Investigation on Surface Roughness for End milling on Aluminum Alloy 6061-T6 for Different Parameters

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Abstract— A set of experimental runs done to get knowledge about the surface quality for the end-milling process have been performed. The purpose of this research is to have a good understanding of the effects of spindle speed, cutting feed rate and depth of cut on the surface roughness and also to build a regression equation. Such an understanding can give idea into the problems of controlling the finish of machined surfaces when the process parameters are adjusted to have a good surface finish. This study has considered the effect of spindle speed, cutting feed rate and depth of cut for predicting the surface roughness values and also interactions between the two variables.

Key words: Surface Finish, Surface Roughness, Minitab, End Milling

I. Introduction

Metal cutting is one of the most significant manufacturing processes in the area of material removal [1]. Metal cutting is defined as the removal of metal chips from a workpiece in order to obtain a finished product with desired attributes of size, shape, and surface roughness [2]. In different machining processes, end milling is one of the significant machining operations. In end milling operation, the milling cutters used are end milling cutters or end mills which are widely used in industry for high-speed machining. End milling cutters are milling cutters with more than one cutting edge called multi-edge. They have edges both on the face end as well as on the periphery end. Each cutting edge removes a small amount of metal with each revolution. End mills integrate the capabilities of peripheral cutting, end cutting and face milling into one tool.

End mills can be used on both vertical and horizontal milling machines for many different operations such as slotting, profiling and facing operations. Among several industrial manufacturing operations, milling is a fundamental machining operation. End milling is the most common metal removal operation encountered. It is widely used in a variety of manufacturing industries including the aerospace and automotive sectors, where quality is an important factor in the production of slots and dies. The quality of the surface plays a major role in the performance of milling as a surface having good finish significantly improves creep life, fatigue strength and corrosion resistance. Surface roughness also affects several functional attributes of parts, such as wearing, heat transmission ability of holding a lubricant, coating, or resisting fatigue. Therefore, the required finish surface is usually specified and the operations needed are selected to reach the required quality. Several factors influence the final surface roughness in end milling operation. Factors such as spindle speed, feed rate, and depth of cut that control the cutting operation can be setup in advance [9]. However, factors such as tool geometry, tool wear, and chip formation, or the material properties of both tool and workpiece are uncontrolled[10].

II. Workpiece Material and Tool Material

The workpiece material selected for the experiment is Aluminium alloy 6061-T6 material. Two plates of dimension 120 × 100 mm having a 30 mm thickness were used.The chemical composition of the AA6061-T6 is provided in Table 1. Table 2 shows the mechanical properties.

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.4 - 0.8	0. 7	0.15 - 0.40	0.1 5	0.8 - 1.2	0.04 - 0.35	0.2 5	0.1 5	Rem .

Table 1: Chemical Composition of AA6061-T6

Properties	
Density	2.7 g/cc
Ultimate Tensile Strength	310 MPa
Yield Tensile strength	276 MPa
Modulus of Elasticity	68.9 GPa
Hardness	40 RC
Thermal Conductivity	167 W/m-K
Machinability	50%
Melting Point	582-652^{O}C

Table 2: Mechanical Properties of AA6061-T6

Alloy 6061 is one of the most commonly used alloys in the 6000 series. This aluminum alloy is one of the most versatile of the alloys which are heat-treatable. As this alloy has good toughness properties, it is widely used for medium to high strength requirements. 6061-T6 aluminum is widely used in airplane construction. Although mostly used in private aircrafts, its strength-to-weight ratio is very high, making it ideal for large parts that need to be very light, such as the plane’s fuselage and wings.

6061-T6 aluminum properties make it a material of choice for builders of boats and watercraft because it’s strong and light weight. It is an ideal material for hulls of big ships that cannot be made from fiberglass. It is also an ideal material for sailboat masts. Small, flat-bottom canoes are almost entirely fabricated from 6061-T6.

The tool material used here is High Speed Steel tool. The advantage of HSS over carbide is its strength to withstand cutting forces and the low cost of the tools. From the tool life point of view, HSS performs very well at intermittent cutting applications. High Speed steel are high-content carbon steels with a high proportion of alloy elements such as tungsten, molybdenum, chromium, vanadium and cobalt. The mean hardness is 75 HRC. The maximum working temperature of HSS is around 500 °C. The dimension of the HSS tool used in experiment are: Milling Diameter–14 mm, Shank Diameter–12 mm, Length of Cut –26 mm, Overall length–83 mm, No of Flutes–4, Straight Shank, Helix angle –35 degree.

III. EXPERIMENTAL SETUP AND PROCEDURE

Experiments have been conducted in order to understand the effects of the process parameters (spindle speed, feed rate and depth of cut) on the surface finish of the machined surface. When an experiment involves two or more factors, the factors can affect the response individually or with each other. Often, the experimental design does not give an idea about the interaction effects of the factors as in the case of one factor at-a time experimentation. All possible factor level combinations experiments conducted are especially useful for testing the interaction effect of the factors. The experiment has been done under dry machining environment. The experimental setup is shown in figure. 1. The response variable was Surface roughness, Ra measured in µm. Several variables were controlled during experiment including the machine on which milling operation was performed (the same machine was used for all experimental work), and the operator (the same operator machined all specimens). The surface roughness data were measured for each of the 27 machining conditions given by the levels of independent variables (3 spindle speeds ×3 cutting feeds × 3 depths of cut). In this experiment, the assignment of factors was carried out using general full factorial method in MINITAB 17 Software. The values of the input process parameters are as under as shown in table 3:

Factors	Level 1	Level 2	Level 3
Speed(rpm)	250	500	710
Feed(mm/min)	100	200	315
Depth of cut(mm)	0.5	1	1.25

Table 3: Values of Input Parameters

The milling machine used for experiment purpose was UF1 which is the model name of Vertical milling machine available in our college is of Bharat Fritz Werner company in Banglore. The surface roughness tester used for surface roughness measurement was Surftest SJ-210 from Mitutoyo company. Fig. 1 shows the end milling operation. Fig. 2 shows the workpieces after end milling operation is done on them by HSS End mill. Fig. 3 shows the surface roughness measurement of workpiece by surface roughness tester.

Fig. 1: End Milling Operation

Fig. 2: Workpieces after machining by HSS end mill

Fig. 3: Surface roughness measurement

Analysis of the results was carried out analytically as well as graphically. All the statistical calculations and plots were generated by MINITAB 17 software. R_a is defined as the arithmetic means value of the deviation of the profile within sampling length. The values of surface roughness, R_a obtained using surface roughness tester for different combinations of input parameters is shown in Table 4.

Experiment no	Speed	Feed	Depth of cut	R_a
A1	250	100	0.5	2.897
A2	250	100	1	4.542
A3	250	100	1.25	5
A4	250	200	0.5	2.281
A5	250	200	1	3.427
A6	250	200	1.25	3.197
A7	250	315	0.5	2.012
A8	250	315	1	2.666
A9	250	315	1.25	3.644
A10	500	100	0.5	1.604
A11	500	100	1	1.717
A12	500	100	1.25	3.64
A13	500	200	0.5	3.157
A14	500	200	1	4.101
A15	500	200	1.25	4.439
A16	500	315	0.5	2.511
A17	500	315	1	3.313

A18	500	315	1.25	3.47
A19	710	100	0.5	1.202
A20	710	100	1	1.824
A21	710	100	1.25	2.274
A22	710	200	0.5	1.852
A23	710	200	1	3.031
A24	710	200	1.25	4.203
A25	710	315	0.5	1.799
A26	710	315	1	2.549
A27	710	315	1.25	2.928

Table 4: Values of Surface Roughness, R_a

IV. ANALYSIS AND RESULTS

The multiple regression model is proposed which is a two-way interaction equation:

$$Z = C+B_1Y_1 +B_2Y_2 + B_3Y_3 + B_{12}Y_1Y_2 + B_{13}Y_1Y_3 + B_{23}Y_2Y_3 \quad (1.1)$$

Where

Z: surface roughness in μ m

Y_1: spindle speed in rpm

Y_2: cutting feed in mm/min

Y_3: depth of cut in mm

In this model, the output variable is the surface roughness (Ra) and the input variables are spindle speed, feed rate, and depth of cut. Because these variables are controllable machining parameters, they can be used to predict the surface roughness in end milling which will then increase quality of the product.

ANOVA plots of the experimental data have been generated to calculate the significance of each factor for each response. Often, researchers choose 90%, 95%, or 99% Confidence Levels; but since most of the researchers have chosen 95% Confidence Level, so for this research work also 95% Confidence Level has been chosen. Thus α = 0.05 was selected for all statistical calculations.

The analysis by Taguchi method utilizes the Signal-to-Noise ratio (S/N) to show the scatter around a target value. A high value of S/N indicates that the signal is much higher than the random effects of the noise factors. Values of Ra are desirable as shown in Table 4. Since surface roughness values should be as minimum as possible for good surface finish, the “smaller the- best” methodology is used for S/N ratio results shown by using MINITABE 17. Table 5 and Table 6 shows the response table for signal to noise ratios and response table for means.

Level	Speed	Feed	Depth of cut
1	-10.016	-7.815	-6.290
2	-9.380	-10.067	-9.189
3	-7.108	-8.621	-11.024
Delta	2.908	2.251	4.734
Rank	2	3	1

Table 5: Response Table For Signal To Noise Ratios (Smaller Is Better)

Level	Speed	Feed	Depth of cut
1	3.296	2.744	2.146
2	3.106	3.299	3.019
3	2.407	2.766	3.644
Delta	0.889	0.554	1.498
Rank	2	3	1

Table 6: Response Table For Means

Term	Coef (B)	SE Coef	P-value
Constant	3.46	1.67	0.051
Speed(N)	-0.00581	0.00269	0.043
Feed(F)	-0.00744	0.00600	0.229
Depth of cut (D)	2.67	1.52	0.094
N×F	0.000020	0.000008	0.018
N×D	-0.00030	0.00222	0.896
F ×D	-0.00274	0.00476	0.571

Table 7: Coefficients of Regression Equation

In Table 7, the coefficients for the independent variables were listed in the column B. Using these coefficients, the multiple regression equation could be expressed as:

$$R_a==3.46-0.00581\times N-0.00744\times F+2.67\times D +0.00002\times(N\times F)-0.0003\times(N\times D)-0.00274\times(F\times D) \quad - (1.2)$$

Source	DF	Adj SS	Adj MS	F-value	P-value
Model	10	23.57	2.36	15.86	< 0.0001
N	2	3.95	1.97	13.28	0.0004
F	2	1.77	0.89	5.97	0.0116
D	2	10.19	5.09	34.28	< 0.0001
N×F	4	7.66	1.92	12.89	< 0.0001
Residual	16	2.38	0.15		
Total	26	25.95			

Table 8: Analysis of Variance

The Model F-value of 15.86 implies the model is significant. There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant.

In this case A, B, C, AB are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. If there are many insignificant model terms (not counting those required to support hierarchy), model reduction may improve your model.

Std. Dev.	0.39	R-Squared	0.9084
Mean	2.94	Adj R-Squared	0.8511
C.V.%	13.13	Pred R-Squared	0.7391
PRESS	6.77	Adeq Precision	15.759

Table 9: Analysis of Variance

From Table 9, the "Pred R-Squared" of 0.7391 is in reasonable agreement with the "Adj R-Squared" of 0.8511; i.e. the difference is less than 0.2."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable. Your ratio of 15.759 indicates an adequate signal. This model can be used to navigate the design space.

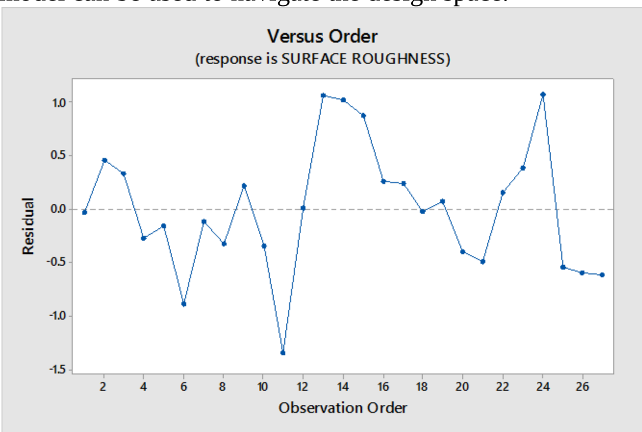

Fig. 4: Versus order between Residual and observation

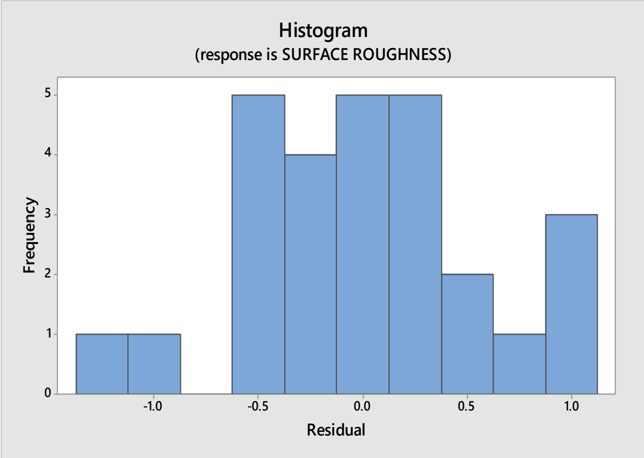

Fig. 5: Histogram graph between frequency and Residual (response surface roughness)

In Fig. 4-5, the signal to noise ratio select for the current work was "smaller to better''. According to Fig.4 of the residuals versus order plot, we can see that there is not any pattern above or below 0 and that the residuals are uncorrelated with each other.Fig.5 shows the histogram graph between frequency and residual. Fig.6 and Fig.7 shows the interaction plot between input parameters and main effects plot respectively.

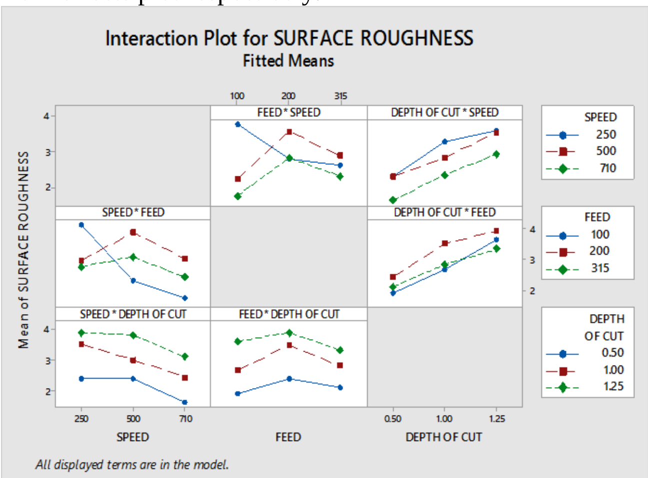

Fig. 6: Interaction plot between input parameters

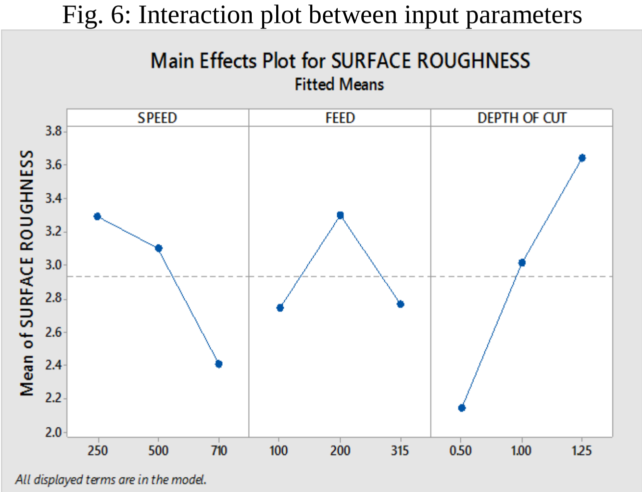

Fig. 7: Main effects plot for surface roughness

Fig. 8 is the residuals versus fits plot from which we can see that the residuals have a constant variance.Fig.9 shows the normal probability plot which shows that the residuals are normally distributed.

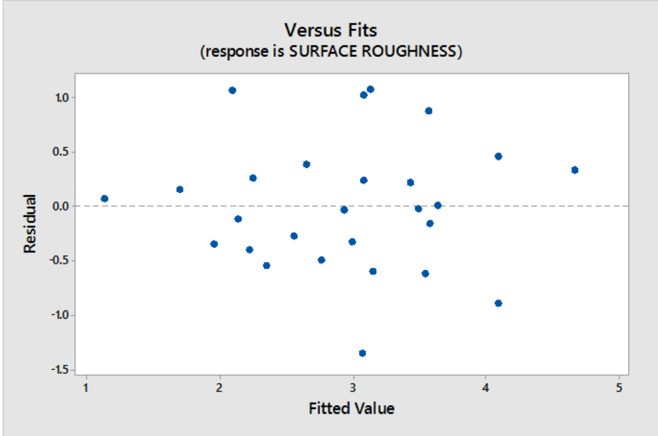

Fig. 8: Versus Fits between Residual and Fitted value

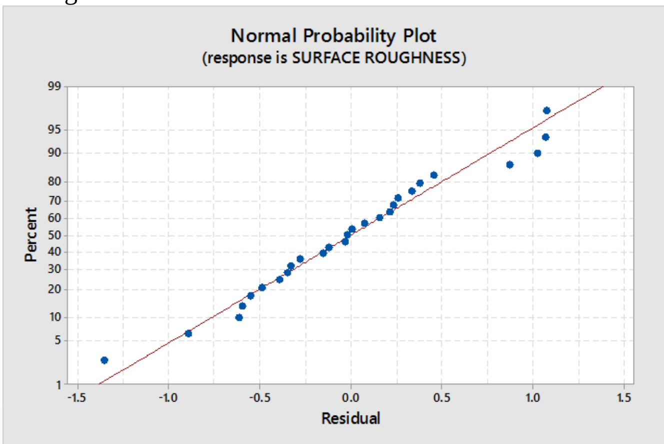

Fig. 9: Normal Probability plot

V. CONCLUSION

From the experimental runs, we found that the lowest value of R_a obtained was 1.202µm at speed of 710 rpm, feed of 100mm/min and depth of cut of 0.5 mm. The order to minimum surface roughness, in sequence, is the depth of cut, spindle speed and feed rate. It is also observed through ANOVA that the depth of cut is the most influential control factor among the three end milling process parameters investigated in the present study, when minimization of surface roughness is considered.

In this research work, the material used is AA6061-T6. The experimentation can also be done for other materials having more hardness to see the effect of parameters on Surface Roughness. In each case, interaction of the different levels of the factors can be included and study can be extended. In DOE the number of trials can be repeated with the same combinations of factors and their interactions to obtain more than one response (Surface Roughness).

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