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Surface Roughness Prediction of Al2014t4 by Responsive Surface Methodology

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Abstract

Now a day's research is prominent to improve surface roughness on mechanical elements has become quite significant in the operational point of view. To enhance accuracy and precision in manufacturing firms are adopting automated systems in order to achieve manufacturing excellence. In this paper the optimizing conditions for best surface roughness on Aluminum alloy 2014T4 and its effect on various parameters spindle speed, tool feed and depth of cut on the surface roughness in precision turning process will be investigated by using response surface methodology(RSM). Three factor-three levels are used, as per the Box-Behnken design matrix. The coefficients are calculated by using Regression analysis and further the model is constructed. Adequacy of developed model is checked by using ANOVA. Interaction effect of various process parameters on surface roughness are studied by using mathematical modeling. This paper is useful for automobile manufacturers, air craft, marine, industries for machining the Aluminum alloys to get optimized surface roughness.
Keywords: Surface Roughness (Ra), Response Surface Methodology (RSM), CNC Turning, Box-Behnken Design Matrix, ANOVA

I. INTRODUCTION

In this paper, Optimization methods in metal cutting processes, considered to be a vital tool for continual improvement of output quality in products and processes include modeling of input–output and in-process parameters relationship and determination of optimal cutting conditions. This paper focuses on developing an empirical model for the prediction of surface roughness in finish turning. The working parameters are work piece hardness (material), feed, cutting tool point angle, depth of cut, spindle speed, and cutting time. One of the most important nonlinear regression analyses with logarithmic data transformation is applied in developing the empirical model[1]. The values of surface roughness predicted by this model are then verified with extra experiments and Metal cutting experiments and statistical tests demonstrate that the model developed in this work produces smaller errors than those from some of the existing models and have a satisfactory result in both model construction and verification. In order to find out the effect of tool geometry parameters on the surface roughness during turning, response surface methodology (RSM)[4] was used and a prediction model was developed related to average surface roughness (Ra) using experimental data. The results indicated that the tool nose radius was the dominant factor on the surface roughness. MINI TAB is a software which is to establish the initial model and refined model. The coefficients of mathematical modeling based on the response surface regression model are determined. In this Response surface methodology software package for surface roughness prediction.

A. Response Surface Methodology (RSM)

It is a collection of mathematical and statistical techniques useful for analyzing problems where several independent variables influence a dependent variable or response and the goal is to optimize this response. It seeks to relate an average response to the value of quantitative variables that affect the response.

II. EXPERIMENTAL METHODOLOGY

The study was carried out using a CNC XLTURN machine equipped with a maximum spindle speed of 3000rpm, feed rate of 1.2 m/min and multiple tool change capabilities (max no. of tools 8) and with 1HP spindle horse power. The machine is capable of a 2-axis movement along X, Z directions. CNC programs can be developed in a FANUC software. The work piece material used was AL 2014-T4 in the form of 80mm length and 25mm diameter cylindrical rods. The level of parameters selected for the experiments were given in table 9. Fifteen experiments are carried out according to the BOX BEHNKEN design. The surface roughness measured by using a mitutoyo surface roughness tester with a sampling length of 10mm.

A. Procedure for Experimental Methodology

1) Aluminum 2014T4 is selected as work piece.

2) Carbide tool is selected for machining.
3) CNC XLTURN machine for step turning.
4) Program for step turning operations are written.
5) Based on Box Behnken for three level three factorial to do 15 experiments are chosen
6) Selection of factors for ANOVA (speed, feed and Depth of cut)
7) Selection of confidence level 95% based on ANOVA to get predicted values
8) Actual surface roughness is measured for machined work pieces using TALYSURF and readings are noted
9) Predicted values are compared with actual values to test the machining inputs (speed, feed and Depth of cut)
10) Results from step 7th and 8th are compared to get outputs in the form of tables, interaction graphs, contour plots, scatter plots and main effect plots.
11) From step 10 conclusions are drawn from best significant parameter to improve surface roughness and step 4 to 9 are repeated for remaining 14 experiments

B. Work Piece

Table – 1
Composition of AL2014-T4

Component	Wt. %	Component	Wt. %	Component	Wt. %
Al	90.4 - 95	Mg	0.2 - 0.8	Si	0.5 - 1.2
Cr	Max 0.1	Mn	0.4 - 1.2	Ti	Max 0.15
Cu	3.9 - 5	Other, each	Max 0.05	Zn	Max 0.25
Fe	Max 0.7	Other, total	Max 0.15		

III. SELECTION OF BOX BEHNKEN

It is one of the designs in the RSM technique that requires fewer treatment combinations than other designs in case of involving 3 or 4 factors. It is rotatable, but it contains regions of poor prediction quality like CCI. Its missing corners may be useful when the experiment should avoid combined factor extremes. This property prevents a potential loss of data in those cases.

Box-Benhken Design matrix for three factor-three level machining, indicating the coded matrix for fifteen number of runs

A. Development of Optimal Working Zones[8]

The optimum working zone depends on the desired work piece. Experiments were conducted separately for each combinations to find the operating working region. Finding of this region was necessary to fix up the limits of the process parameters. The upper and lower limits are denoted as +1, and –1 respectively. Trial runs were conducted by changing one of the factors and keeping the remaining at constant value. The maximum and minimum limits of all the factors were thus fixed.

Table – 2
Input parameters and their levels

Parameter	*-1*	*0*	*+1*
Spindle speed(rpm)	*600*	*1200*	*1800*
Feed(mm/min)	*30*	*60*	*90*
Depth of cut(mm)	*0.2*	*0.5*	*0.8*

There are four common quadratic designs which includes Box behnken design, Central Composite Circumscribed (CCC), Central Composite Inscribed (CCI) and Central Composite Face centered (CCF). In all these designs Box Behnken provides optimum design matrix for 3 level - 3 factor case. And it requires fewer runs than other designs

B. Design of the Experiment[11]

It is known that the general quantitative approach is based on a more sound logic than another approach for the generalization of data. Thus, it was decided to take this approach as the basis for designing experiments. There are various techniques available from the statistical theory of experimental design which are well suited to Engineering investigations. One such important technique is a Surface Response Technique for studying the effects of parameters on response and this is the one which was selected for the experiment. The design of an experiment is the procedure of selecting the number of trails and conditions for running them, essential and sufficient for solving the problem that has been set with the required precision.

Table – 3
Coded Value

	Coded Values		
SI.No	*Speed*	*Feed*	*Depth of cut*
1	*-1*	*-1*	*0*
2	*1*	*-1*	*0*
3	*-1*	*1*	*0*
4	*1*	*1*	*0*
5	*-1*	*0*	*-1*

6	*1*	*0*	*-1*
7	*-1*	*0*	*1*
8	*1*	*0*	*1*
9	*0*	*-1*	*-1*
10	*0*	*1*	*-1*
11	*0*	*-1*	*1*
12	*0*	*1*	*1*
13	*0*	*0*	*0*
14	*0*	*0*	*0*
15	*0*	*0*	*0*

C. Conducting the Experiments as per the Design Matrix[7]

The experiments were conducted according to the design matrix by using CNC XL-TURN Machine. The number of runs required by a full 2^k RSM design increase geometrically as K is increased and the larger the number of trials called for is primarily to provide estimates of the increasing number of higher order interactions which most likely do not exist. Therefore experiments for such estimates would be wasted, increasing the cost and time of experiments. Under such conditions it is possible and advantages to use only part of the full factor design i.e., fractional factorial design and the concept of compounding. Surface response design constitutes the main parameters of major interests and is compounded (mixed up) with effects of higher order interactions and since these interaction effects are assumed to be small and negligible, the resulting estimates are essentially the main effects of primary interest.

D. Selection of Design and Mathematical Model

Effect of the machining parameters on surface finish being the major part of investigation it was considered best to design the experiments.

E. Selection of Factors

1) Identification of important process control variables

Identification of correct factors is very important to get a good and accurate model. Among many parameters that effect the surface roughness, the following were important: Speed, feed and depth of cut.

2) Finding the limits of the process variables[5]

Trial experiments were carried out to find out the working range or both surface roughness range and material removal range by varying one process variable and keeping other process variable constant.

The various values of factor examined in an experiment are known as limits.

1) For the convenience of recording and processing, the experimental data was observed.
2) The upper and lower limits were coded as +1, -1 respectively or simply (+) and (-) for the case of recording and processing of the observed data by using the following relationship.

Coded Value = (Natural value – Average value) / Variation in the value

Natural Value = Value under consideration

Average Value = (upper limit + lower limit) /2

Variation value = (upper limit – lower limit)

F. Development of Optimal Working Zones[8]

The optimum working zone depends on the desired work piece. Experiments were conducted separately for each combinations to find the operating working region. Finding of this region was necessary to fix up the limits of the process parameters. The upper and lower limits are denoted as +1, and –1 respectively. Trial runs were conducted by changing one of the factors and keeping the remaining at constant value. The maximum and minimum limits of all the factors were thus fixed.

Table – 4
Input parameters and their levels

Parameter	*-1*	*0*	*+1*
Spindle speed(rpm)	*600*	*1200*	*1800*
Feed(mm/min)	*30*	*60*	*90*
Depth of cut(mm)	*0.2*	*0.5*	*0.8*

IV. RESULTS AND DISCUSSIONS

Trail experiments are carried out on Aluminium 2014 using carbide tipped tool for different input conditions and their ranges were decided and tabulated in Table**.**

A. Input Parameters and their Levels

Box-Behnken design is used to decide the number of experiments to be performed. Total 15 experiments are performed for different combinations of plain turning. Table indicates the design matrix for dry machining.

Table - 5
Indicates the design matrix for dry machining

	Coded Values			*Uncoded Values*			*Surface Finish (Microns)*	
SI.No	*Speed (rpm)*	*Feed (mm/min)*	*Depth of cut(mm)*	*Speed (rpm)*	*Feed (mm/min)*	*Depth of cut (mm)*	*Actual values*	*Predicted values*
1	*-1*	*-1*	*0*	*600*	*30*	*0.5*	*2.07*	*1.895*
2	*1*	*-1*	*0*	*1800*	*30*	*0.5*	*1.84*	*1.787*
3	*-1*	*1*	*0*	*600*	*90*	*0.5*	*1.64*	*1.692*
4	*1*	*1*	*0*	*1800*	*90*	*0.5*	*0.64*	*0.815*
5	*-1*	*0*	*-1*	*600*	*60*	*0.2*	*1.40*	*1.573*
6	*1*	*0*	*-1*	*1800*	*60*	*0.2*	*1.02*	*1.071*
7	*-1*	*0*	*1*	*600*	*60*	*0.8*	*2.02*	*1.968*
8	*1*	*0*	*1*	*1800*	*60*	*0.8*	*1.66*	*1.486*
9	*0*	*-1*	*-1*	*1200*	*30*	*0.2*	*1.26*	*1.216*
10	*0*	*1*	*-1*	*1200*	*90*	*0.2*	*0.67*	*0.443*
11	*0*	*-1*	*1*	*1200*	*30*	*0.8*	*1.21*	*1.436*
12	*0*	*1*	*1*	*1200*	*90*	*0.8*	*1.08*	*1.078*
13	*0*	*0*	*0*	*1200*	*60*	*0.5*	*1.19*	*1.160*
14	*0*	*0*	*0*	*1200*	*60*	*0.5*	*1.13*	*1.160*
15	*0*	*0*	*0*	*1200*	*60*	*0.5*	*1.16*	*1.160*

Regression coefficients are calculated using MINITAB 14 software and are presented Table **.** Estimated Regression Coefficients for SURFACE FINISH (Microns)

Term	Coef	SE Coef	T	P
Constant	1.16000	0.12559	9.237	0.000
Speed(rpm)	-0.24625	0.07690	-3.202	0.024
Feed(mm/min)	-0.29375	0.07690	-3.820	0.012
Doc(mm)	0.20250	0.07690	2.633	0.046
speed*speed	0.42875	0.11320	3.788	0.013
feed*feed	-0.04125	0.11320	-0.364	0.730
doc*doc	-0.06375	0.11320	-0.563	0.598
speed*feed	-0.19250	0.10876	-1.770	0.137
speed*doc	0.00500	0.10876	0.046	0.965
feed*doc	0.11500	0.10876	1.057	0.339
S = 0.2175	R-Sq = 91.1%	R-Sq(adj) = 75.2%		

Empirical model for plain turning is developed using significant coefficients and shown in Equation 1.

$$A= 1.16000-0.24625X_1-0.29375X_2+0.20250X_3-0.42875X_1X_1. \qquad \text{Equation (a)}$$

B. Checking the Accuracy of the Developed Model

The adequacy of the developed model was tested using the Analysis of Variance technique (ANOVA). As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} (from F-table) value at a desired level of confidence (say 95%), then the model is said to be adequate within the confidence limit. ANOVA test results presented in Table are found to be adequate at 95% confidence level.

C. Analysis of Variance for Surface Finish (Microns)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2.43512	2.43512	0.270569	5.72	0.035
Linear	3	1.50348	1.50348	0.501158	10.59	0.013
Square	3	0.73042	0.73042	0.243473	5.15	0.055
Interaction	3	0.20123	0.20123	0.067075	1.42	0.341
Residual Error	5	0.23657	0.23657	0.047315		
Lack-of-Fit	3	0.23477	0.23477	0.078258	86.95	0.011
Pure Error	2	0.00180	0.00180	0.000900		
Total	14	2.67169				

D. Analysis of Plots

Scatter plots are drawn for actual and predicted values for precision turning and is presented in Fig 1 It is observed that predicted values are fairly closed to the actual values.

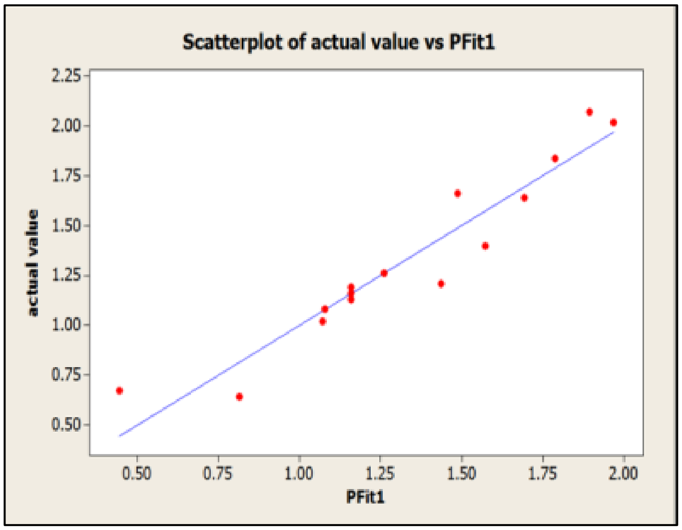

Fig. 1: Predicted Values for Precision Turning

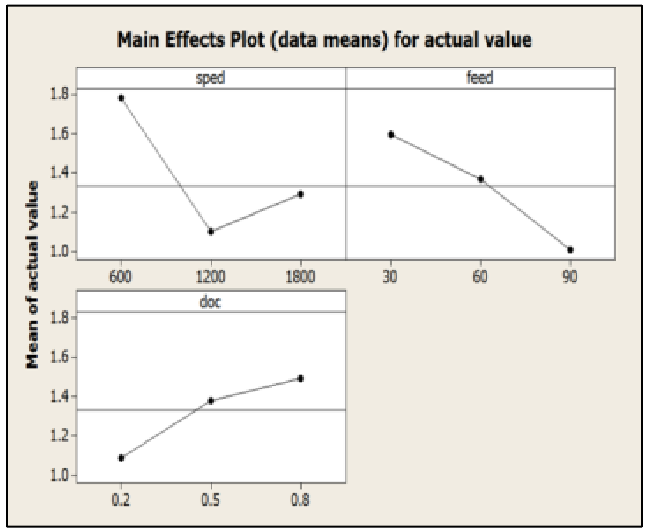

Fig. 2: Plots

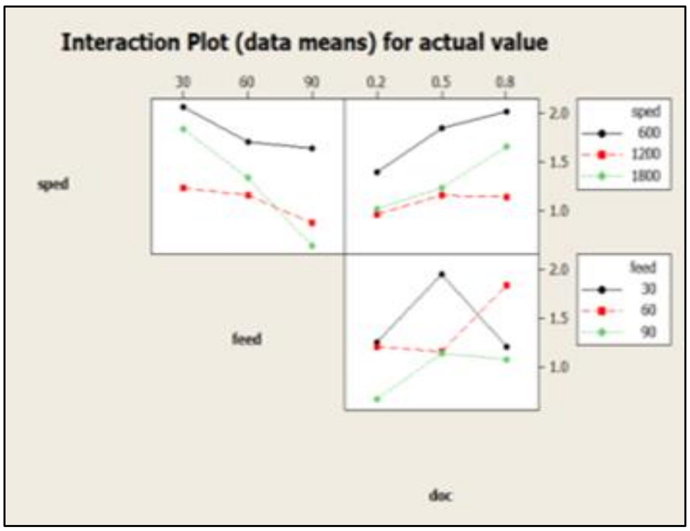

Fig. 3: Plots

E. Effect of Input Parameters on Responses

Main effect plots are drawn to understand the effect of each input parameter separately on the output response as shown in Figure 2.

F. Main Effect Plots for Precision Turning

1) Speed increases surface finish decreases upto medium level and gradually increases on increasing the speed to maximum level.
2) It shows that as feed increases simultaneously surface roughness decreases.
3) In the case of Depth of cut (doc), roughness increases with increase in doc.

Interaction plot is to understand the effect of all the input parameters at a constant rate on the output response and is shown in Figure 3.

G. Interaction Plot for Precision Turning

Interaction plot shows the effect of interaction of process parameters at Constant rates. From this plot we can observe various ranges of surface roughness for different ranges of parameters , i.e, are indicated with three colors black for minimum level, red for medium level, green for maximum level. By this we can choose levels of parameters for achieving desired surface roughness. Contour plot shows that the dominating parameter which effects the surface roughness mostly among two parameters.

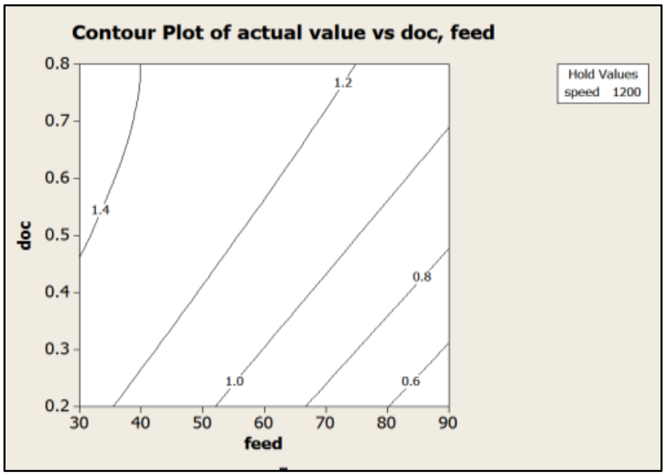

Fig. 4: Contour plot for feed and depth of cut

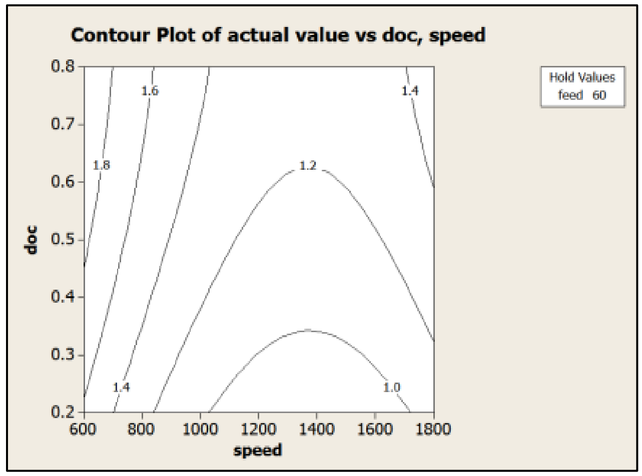

Fig. 5: Contour plot for depth of cut and speed

From the above figure we can observe that contour plot between feed and depth of cut indicates the maximum lines of contour are varying with changes in feed than the Changes in depth of cut, so among these two feed will impact the surface roughness more. contour lines indicates the surface roughness values with respect to two planes.

From the above figure the contour plot between speed and depth of cut is showed , and it is clear that maximum contour lines are converging towards the depth of cut than the speed so, here the dominant parameter in these two will be the depth of cut(doc).

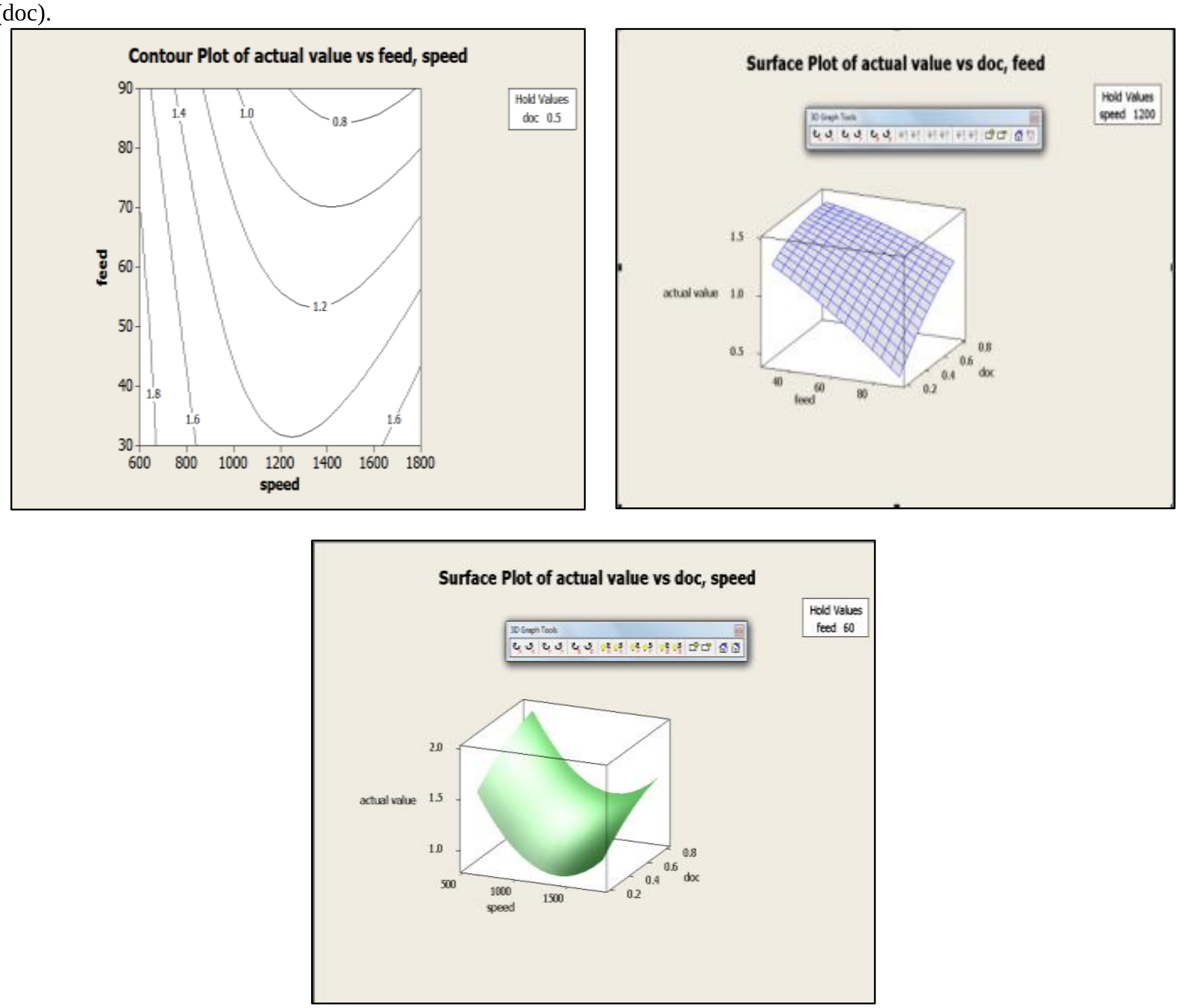

Fig. 6: Plots

H. Inferences from the Graph

1) From the above figure we can identified that the contour lines are converging towards feed compared to speed, so among these two parameters the dominating parameter will be feed.
2) Surface plots are for finding the maximum and minimum values of surface roughness in this experimental range.
3) Surface plots indicates the maximum value and minimum value of surface roughness at corresponding values of speed and feed, and also shows the region of response for all values of parameters in a sheet model.
4) Above figure represents the surface plot of actual value vs doc and speed, it shows the maximum roughness at minimum speed and maximum depth of cut, and roughness value minimum at speed range above 1500, and doc at 0.2-0.4 level
5) From this we can observe the surface plot in wire frame model, clearly identifies the where we obtain maximum and minimum roughness values. In the above roughness is minimum at feed above 80 and depth of cut at range of 0.2, and is maximum at feed below 40 and depth of cut at range of 0.6-0.8.

V. CONCLUSIONS

From the experiments performed the following results are drawn.

Empirical mathematical model is developed for surface roughness in order to predicted the values of surface roughness within the range of the turning parameters selected.

1) The experimental and predicted values are very close to each other, which indicate the accuracy of the developed model.
2) The adequacy of the developed model is checked using ANOVA at 95% confidence level is found to be adequate.
3) From the scatter plot it is understood that experimental and predicted values are close to each other.
4) From the main effect plots, it is clear that the given input parameter has a significant effect on surface roughness in this experimental range.
5) Roughness decreases with increase in speed upto medium level, and again increases on further increase in speed.
6) Roughness decreases with gradual increase in feed.
7) Roughness increases with increase in depth of cut.
8) From the contour plot, the most dominating parameter effecting surface roughness is feed, followed by spindle speed and depth of cut.
9) From the surface plots we can obtain the parameter ranges for maximum and minimum surface roughness in this experimental range.
10) The developed model is valid within the range of the selected turning parameters.

A. Limitations and Future Work

1) Our experiments is limited to 15 only based on Box Behnken and it can be conducted to 27 or 36 based on CCI,CCF and Taguchi.
2) By choosing other Significant factors that affect surface roughness apart from feed, speed, depth of cut, further reach work can be carried.
3) By changing work piece composition and type of tool same experiments can be carried out to get surface improvement.

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