73
13	4	1	4	2	2,48
14	4	2	3	1	2,24
15	4	3	2	4	2,02
16	4	4	1	3	0,74

Table 4. S/N ratios for Ra in L_{16} orthogonal array

Experiment Number	Symbol				Average Surface Roughness (Ra) S/N
	A	B	C	D	
1	1	1	1	1	-4,56
2	1	2	2	2	-5,01
3	1	3	3	3	-5,30
4	1	4	4	4	-6,61
5	2	1	2	3	-3,46
6	2	2	1	4	-2,80
7	2	3	4	1	-7,16
8	2	4	3	2	-7,23
9	3	1	3	4	-6,15
10	3	2	4	3	-4,86
11	3	3	1	2	-3,86
12	3	4	2	1	-4,76
13	4	1	4	2	-7,89
14	4	2	3	1	-7,00
15	4	3	2	4	-6,11
16	4	4	1	3	2,62

The most important factor for the analysis of the data in the Taguchi method is the signal/noise (S/N) ratio. According to the Taguchi method used in this study, the S/N ratio must be maximized in order to obtain optimum cutting conditions. Accordingly, the optimum cutting condition in the L_{16} orthogonal array has an S/N ratio of 2.62 for Ra as shown in Table 4. This value also confirms the factor level graph of S/N ratios shown in Figure 4. For Ra, 4413 orthogonal array was the optimal; in other words, the optimum cutting conditions obtained were a cutting speed of 220 m/min., a feed rate of 1100 mm/min, a stepover of 0.5mm, and spiral machining. According to Taguchi design, the factor levels obtained in MINITAB 14 program for Ra are shown in Table 5. And, Figure 4 shows a graph of the factor levels given in Table 5. For determining the optimum cutting conditions of the experiments to be carried out under similar conditions, the A, B, C, D factor levels denoted in Table 5 and Figure 4 are interpreted accordingly. As shown in Table 5, the effect of cutting factors on the average surface roughness was stepover (C), machining strategy (D), feed rate (B) and cutting speed (A) in order of importance.

In Figure 4, the machining strategy (D) is irregular in the graph because it is an independent variable. The most suitable machining strategy seems to be spiral in third. At the same time, there is also a fluctuation in the feed rate (B). At the third level of feed rate, the S / N ratio appears to be lower. This irregular fluctuation can be neglected as the S / N ratios are very close to each other in the first three levels. This irregularity may have occurred during machining due to external factors, for example due to vibrations of milling machine or tool deflection. However, since the S / N ratio at the fourth level is obviously high, the fluctuation can be ignored.

Table 5. S/N response table for surface roughness

Level	A	B	C	D
1	-5,368	-5,515	-2,151	-5,871
2	-5,164	-4,918	-4,835	-5,999
3	-4,909	-5,606	-6,421	-2,751
4	-4,596	-3,997	-6,629	-5,416
Delta	0,771	1,609	4,479	3,247
Rank	4	3	1	2

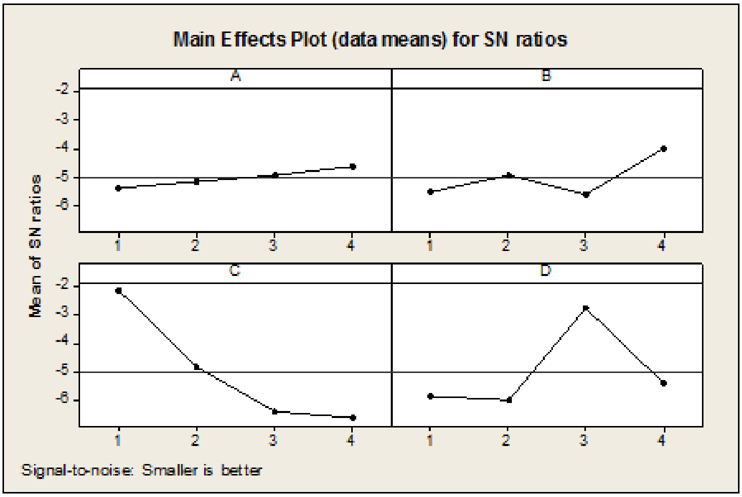

Figure 4. The graphic of A, B, C, D factor levels according to the smaller-better S/N ratios of surface roughness

In determining the optimum cutting conditions through the S/N ratio obtained by the Taguchi method, variance analysis was used to determine the relationship between the cutting parameters. The relationship between S/N and cutting speed, feed rate, stepover, and machining strategy was evaluated. The S/N ANOVA results for average surface roughness are shown in Table 6. $P<0.05$ and $p<0.01$ were accepted as the level of significance according to the ANOVA results. According to these results, the stepover, machining strategy, feed rate and cutting speed are the most significant values in order of importance. Cutting speed, feed rate, stepover, and machining strategy were effective with a 95% confidence interval.

Table 6. The relationship among S/N-cutting speed, feed rate, step over and machining strategy for Ra

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	3	0,03	0,03	0,01	0,25	0,86
B	3	0,12	0,12	0,04	1,05	0,49
C	3	1,71	1,71	0,57	15,18	0,03
D	3	0,83	0,83	0,28	7,39	0,07
Residual Error	3	0,11	0,11	0,04		
Total	15	2,80				

3. CONCLUSIONS

The most suitable cutting parameters and conditions were investigated to facilitate the manufacture of free form surfaces. Using Taguchi experimental design, average surface roughness (Ra) was analyzed on the basis of cutting factors. L_{16} orthogonal array was obtained by Taguchi method in MINITAB 14 program by determining four cutting parameters of cutting speed, feed rate, stepover and machining strategy, and four different levels for each respectively. In this way, 16 experiments were performed instead of 256 experiments in full factorial. S/N ratios were found by Taguchi method by measuring the average surface roughness in the experiments carried out according to the L_{16} orthogonal array. Using the smaller-the-better S/N ratio equation, the maximum value of S/N ratio was sought. The maximum S/N ratio gave the most optimal cutting parameters. The results obtained in the study are given below.

In machining the free form surfaces in Al 7075-T6 materials, the optimal cutting factors to obtain the lowest surface roughness are determined as below.

- The condition for the lowest Ra in machining free form surfaces was achieved in the 4413 array. That is, the optimal condition was obtained with cutting speed of 220 m/min, feed rate of 1100 mm/min, 0.5 mm stepover, and spiral machining.
- The effect of cutting factors on the average surface roughness was stepover (C), machining strategy (D), feed rate (B) and cutting speed (A) in order of importance.
- It has been observed that as the cutting speed (A) increases, the surface roughness decreases.
- Contrary to the cutting speed (A), the increase in the step over (C) increases the surface roughness.
- It was observed that the lowest surface roughness was in the spiral machining and the most surface roughness was found in the zig-zag machining.
- The relationship between cutting factors and Ra were determined by applying variance analysis to the S/N ratios. According to ANOVA, the stepover, machining strategy, feed rate, and cutting speed were effective on Ra value with a 95% confidence interval.

In further studies, when free form surfaces are being machined, the tool deflections, cutting forces and form error in free form surfaces can be examined.

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