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Optimization of machining parameters on AL 6061 alloy using response surface methodology

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Abstract
The present work deals with the mathematical modeling and analysis of machining response such as the surface roughness and tool wear in the turning of aluminum alloy 6061. There are several process parameters namely spindle speed, depth of cut and feed rate used to determine the quality of surface roughness. Experiments are conducted as per central composite face centered design. Among the following process parameter the spindle speed, depth of cut and feed rate for the purpose of analysis. Response surface methodology is utilized to develop an effective mathematical model to predict optimum level. A comparison study is made for tabulated values and experimental values for surface roughness by using analysis of variance. The model found statistically fit for 95% confidence level.

Keywords: *Surface Roughness, Aluminum alloy 6061, CCD, ANOVA, RSM.*

1. Introduction
Al 6061 alloy is widely used for commercial applications in the aerospace, automotive parts construction and engineering industries. It possesses excellent mechanical properties in addition to good corrosion resistance due to which the alloy finds extensive applications in naval vessels manufacturing. 6061 is a precipitation hardening aluminum alloy, containing magnesium and silicon as its major alloying elements. It has good mechanical properties and exhibits good weldability. Palanikumar [1] developed a model for surface roughness through RSM while measuring GFRP composites. Four factors five level central composite rotatable design matrix was employed to carry out the experimental investigation. Analysis of variance (ANOVA) was used to check the validity of the model. Muthukrishnan. *et al.* [2] developed two modeling techniques used to predict the surface roughness namely ANOVA and ANN. In ANOVA it is revealed that the feed rate is highest physical as well as a statistical influence on the surface roughness right after the depth of cut and the cutting speed. Neseli *et al.* [2] experimented to optimization of tool geometry parameters for turning operations based on the response surface methodology. In this study, experiments were designed by using Taguchi L27 orthogonal array. The effect of tool geometry parameters on the surface roughness during turning of AISI 1040 steel obtained through response surface methodology (RSM) and prediction model was developed related to average surface roughness (Ra).

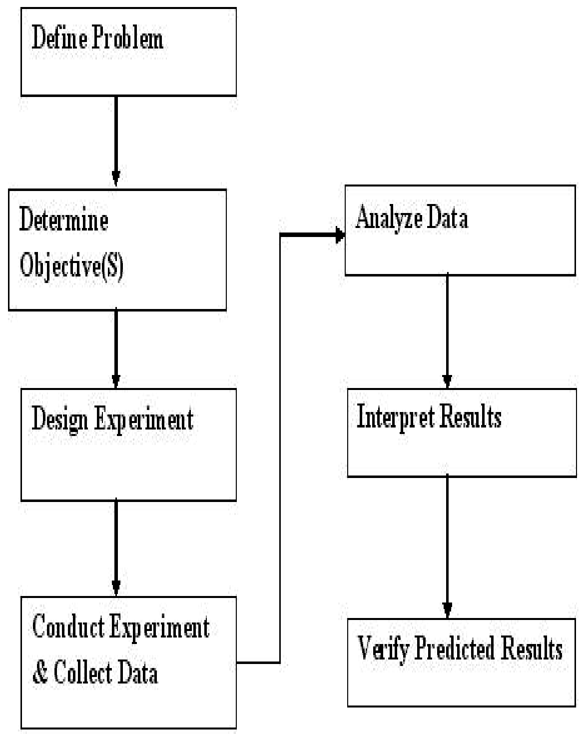
Fig 1: Experimental set-up

The aluminum alloy 6061 chemical composition are given table 1.

Table 1: Chemical composition of Al 6061 alloy

Si	Fe	Cu	Mn	Mg	Zn	Ti	Cr	Al
0.49	0.195	00.388	0.068	1.07	0.003	0.019	0.243	Balance

2. Experimental Procedures
2.1 Plan of Experiments



An important stage in response surface model generation by RSM is the planning of experiments. The factors which have a significant influence on surface roughness and tool wear were identified they are spindle speed, feed rate and depth of cut of turning. Aluminum alloy 6061 round rod Ø32 mm using to determine optimum values of machining parameters. The process parameters and their levels are given from table 2.

Table 2: Process parameters and their actual values

Factors	Notation	Unit	Factor Level		
			Low	Middle	High
Spindle Speed	S	RPM	600	700	800
Feed rate	F	mm/rev	0.5	0.10	0.15
Depth of cut	D	Mm	0.05	0.1	0.15

2.2 Response surface Methodology
Response surface methodology is a collection of mathematical and statistical techniques for empirical model building. By careful design of experiments the objective is optimize a response which is influenced by several independent variables. An experiment is a series of tests, called runs, in which changes are made in the input variables in order to identify the reasons for changes in the output response. The second order mathematical models have been developed on surface roughness.

$$yi = \beta_0 + \sum_{j=1}^{q} \beta j xj + \sum_{j=1}^{q} \beta jj xj^2 + \sum \sum_{i<j}^{s} \beta ij\, xi\, xj$$

Where y_i is response, i.e., tool wear; x_j represents cutting speed, feed rate depth of cut β_0, β_j, β_{jj}, and β_{ij} represent the constant, linear, quadratic, and interaction terms, respectively. The surface roughness obtained from experimental results for different combination of parameters is given as input to the design expert software, and a second order mathematical model for surface roughness is developed.

Surface Roughness = 27.10-4.10× (A) -11.50× (B)-5.40× (C)-6.00× (A^2) +8.00× (B^2) -0.50× (C^2) +2.00 × (AB) +1.50× (AC) +6.00× (BC)……………….(1)

Table 3: Experimental values of surface roughness

S. No	Spindle Speed (RPM)	Feed Rate (mm/rev)	Depth of Cut (mm)	Surface Roughness (Ra) (µm)
1	700	0.1	0.75	27
2	700	0.1	0.75	27
3	700	0.1	0.5	30
4	600	0.1	0.75	28
5	700	0.1	0.75	26
6	700	0.1	1	24
7	700	0.1	0.75	27
8	600	0.15	1	18
9	800	0.15	1	15
10	700	0.1	0.75	27
11	800	0.15	0.5	15
12	600	0.05	1	31
13	800	0.05	0.5	44
14	700	0.05	0.75	45
15	700	0.15	0.75	26
16	700	0.1	0.75	27
17	800	0.1	0.75	15
18	800	0.05	1	26
19	600	0.15	0.5	18
20	600	0.05	0.5	61

3. Results and Discussion
3.1 Analysis of variance

Table 4: ANOVA Quadratic Model Result

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	2327.45	9	258.6056	43.7572	< 0.0001
A	168.1	1	168.1	28.4433	0.0003
B	1322.5	1	1322.5	223.773	< 0.0001
C	291.6	1	291.6	49.3401	< 0.0001
A^2	99	1	99	16.7512	0.0022
B^2	176	1	176	29.7800	0.0003
C^2	0.6875	1	0.6875	0.11632	0.7401
AB	32	1	32	5.41455	0.0423
AC	18	1	18	3.04568	0.1115
BC	288	1	288	48.7309	< 0.0001
Residual	59.1	10	5.91		
Lack of Fit	58.26667	5	11.65333	69.92	0.0001
Pure Error	0.833333	5	0.166667		
Cor Total	2386.55	19			

The model F-value of 43.76 implies the model is significant. There is only a 0.01% chance that a "Model 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, A^2, B^2, AB, BC are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

3.2 Analysis of Response Surface Graphs
Response surfaces were developed for the empirical relationship, taking two parameters in the 'X' and 'Y' axis and response in 'Z' axis. The response surfaces clearly indicate the optimal response point. The different colored surfaces show that the value of surface roughness obtained for the corresponding values of input parameters. The relationship between independent and dependent variables was graphically represented by three dimensional response surface graphs and two dimensional contour plots (Figures 3-8).

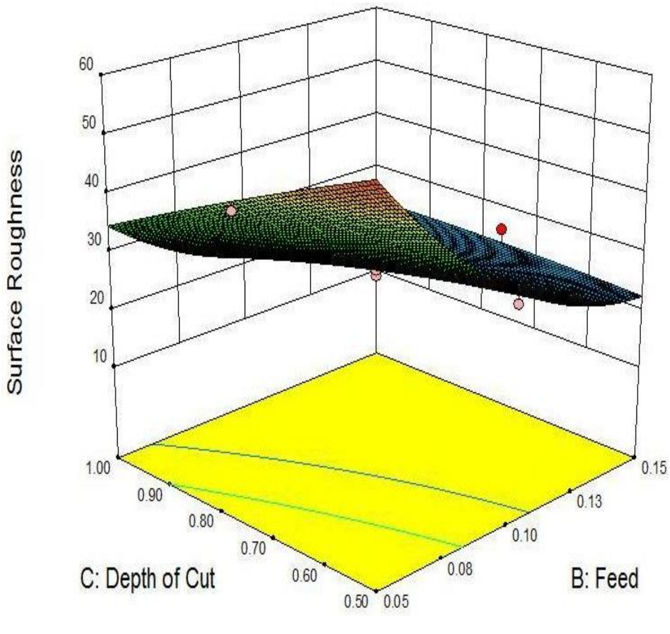


Fig 3: Response surface due to interaction of depth of cut and Feed rate on surface roughness

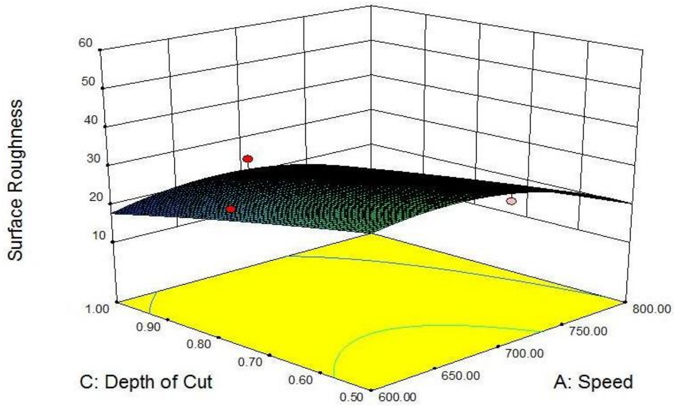


Fig 4: Response surface due to interaction of depth of cut and Spindle speed on surface roughness

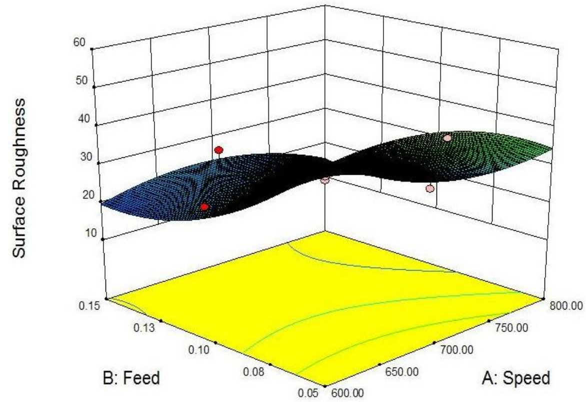


Fig 5: Response surface due to interaction of spindle speed and Feed rate on surface roughness

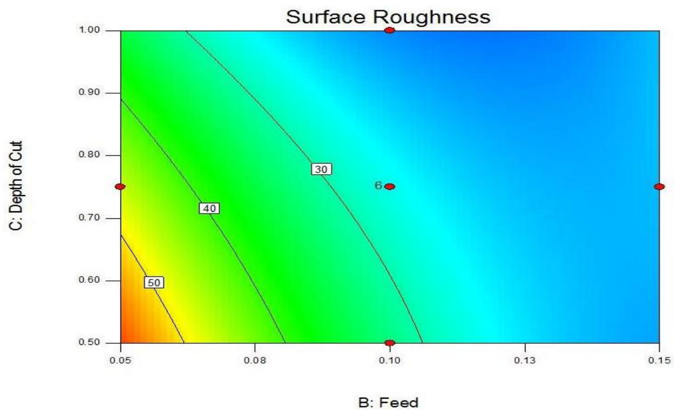


Fig 6: Contour plot due to interaction of depth of cut and Feed rate on surface roughness

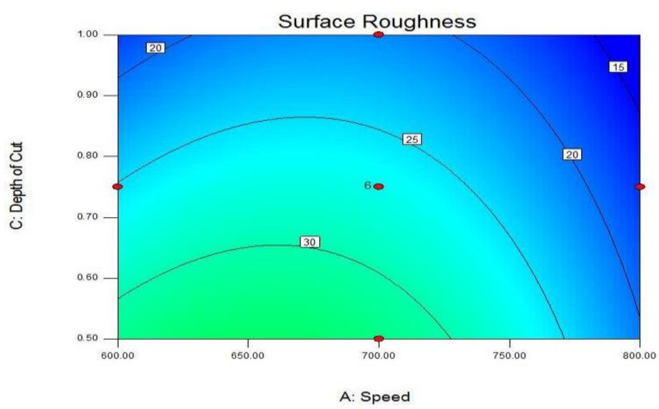


Fig 7: Contour plot due to interaction of spindle speed and Feed rate on surface roughness

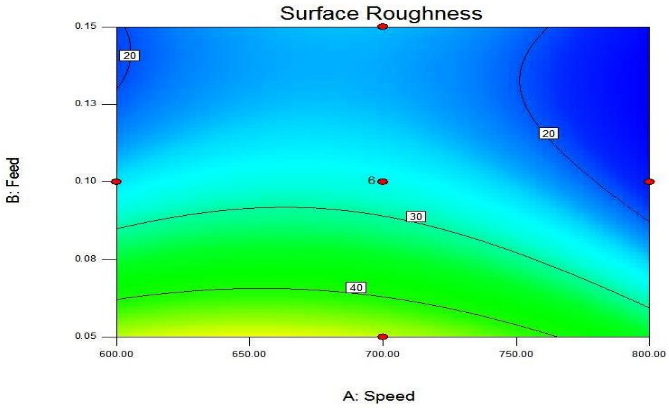


Fig 8: Contour plot due to interaction of spindle speed and Feed rate on surface roughness

Different shape of the response surface graphs and contour plots indicated different interactions between the variables, an contour plot indicated the interaction between the variables were significant while a circular contour plot means otherwise. Response surface graphs (Figures 3-5) for the response surface roughness obtained from the regression model. The response surface graphs for the surface roughness between feed rate and depth of cut the surface roughness is increasing with decreasing the depth of cut and low amount of feed rate. Figure 4 showed the interaction between spindle speed and depth of cut on the surface roughness. Increase the spindle speed improves the surface finish. However, when the depth of cut over the range there was a gradual decline in response [5]. The response surface graphs for surface roughness between feed rate and cutting speed, it can be seen from this figure 5 that surface roughness increases with increase of cutting speed and decreasing of feed rate. It is inferred that surface roughness conditions of high cutting speed and low feed rate produce high surface finish.

4. Conclusion

In this study, the aim of optimization was to find the conditions which gave the maximum surface finish. Design Expert-9 generated the optimum spindle speed, depth of cut and feed rate was 700rpm, 0.5 mm and 0.05 mm/rev approximate respectively. Experiments were conducted on lathe machine using Al 6061 alloy the data surface roughness was collected under different turning machining conditions for various combination of cutting speed, feed rate, and depth of cut environment.

- RSM provides a large amount of information with a small amount of experimentation.
- The RSM based surface roughness model in terms of cutting speed, feed rate, and Depth of cut environment was developed by means of the experimental database as per central composite design of experiments.
- The quadratic modes developed using RSM were reasonable accurate and can be used for prediction within the limits of the factors investigated.
- The second order quadratic model was used to predict surface roughness values for experimental value by response surface methodology.
- A comparison study is made for tabulated values and experimental values for surface roughness by using analysis of variance the model is statistically fit found on 95% confidence level.

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