An Experimental Investigation of Tool Geometry Influence on Surface Roughness in Milling Operation

D. K. Suker, Y. S. Alqurashi

***Abstract*— This paper presents experimental and analytical results of an investigation of the tool geometry and major cutting parameters such as speed, feed rate, and depth of cut, tool helix angle and tool diameter that affect the surface finish of milled parts in end milling. The selected work materials were aluminum (AA6082) and stainless steel (AISI 304). Taguchi techniques have been used to accomplish the objective of the experimental study. L18 orthogonal array design have been used for conducting the experiments. The results were analyzed applying two methods such as analysis of variance (ANOVA) and the signal-to-noise (S/N) ratio. Finally, The results indicate that tool helix angle is the most significant factor affecting surface roughness .**

***Index Terms*— CNC end milling, Aluminum alloy 6082, Stainless steel 304, Taguchi, ANOVA**

I. Introduction

The surface quality is quite important for the efficient working of machine parts. The structure of a machined surface is one of the most important criteria in terms of quality, and tribological properties of the machined surface are considerably affected from the surface tissue. Generally, the surface quality is characterized with surface roughness. Surface roughness is an important factor which must be considered not only in the conventional subjects of tribology such as abrasion, friction and lubrication but also in different fields such as sealing, hydrodynamics, electrical and heat conductivity. Surface roughness is mainly affected during the machining process by cutting parameters such as cutting speed, feed rate and depth of cut [1,2,3]. If these parameters are not chosen convenient, the surface roughness increases. This situation creates a notch effect and results in crack initiation, decrease in fatigue strength and corrosion resistance. So, the characterization and measurement of surface roughness has a great important in the sense of the optimization of machining process [4,5].
Many experiments have been made in order to investigate surface roughness in CNC machining. The most parameters that widely considered when investigating the optimal surface roughness are feed rate, spindle speed and depth of cut. Most of the researches did not consider the uncontrolled parameters, such as tool geometry, tool wear, chip loads, and chip formations, or the material properties of both tool and work piece.
Therefore, this research will focus on effect of tool geometry and machining parameters on surface roughness.

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D. K. Suker, Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia
Y. S. alqurashi, Department of Mechanical Engineering, Umm Al-Qura University, Makkah, Kingdom of Saudi Arabia

II. METHODOLOGY

Taguchi method design of experiment is a method which used optimization of machining parameters in order to obtain high quality product, efficient process and decrease the manufacturing cost. Compare to other design of experiment method, Taguchi method is much easy to perform and not complex to understand. In this study, this method is used to find the effect of machining parameters on surface roughness which is confirmed by signal-to-noise (S/N) ratio and analysis of variance (ANOVA).
The Taguchi method applies the signal-to-noise ratio to optimize the outcome of a manufacturing process. The signal-to-noise ratio can be calculated using the following formula:

$$\eta - S/N - -10 \log(\tfrac{1}{n}\textstyle\sum_{i=1}^{n} y_i^{\,2}) \qquad (1)$$

Where S/N is the signal-to-noise ratio (in dB), n is the number of observations, and y is the observed data.
The above formula is suitable for quality characteristics in which the adage 'the smaller the better' holds true, which is the case for surface roughness. The higher the value of the S/N ratio, the better the result is because it guarantees optimum quality with minimum variance. A thorough treatment of the Taguchi method can be found in Ross [6].
In order to understand the relationships between process parameters and measured responses, a Taguchi method was used to identify which parameters had a statistically significant influence on responses. The process parameters were arranged in standard Taguchi's L18 OA.

III. Experimental Procedure

A. WORK PIECE MATERIAL

In this study, stainless steel AISI304 and aluminum AA6082 was used as work material for experimentation using a CNC milling machine. The chemical compositions and mechanical properties of work materials are shown in Tables 1 and 2, respectively.

Table 1.Chemical compositions of Stainless steel AISI304

C	Mn	Si	S	P	Ni	Cr	N	Fe
0.02	1.84	0.47	0.02	0.037	8.65	18.45	0.089	Balan.

Table 2. Chemical compositions of Aluminium 6082 .

Fe	Mn	Cu	Si	Zn	Ti	Mg	Al
0.4	0.64	0.08	1.02	0.04	0.03	0.87	Balan

B. SELECTION OF PARAMETERS

Several factors will influence the final surface roughness in a CNC milling. In this study, the experiment was conducted by considering five variable parameters namely feed rate, spindle speed, tool diameter, helix angle and depth of cut. The objective was to find the surface roughness and to study the effects of the tool geometry as tool diameter and tool helix angle and milling conditions as feed rate, spindle speed and depth of cut on this characteristic. The values of process parameters were selected from the manufacturer's handbook recommended and the preliminary experiments for the tested material. Process parameters and their levels are shown in Table 3.

Table 3. Selected Parameters and their respective levels.

Factor	Machining Parameters	Level 1	Level 2	Level 3
A	Tool Feed (mm/min)	40	60	--
B	Spindle Speed (RPM)	1000	1500	2000
C	Tool Diameter (mm)	8	10	12
D	Helix Angle (degree)	40	50	60
E	Depth of cut (mm)	0.25	0.5	075

C. EXPERIMENTAL SETUP

The Experiments for the testing are carried out on DMC 635 V vertical machining center for the Stainless steel AISI304 and Aluminum AA6082, using various solid carbide cutting tool at different cutting machining parameters combinations. A slot milling operation was carried out on rectangular blocks of size 150 mm X 250 mm X 40 mm. For each test, the cutting length of slot 70mm×18 slots is milled along –Y direction. The experiments include slot milling as illustrated in Figure.1.

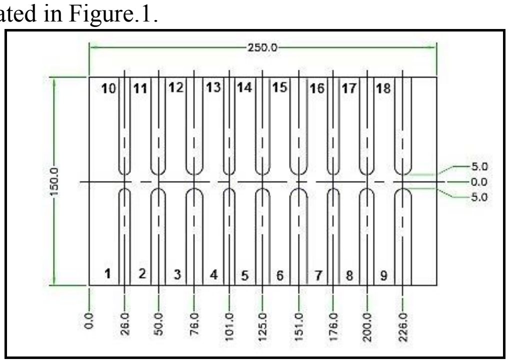

Figure 1. Experimental setup of work piece.

The surface roughness of the milled surface machined slots for each machining condition was measured by using a Taylor Hobson Form Talysurf Intra 60 with Taylor Hobson µltra software (FTS Iµ). The average roughness values of surface roughness were evaluated. Surface roughness measurement with the help of stylus has been shown in Figure 2.

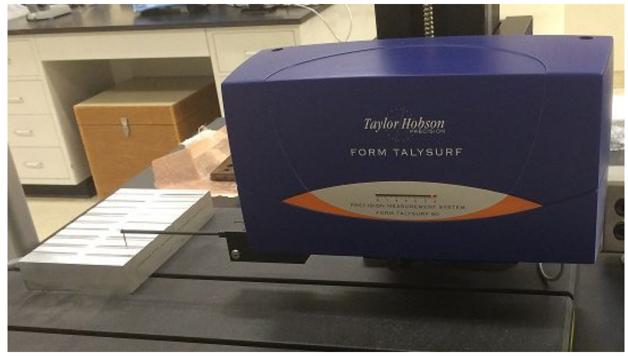

Figure 2. Talysurf during surface roughness measurement.

IV. RESULTS AND DISCUSSION

The measured values of surface roughness for the machined surfaces corresponding to all the experimental runs are given in Table 4 and Table 5. Also, The S/N ratios for all the eighteen experiments were calculated by using Eq. (1) and listed in Table 4 and Table 5.

Table 4. Experimental layout and S/N ratios of experimental results for surface roughness of stainless steel.

EX. No.	A	B	C	D	E	Ra (µm)	S/N (dB)
1	40	1000	8	40	0.25	0.113	18.90
2	40	1000	10	50	0.50	0.321	9.86
3	40	1000	12	60	0.75	0.238	12.44
4	40	1500	8	40	0.50	0.099	20.06
5	40	1500	10	50	0.75	0.245	12.19
6	40	1500	12	60	0.25	0.245	12.19
7	40	2000	8	50	0.25	0.373	8.56
8	40	2000	10	60	0.50	0.220	13.12
9	40	2000	12	40	0.75	0.103	19.68
10	60	1000	8	60	0.75	0.367	8.70
11	60	1000	10	40	0.25	0.126	17.94
12	60	1000	12	50	0.50	0.352	9.04
13	60	1500	8	50	0.75	0.164	16.21
14	60	1500	10	60	0.25	0.357	8.92
15	60	1500	12	40	0.50	0.119	18.48
16	60	2000	8	60	0.50	0.296	10.56
17	60	2000	10	40	0.75	0.199	14.02
18	60	2000	12	50	0.25	0.140	17.07

Table 5. Experimental layout and S/N ratios of experimental results for surface roughness of Aluminum.

EX. No.	A	B	C	D	E	Ra (μm)	S/N (dB)
1	40	1000	8	40	0.25	0.066	23.53
2	40	1000	10	50	0.50	0.222	13.04
3	40	1000	12	60	0.75	0.176	15.05
4	40	1500	8	40	0.50	0.082	21.68
5	40	1500	10	50	0.75	0.092	20.63
6	40	1500	12	60	0.25	0.121	18.32
7	40	2000	8	50	0.25	0.094	20.52
8	40	2000	10	60	0.50	0.239	12.42
9	40	2000	12	40	0.75	0.086	21.29
10	60	1000	8	60	0.75	0.195	14.16
11	60	1000	10	40	0.25	0.099	20.04
12	60	1000	12	50	0.50	0.106	19.42
13	60	1500	8	50	0.75	0.093	20.54
14	60	1500	10	60	0.25	0.137	17.24
15	60	1500	12	40	0.50	0.066	23.49
16	60	2000	8	60	0.50	0.138	17.14
17	60	2000	10	40	0.75	0.072	22.84
18	60	2000	12	50	0.25	0.082	21.69

A. SIGNAL TO NOISE RATIO ANALYSIS

Analysis of the influence of each control factor on the surface roughness Ra has been performed with a so-called signal to noise ratio response table. Response tables of S/N ratio for surface roughness are shown in Table 6. and Table 7. Respectively. It show the S/N ratio at each level of control factor and how it is changed when settings of each control factor are changed from one level to other.

Table 6. Response table for S/N ratios for surface roughness of Stainless steel.

Level	A	B	C	D	E
1	14.12	12.82	13.75	18.19	13.93
2	13.38	14.59	12.68	12.07	13.53
3	-	13.84	14.82	10.99	13.79
Delta	0.74	1.77	2.14	7.19	0.41
Rank	4	3	2	1	5

Table 7. Response table for S/N ratios for surface roughness of Aluminum.

Level	A	B	C	D	E
1	18.50	17.54	19.60	22.15	20.23
2	19.62	20.32	17.71	19.31	17.87
3	--	19.32	19.88	15.73	19.09
Delta	1.12	2.78	2.17	6.42	2.36
Rank	5	2	4	1	3

For stainless steel, It can be seen from table 6 the tool helix angle is the most important factor to explain the average behavior of surface roughness because of its larger deviation from the mean as compared to others. The second largest deviation is for tool diameter, then spindle speed, then tool feed and finally depth of cut.

For Aluminum, It can be seen from table 7 the Tool helix angle is the most important factor to explain the average behavior of surface roughness because of its larger deviation from the mean as compared to others. The second largest deviation is for spindle speed, then depth of cut, then tool diameter and finally tool feed.

B. ANALYSIS OF VARIANCE ANOVA

The experimental results were analyzed with Analysis Of Variance (ANOVA), which is used for identifying the factors significantly affecting the performance measures. The results of the ANOVA with surface roughness are shown in Table 8 and 9, respectively. This analysis was carried out for significance level of □ = 0.05, i.e. for a confidence level of 95%.

Table 8. Analysis of Variance (ANOVA) for SN ratios of stainless steel.

Source	DF	SS	MS	F Value	P value	Cont. (%)
A	1	2.049	2.049	0.20	0.669	0.7
B	2	10.42	5.210	0.50	0.624	3.6
C	2	13.76	6.880	0.66	0.542	4.8
D	2	178.7	89.39	8.59	0.010	61.9
E	2	0.588	0.294	0.03	0.972	0.2
Error	8	83.21	10.40			28.8
Total	17					

Table 9. Analysis of Variance (ANOVA) for SN ratios of Aluminum.

Source	DF	SS	MS	F Value	P value	Cont. (%)
A	1	5.619	5.619	2.11	0.184	2.7
B	2	26.79	11.89	4.47	0.05	11.4
C	2	16.71	8.36	3.14	0.098	8.02
D	2	124.1	62.09	23.34	0.000	59.6
E	2	16.78	8.39	3.15	0.098	8.05
Error	8	21.28	2.660			10.2
Total	17					

For stainless steel, it can be seen from the ANOVA results table 8, the percentage contributions of feed rate, spindle speed, tool diameter, helix angle and depth of cut for the surface roughness are 0.7%, 3.6%, 4.8%, 61.9% and 0.2% respectively,. In addition, From the ANOVA results, it can be seen that the most influential parameter on the surface roughness of stainless steel is helix angle with 61.9% for milling parameter, while tool diameter, spindle speed, feed rate and depth of cut are not significant.

For Aluminum, it can be seen from the ANOVA results table 9, the percentage contributions of feed rate, spindle speed, tool diameter, helix angle and depth of cut for the surface roughness are 2.7%, 11.42%, 8.02%, 59.6% and 8.07% respectively, and the error is 10.21%. In this case, the most effective parameter for the surface roughness is the helix angle (59.6%). In addition, From the ANOVA results, it can be seen that helix angle and spindle speed are statistically significant for affecting average surface roughness (Ra). The feed rate, tool diameter and depth of cut do not have a significant effect on the surface roughness.

A comparison of percentage contribution diagrams for different materials is illustrated in Figure 3, in which the dominant effect of tool helix angle on surface finish is evident. Within the selected range of variation, feed rate showed negligible effect on surface roughness.

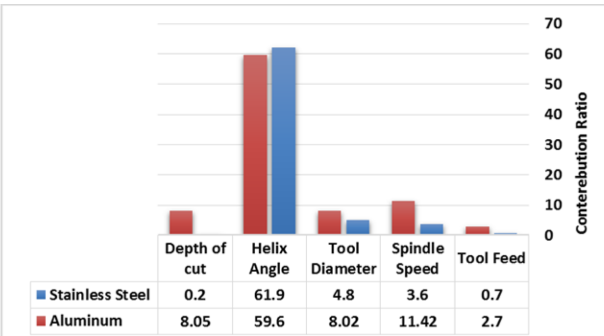

Figure 3. Milling parameters percentage contribution for different materials.

CONCLUSION

- The statistical analysis (ANOVA) of surface roughness for stainless steel 304 shows that the tool helix angle significantly influence at 95% confidence level.
- It was also evident from the analysis (ANOVA) of surface roughness for aluminum 6082 is influenced by tool helix angle and spindle speed at 95% confidence level.
- Under the experimental conditions investigated in this study, it has been seen that if the tool helix angle increases the surface roughness increases.
- The smallest surface roughness (Ra) value occurred in machining of stainless steel 304 is 0.0992 µm at feed rate = 40 mm/min, spindle speed =1500 rpm, tool diameter = 8 mm, helix angle = 40 degree and depth of cut = 0.5 mm.
- The smallest surface roughness (Ra) value occurred in machining of aluminum 6082 is 0.0666 µm at feed rate 40 mm/min, spindle speed 1000 rpm, tool diameter 8 mm, helix angle 40 degree and depth of cut 0.25 mm.
- The Taguchi design of experiment method provides a systematic and efficient methodology for the design optimization of the process parameters resulting in the surface roughness with far less effect than would be required for most optimization techniques.
- According to results of S/N ratio, the optimal experimental condition for stainless steel AISI 304 and surface roughness (Ra) were obtained on the first level of feed rate (40 mm/min), spindle speed (1500 rpm), tool diameter (12 mm), helix angle (40 degree) and depth cut (0.25 mm).
- According to results of S/N ratio, the optimal experimental condition for aluminum 6082 and surface roughness (Ra) were obtained on the feed rate (60 mm/min), spindle speed (1500 rpm), tool diameter (12 mm) , helix angle (40 degree) and depth cut (0.25 mm).
- Estimation the influences of cutting tool geometry on the surface quality is the most important factor to increase the efficiency and productivity, improved surface roughness and increase cutting tool life, thus reducing the time wasted.

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