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Experimental Analysis of the Effect of Process Parameters on Surface Finish in Radial Drilling Process

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Abstract- Productivity and the quality of the machined parts are the main challenges of metal cutting industry during drilling processes. Therefore cutting parameters must be chosen and their effect is studied in such a way that the required surface quality can be controlled. Hence statistical design of experiments (DOE) is used quite extensively. Statistical design of experiment refers to the process of planning the experimental work so that the appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusion. This paper presents an Experimental Analysis of process parameters (drill bit diameter, speed, feed) effecting the surface finish in radial drilling process to achieve better surface finish. The experimental layout was designed based on the Response surface Methodology (RSM) technique and analysis of variance (ANOVA) was performed to identify the effect of the cutting parameters on the surface finish. The coefficients were calculated by using regression analysis and the model is constructed. The model is tested for its adequacy by using Fisher's test at 95 % confidence level. The main and interaction plots are drawn using MINITAB 14 and the effect of various process parameters on surface finish was studied.

Key Words: **DOE, ANOVA, RSM, MINITAB 14.**

I. INTRODUCTION

Surface finish is the measure of the finer surface irregularities in the surface texture. The final surface depends on the rotational speed of the cutter, feed rate and mechanical properties of work pieces being machined. Surface finish also plays a significant role in determining and evaluating the surface quality of a product. Because surface finish affects the functional characteristic of products such as fatigue, friction, wearing, light reflection, heat transmission, and lubrication, the product quality is required to be at the high level. Design of Experiment (DOE) is an experimental or analytical method that is commonly used to statistically signify the relationship between input parameters and output responses, where in a systematic planning of experiments, collection and analysis of data is executed. There are many techniques are available to get output response out of which RSM is an anthology of statistical and mathematical methods, helpful in generating improved methods and optimizing the process. RSM is more frequently used in analyzing the relationships and the influences of input parameters on the responses.

The following two designs are widely used for fitting a quadratic model in RSM.

A. Central Composite Designs

Central Composite Designs (CCDs), also known as Box-Wilson designs are appropriate for calibrating the full quadratic models described in Response Surface Models. There are three types of CCDs, *viz.* circumscribed, inscribed and faced.

B. Box-Behnken Designs

Box-Behnken designs are used to calibrate full quadratic models. These are for a small number of factors (four or less), rotatable and require fewer runs than CCDs. By avoiding the corners these designs allow researchers to work around extreme factor combinations like an inscribed CCD. Paul Becker et al.[1] conducted experiments of high-throughput drilling of Ti–6Al–4V at 183m/min cutting speed and 156mm3/s Material Removal Rate (MRR) using a 4 mm diameter WC–Co spiral point drill were conducted. The tool wear mechanism, hole surface roughness and chip light emission and morphology for high-throughput drilling were investigated. Samar Singh et al. [2] developed an Electric Discharge Drill Machine (EDDM) to produce micro holes in conductive materials in which brass rod 2 mm diameter was selected as a tool electrode. Taguchi approach is used to identify optimum MRR in drilling of Al-7075.Noorul Haq et al. [3] presented an approach for the optimization of drilling parameters on drilling Al/SiC metal matrix composite with multiple responses based on orthogonal array with grey relational analysis. Experiments were conducted on LM25-based aluminium alloy reinforced with green bonded silicon carbide of size 25 µm (10% volume fraction). Based on the grey relational grade, optimum levels of parameters have been identified and significant contribution of parameters is determined by Analysis of Variance (ANOVA).P. N. E. Naveen et al.[4] studied about composite materials which are being used in automobiles. Investigated the effects of the drilling parameters namely speed and feed, on the damage factor in drilling composites like glass, hemp &

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sandwich fibers with different fiber volume fractions(i.e10%,20%&30%).Yogendra tyagi et al.[5] carried out drilling on mild steel with the help of CNC drilling machining operation by applying taguchi methodology. Signal-to-Noise ratio is applied to find optimum process parameter for CNC drilling machining. L_9 orthogonal array and ANOVA are applied. R. Vimal Sam Singh et al. [6] conducted experiments using 8 Facet Solid Carbide drills. L_{27} orthogonal array is used to perform the experiments. The process parameters investigated are spindle speed, feed rate and drill diameter. Fuzzy rule based model is developed to predict thrust force and torque in drilling of Fiber Reinforced Plastic (FRP) composites.

II. METHODOLOGY

A. Identification of important process control variables

Identification of correct factors is very important to get a good and accurate model. Among them many parameters that affect the surface finish, the following were important: Speed, feed and drill diameter.

B. Finding the limits of the process variables

- Trial experiments were carried out to find out the working range or both surface finish range and material removal range by varying one process variable and keeping other process variable as constant.
- The various values of factor examined in an experiment are known as limits.
- The upper and lower limits were coded as +1, -1 respectively or simply (+) and (-) for the case of recording 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)

C. Development of Optimal Working Zones

The optimum working zone depends on the desired work piece. Experiments were conducted separately for each combination 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.

D. Design of the Experiment

There are various techniques available from the statistical theory of experimental design which is well suited to Engineering investigations. One such important technique is a Response Surface Technique for studying the effect of parameters on response and this is one which was selected for the experiment. The design of 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.

E. Conducting the Experiments as per the Design Matrix

The experiments were conducted according to the design matrix by using Radial Drilling Machine. The typical Design Matrix is shown in Table II.1.The number of runs required by a full 2k 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 advantageous to use only part of the full factor design i.e., fractional factorial design and the concept of compounding.

	Coded Values		
SI.No	**Drill Diameter**	**Drill Speed**	**Drill Feed**
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

Table II.1 Typical Design Matrix

F. 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 for the phase of study which included the effect of maximum number of parameters could be used for all other phases.

G. Checking the Adequacies of the Models

All the above estimated coefficients were used to construct the models for the response parameter and these models were used to construct the models for the response parameter and these models were tested by applying analysis of variance (ANOVA) techniques F-ratio was calculated and compared, with the standard values for 95% confidence level. If the calculated value is less than the F-table values the model is consider adequate.

III. EXPERIMENTAL WORK

Experimental work was conducted on Radial Drilling Machine. Brass is chosen as work piece materials and High Speed Steel drill bits are chosen as cutting tool material. Machining has been done as per the Design Matrix, Box-Behnken design is used to decide the number of experiments to be performed. In this current paper Speed, feed and Depth of Cut are chosen as the influencing parameter (Shown in Table III.1) of Surface Roughness and their minimum and maximum varying values are decided after conducting trail experiments.

Table III.1: Input parameters and their levels

Parameter	--1	0	++1
Drill Diameter(mm)	10	12	14
Drill Speed(rpm)	280	450	710
Drill Feed(mm/min)	0.13	0.21	0.33

Fig III.1 Radial Drilling Machine

Fig III.2 Work piece used for machining

IV. EXPERIMENTAL RESULTS

Table IV.1 Design Matrix for Dry Machining

	Coded Values			Un coded Values			Surface Finish (Microns)	
S.No	Drill Diameter	Drill Speed	Drill Feed	Drill Diameter(mm)	Drill Speed(rpm)	Drill Feed (mm/min)	Actual	Predicted
1	-1	-1	0	10	280	0.21	1.94	1.87
2	1	-1	0	14	280	0.21	1.84	1.96
3	-1	1	0	10	710	0.21	2.26	2.14
4	1	1	0	14	710	0.21	0.98	1.05
5	-1	0	-1	10	450	0.13	1.86	1.98
6	1	0	-1	14	450	0.13	0.98	0.91
7	-1	0	1	10	450	0.33	2.12	2.19
8	1	0	1	14	450	0.33	2.38	2.26
9	0	-1	-1	12	280	0.13	1.56	1.51
10	0	1	-1	12	710	0.13	0.92	0.93
11	0	-1	1	12	280	0.33	2.04	2.04
12	0	1	1	12	710	0.33	1.92	1.97
13	0	0	0	12	450	0.21	1.68	1.65
14	0	0	0	12	450	0.21	1.52	1.65

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Table IV.2 Estimated Regression Coefficients for Surface Finish (Microns)

Term	Coef	SE Coef	T	P
Constant	1.64667	0.08492	19.391	0.000
DIAMETER(mm)	-0.25000	0.05200	-4.808	0.005
SPEED (rpm)	-0.16250	0.05200	-3.125	0.026
FEED (mm/min)	0.39250	0.05200	7.548	0.001
DIAMETER(mm)*DIAMETER(mm)	0.16667	0.07654	2.177	0.081
SPEED (rpm)*SPEED (rpm)	-0.05833	0.07654	-0.762	0.480
FEED (mm/min)*FEED (mm/min)	0.02167	0.07654	0.283	0.788
DIAMETER(mm)*SPEED (rpm)	-0.29500	0.07354	-4.011	0.010
DIAMETER(mm)*FEED (mm/min)	0.28500	0.07354	3.875	0.012
SPEED (rpm)*FEED (mm/min)	0.13000	0.07354	1.768	0.137
S = 0.1471 R-Sq = 96.3% R-Sq(adj) = 89.6%				

Empirical model for dry machining is developed using significant coefficients and shown in Equation IV.1

$A = 1.64667 - 0.25000X_1 - 0.162250X_2 + 0.39250X_3 - 0.29500X_1X_2 + 0.28500X_1X_3$ Equation (IV.1)

A. Checking the accuracy of the developed model for dry machining

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} value at a desired level of confidence (95%), then the model is said to be adequate within the confidence limit.

Table IV.3 Analysis of Variance for surface finish (Microns) for dry machining

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2.80639	2.80639	0.31182	14.41	0.004
Linear	3	1.94370	1.94370	0.64790	29.95	0.001
Square	3	0.12209	0.12209	0.04070	1.88	0.250
Interaction	3	0.74060	0.74060	0.24687	11.41	0.011
Residual Error	5	0.10817	0.10817	0.02163		
Lack-of-Fit	3	0.08230	0.08230	0.02743	2.12	0.336
Pure Error	2	0.02587	0.02587	0.01293		
Total	14	2.91456				

Scatter plots are drawn for actual and predicted values for dry machining and is presented in Fig IV.1

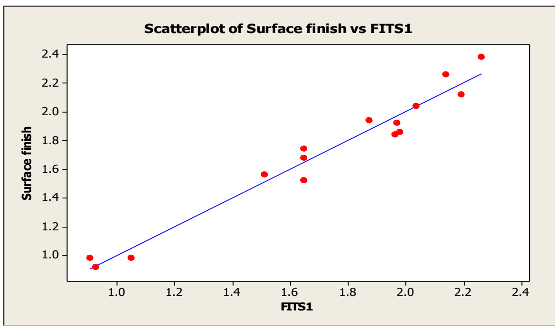

Fig IV.1 Scatter plot for dry machining

B. Effect of input parameters on responses for dry machining

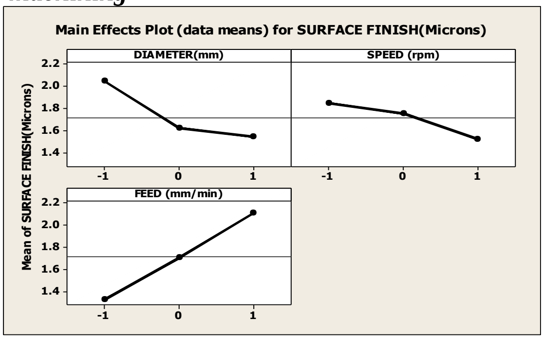

Fig IV.2 Main effect plots for dry machining

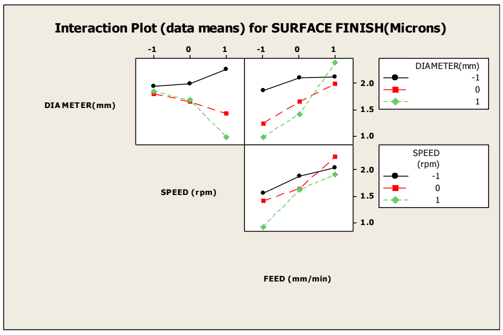

Fig IV.3 Interaction plot for dry machining

Main plots are drawn to understand the effect of each input parameter separately on the output response as shown in Figure IV.2.Interaction plot is also drawn to understand the effect of all the input parameters at a time on the output response and is shown in Figure IV.3. Contour plots are drawn to understand the dominating parameter. From Fig IV.4, it is understood that drill speed is more dominating over drill diameter. From Fig IV.5, it is clear the feed is more dominating than diameter. From Fig IV.6, it is understood that speed is dominating over feed. Surface plots are drawn to determine the values of input parameters at maximum surface finish shown in Fig IV.7, Fig IV.8& Fig IV.9.

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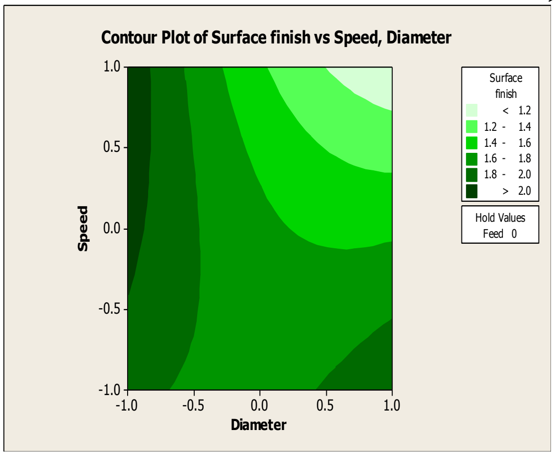

Fig IV.4 Contour plot for speed and diameter

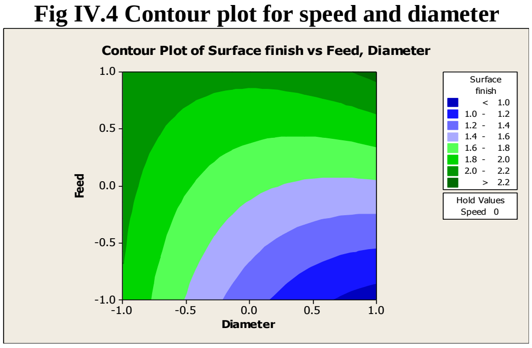

Fig IV.5 Contour plot for feed and diameter

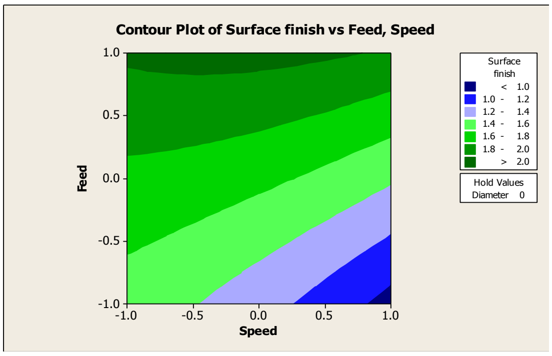

Fig IV.6 Contour plot for speed and feed

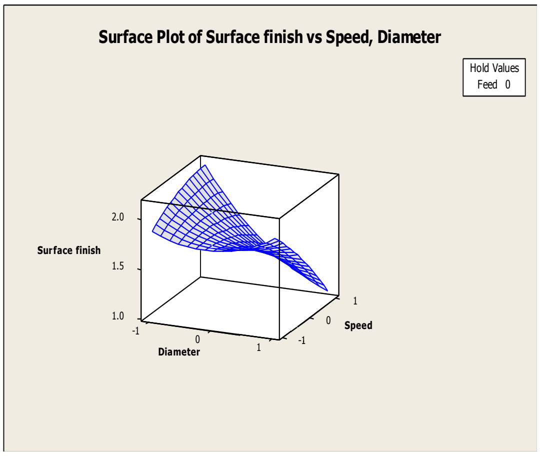

Fig IV.7 Surface plot for surface finish Vs Speed, Diameter

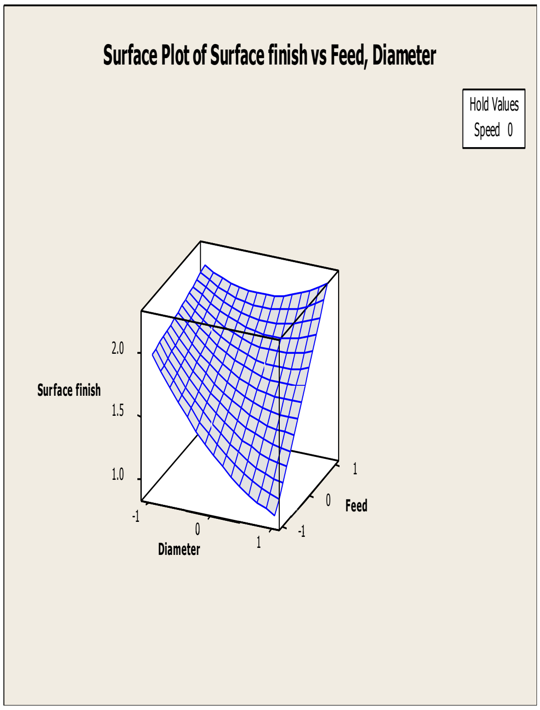

Fig. IV.8 Surface plot for Surface finish Vs Feed, Diameter

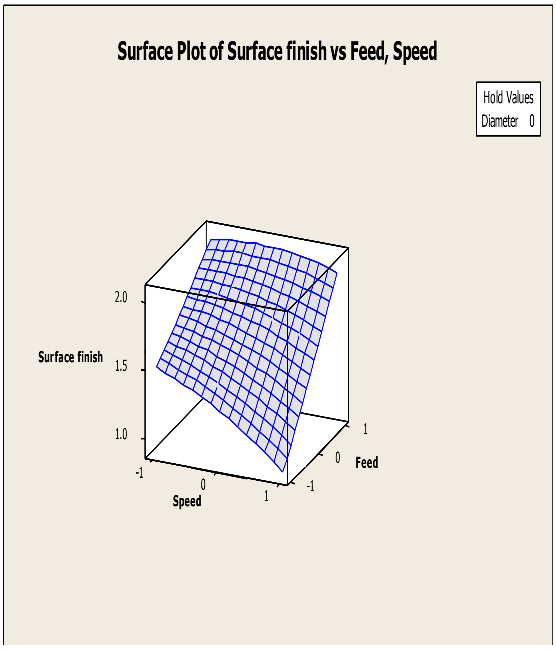

Fig. IV.9 Surface plot for Surface finish Vs Feed, Speed

Empirical model for dry machining is developed using significant coefficients and shown in Equation IV.2

$$B = 1.39333 - 0.23875X_1 - 0.14625X_2 + 0.37000X_3 + 0.22208X_1^2 - 0.31750X_1X_2 + 0.28000X_1X_3 \quad \text{Equation (IV.2)}$$

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	Coded Values			Uncoded Values			Surface Finish (Microns)	
SI.No	Drill Diameter	Drill Speed	Drill Feed	Drill Diameter(mm)	Drill Speed(rpm)	Drill Feed (mm/min)	Actual	Predicted
1	-1	-1	0	10	280	0.21	1.82	1.72
2	1	-1	0	14	280	0.21	1.74	1.87
3	-1	1	0	10	710	0.21	2.19	2.06
4	1	1	0	14	710	0.21	0.84	0.95
5	-1	0	-1	10	450	0.13	1.72	1.85
6	1	0	-1	14	450	0.13	0.92	0.81
7	-1	0	1	10	450	0.33	1.92	2.03
8	1	0	1	14	450	0.33	2.24	2.11
9	0	-1	-1	12	280	0.13	1.42	1.40
10	0	1	-1	12	710	0.13	0.88	0.88
11	0	-1	1	12	280	0.33	1.92	1.92
12	0	1	1	12	710	0.33	1.82	1.84
13	0	0	0	12	450	0.21	1.38	1.39
14	0	0	0	12	450	0.21	1.42	1.39
15	0	0	0	12	450	0.21	1.38	1.39

Table IV.4 Design matrix for wet machining

Term	Coef	SE Coef	T	P
Constant	1.39333	0.08801	15.831	0.000
DIAMETER(mm)	-0.23875	0.05390	-4.430	0.007
SPEED (rpm)	-0.14625	0.05390	-2.714	0.042
FEED (mm/min)	0.37000	0.05390	6.865	0.001
DIAMETER(mm)*DIAMETER(mm)	0.22208	0.07933	2.799	0.038
SPEED (rpm)*SPEED (rpm)	0.03208	0.07933	0.404	0.703
FEED (mm/min)*FEED (mm/min)	0.08458	0.07933	1.066	0.335
DIAMETER(mm)*SPEED (rpm)	-0.31750	0.07622	-4.166	0.009
DIAMETER(mm)*FEED (mm/min)	0.28000	0.07622	3.674	0.014
SPEED (rpm)*FEED (mm/min)	0.11000	0.07622	1.443	0.209
S = 0.1524 R-Sq = 95.9% R-Sq(adj) = 88.4%				

Table IV.5 Estimated Regression Coefficients for Surface Finish (Microns)

C. checking the accuracy of the developed model for wet machining

The adequacy of the developed model was tested using the Analysis of Variance technique. As per this technique, if the calculated value of the F_{ratio} of the developed model is less than the standard F_{ratio} 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 IV.6 are found to be adequate at 95% confidence level.

Table IV.6: Analysis of Variance for Surface Finish (Microns)

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	2.68697	2.68697	0.298552	12.85	0.006
Linear	3	1.72233	1.72233	0.574108	24.71	0.002
Square	3	0.19942	0.19942	0.066473	2.86	0.144
Interaction	3	0.76523	0.76523	0.255075	10.98	0.012
Residual Error	5	0.11619	0.11619	0.023238		
Lack-of-Fit	3	0.11513	0.11513	0.038375	71.95	0.014
Pure Error	2	0.00107	0.00107	0.000533		
Total	14	2.80316				

Scatter plots are drawn for actual and predicted values for wet machining and is presented in Fig IV.10

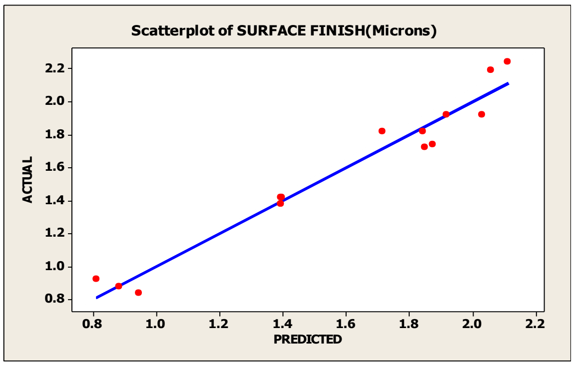

Fig IV.10 Scatter plot for wet machining

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D. Effect of input parameters on responses for wet machining

Main plots are drawn to understand the effect of each input parameter separately on the output response as shown in Fig IV.11.

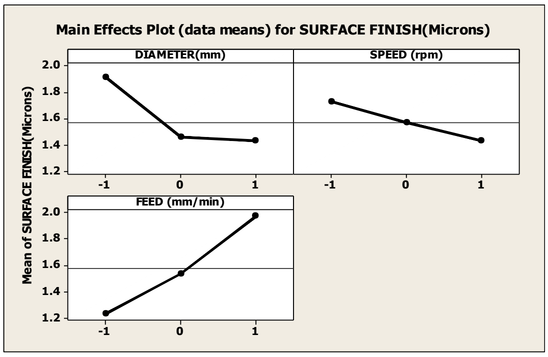

Fig IV.11 Main effect plots for wet machining

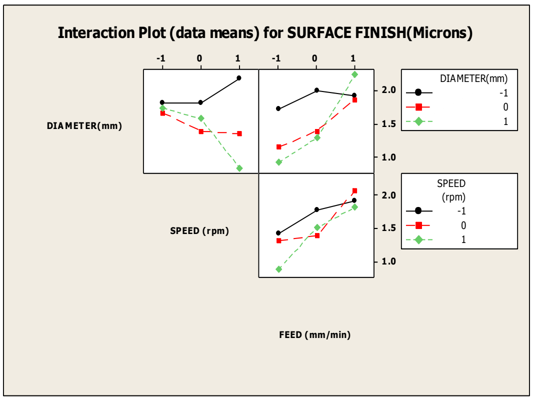

Fig IV.12 Interaction plot for wet machining

From the main effect plot it is understood that as diameter of drill bit increases surface finish decreases, as the number of contacting teeth will be more for constant work piece width. Surface finish decreases with drill speed, where as surface finish increases with drill feed. Interaction plot is also drawn to understand the effect of all the input parameters at a time on the output response and is shown in Fig IV.12. Contour plots are drawn to understand the dominating parameter. From Fig IV.13, it is understood that drill speed is more dominating over drill diameter. From Fig IV.14, it is clear the feed is more dominating than diameter. From Figure IV.14, it is understood that speed is dominating over feed.

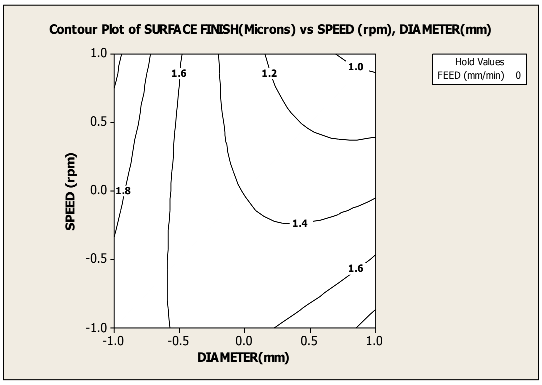

Fig IV.13 Contour plot for speed and diameter

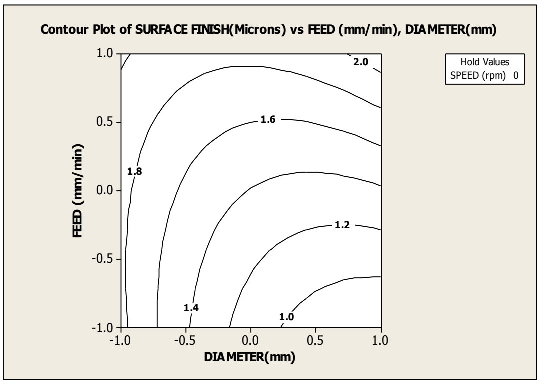

Fig IV.14 Contour plot for feed and diameter

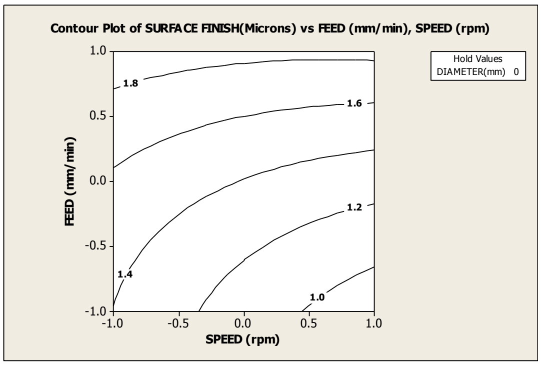

Fig IV.15 Contour plot for speed and feed

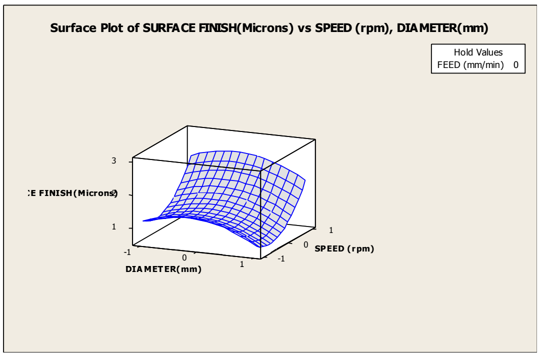

Fig IV.16 Surface plot for Surface finish Vs Speed, Diameter

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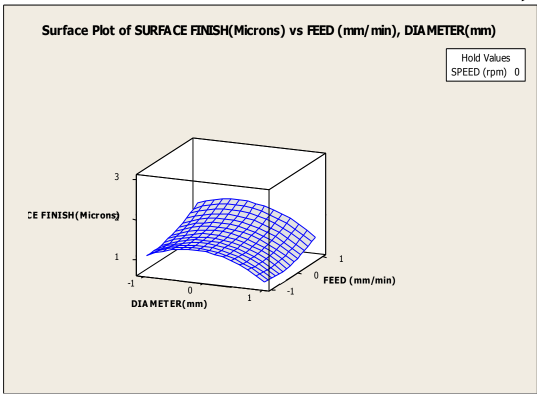

Fig IV.17 Surface plot of Surface finish Vs Feed,Diameter

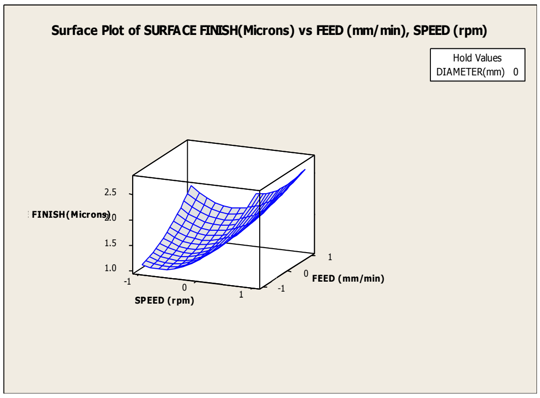

Fig IV.18 Surface plot of Surface finish Vs Feed, Speed

IV. CONCLUSION

Empirical mathematical model is developed for surface roughness in order to predict the values of surface finish within the range of the drilling parameters selected. The experimental and predicted values are very close to each other, which indicate the accuracy of the developed model. The adequacy of the developed model is checked using ANOVA at 95% confidence level at found to be adequate. From the scatter plot it is understood that experimental and predicted values are close to each other. From the main effect plots, it is clear that surface finish of the drilled hole decreases with drill speed, drill feed rate and from dry condition to wet condition. However by increasing the drill diameter surface finish value increases.

V. FUTURE SCOPE

The effect of various process parameters like drill bit diameter, spindle speed, feed on surface finish were studied with their predicted values. In the future work the experiments can be carried out to determine the effect of some other process parameters like cutting fluid, cutting angle, Material Removal Rate etc., on the machined surfaces in drilling operation.

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