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RESEARCH ARTICLE

Effect of Process Parameters on Surface Finish and Material Removal Rate in Radial Drilling Process

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ABSTRACT

In the present situation, the increase in the production and the increase in the quality of the machinery equipment are the primary encounters of the industries that undergo the process of cutting metals while the drilling process is being done. So, the parameters for the rock that needs to be cut must be selected and its results should be calculated, at a pace that the quality of the needed surface is maintained. Therefore statistical design of experiments is made handy and pretty broad, which indicates the activity of scheduling under experiments. This leads to the exact analysis of information by statistical techniques, which results in worthless and impartial finishing. Our work expresses a study and determination of the parameters that are involved in the process, like diameter of the drill bit, speed and feed, which shows effects on the surface finish and the Material Removal Rate (MRR) in the drilling process which is a radial one to attain an improved finish in the surface. Our experiment's design was based on the Response Surface Methodology abbreviated as RSM and the analysis of variance which is abbreviated as ANOVA was implemented to find the consequence of the parameters that are used in the process which acts for the purpose of the surface finish and the rate involved in the removal of the material. By using the regression analysis, the coefficients were measured. With the help of these coefficients, the construction of the model is done. By using the Fisher's test, the model constructed was examined for its capability. This test was done at 95 percent of level of confidence. MINITAB 14 was found handy to plot the main plots and the interaction plots. And also the consequence of several parameters such as surface finish and the MMR were determined.
Keywords: ANOVA, MINITAB, MRR, RSM, Fisher's test.

1. INTRODUCTION

The machinery surface that exhibits surface finish acts to be a key player in the process of production. If the surface is finished in a bad way, it will cause the oil films to tear on the heights of the micro irregularities. This causes the friction to be dry and causes critical wear of the surface being rubbed. So to achieve a higher finish in the surface, the finishing procedures of several complex machineries are taken aid of. There are several methodologies present from the concept of statistical Design of Experiments (DOE), which are apt to be applied for engineering purposes. In our experiment, RSM is one of the methods to study the consequence of the parameters. For the purpose to build an empirical model, RSM is found to be a pool of statistical and mathematical techniques. DOE's aim is to enhance a reaction by producing a variable as output, which is triggered by many input independent variables. The experimentation involves series of assessments, termed as runs, where the deviations are done in the input variables so that the causes of deviations in the output variables are found out. Experiments involving cutting process with high-throughput drilling speed of about Ti–6Al–4V at 183m/min and MRR with a speed of 156mm^3/s with the help of WC– Co spiral point drill with a diameter of 4 mm were done [1]. The examination of chip light emission, hole surface roughness, mechanism for tool wear and the design for

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high-throughput drilling were performed. The development of Electric Discharge Drill Machine (EDDM) that creates micro holes in materials that can cause conductance, that has brass rod with a radius of 1 mm diameter was performed [2]. The methodology followed by Taguchi, is found handy in identifying the optimal material removal rate while Al7075 is drilled. A technique that optimizes the parameters that are involved in the process of drilling Al/SiC metal matrix composite with manifold reactions that is established on orthogonal array with grey relational analysis is offered in [3]. Several experimentations were performed on LM25-based aluminium alloyarmoured with green bonded silicon carbide having 25μm which is ten percent in the fractional volume of size. The study of composite materials found useful in vehicles was performed in [4, 5]. The investigation on the parameters which are involved in drilling like, feed and speed were performed and also investigations on glass, hemp and sandwich fibres that exhibit varied fibre volume fraction of about 10, 20 and 30 percent were carried out while taking damage factor composites into account. The operation of mild steel that was drilled with the aid of a machine involved in drilling was done by using the technique established by Taguchi. The optimal parameter required to drill CNC was found out using the Signal-to-Noise ratio and also the application of L9 orthogonal array and analysis of variance. Experimentations were performed with the help of eight facet solid carbide drills [6-8]. The experimentations were done by the help of L27 orthogonal array. The parameters that are involved in the process like, the speed of the spindle, the feed date and the diameter of the drill are examined. To forecast the torque involved in the drilling of fibre reinforced plastic composites and the force involved in thrust, a model constructed on the Fuzzy rule was created.

2. METHODOLOGY

2.1. Finding out the control variables of important process

Finding out the exact triggering control variables involved in the process was crucially significant to achieve a worthy and exact model. Midst of all the parameters, the most significant parameters are the speed, feed, diameter of drill bit and the radius of the nose. These are the parameters that trigger the surface finish and MRR.

2.2. Identifying the bounds of the process variables

- Sample experimentations were undertaken to identify the rate of forces involved to cut by altering one of the parameter while keeping the other parameter unchanged.
- The maximum and the minimum limits were identified by altering the parameters.
- Observation of the data under experiment for the betterment of recording and processing.
- The maximum limit was coded either as +1 or + and the minimum limit was coded as -1 or – in the situation of recording.

The coded value is defined as the difference between the natural and the average value together divided by the change in the value. Here the natural value equals the value to be considered. The average value equals the sum of the upper and the lower limits together divided by 2 and finally the change in the value equals the difference between the upper and the lower limits.

2.3. Development of peak working area

The optimal or the peak area to work relies on the preferred portion of the work. Experimentations were performed independently for every grouping to identify the working area under operation. Identification of this area was crucial to set the limits of the parameters involved in the process. +1 denotes the upper limit. -1 denotes the lower limit. Experimental runs were performed by altering one of the parameters, while the rest are maintained at an unchanged value. This helps in successfully fixing the extreme limits of all the parameters.

2.4. Statistical Design of Experiment (DOE)

The DOE is an experimental technique that was generally involved to statistically indicate the connection between parameters involved in the input process and the responses achieved as the output. The design of experiment was essentially an experimental based modelling and was better than the unplanned methodology. In this methodology, an orderly procedure will be involved for the planning of the experiment, collection of the data and for the process of analysing the collected data. Amongst the supremely used design of experiment methods, RSM with central composite design, Taguchi's approach and factorial design techniques are the best. In the design of experiment technique, the interaction amid the mathematical techniques and the statistical techniques are taken into account. These include regression analysis, ANOVA, non-linear optimization and finally the desirability functions. All these aid in optimizing the worth of the characteristics involved in a DOE to lead the process to achieve the cost effectiveness criteria.

Table 1.Design matrix

S. No	Spindle Speed	Feed	Drill Diameter
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

2.5. Improvement of the mathematical model

A low-order polynomial was taken for improving the mathematical model. This was done to forecast the Fisher's value. The function of approximation was the first order model as expressed below in equation (2.1), when the outcome was finely exhibited by a linear function of the independent variables. The values estimated prior, were crossly examined by the actual experimentations. This was performed by setting the parameters' value involved in the process at certain values, without setting values for the parameters that are involved in the development of the models. While this experimentations were performed, the results got inside the area, were pleasing. These models lead to the graphs to be drawn. And finally the outcomes were analysed.

$$Y = \beta + \beta_1 x_1 + \beta_2 x_2 + \cdots \_\beta_x x_x + \varepsilon \quad (2.1)$$

2.6. Estimated of regression coefficients

For the estimation of the model's regression coefficient, a matrix was developed to formulate the above equation. This matrix is shown in table A1. Since the matrix developed is orthogonal, the regression coefficients predicted link with one another. The minimum variance was exhibited by the technique of least square. The above equation represents all the model's coefficients of regression. All these regression coefficients were assessed for the parameters such as surface finish and the MRR. Table A2 indicates the design matrix for brass.

2.7. Examining the model's sufficiency

The whole predicted coefficients mentioned above were found handy to build the models involved in the response parameter. With the application of ANOVA, these models were experimented and the F-ratio calculation was performed and matched with the confidence level of 95 percent as a usual value. The model was found to be sufficient if, the value generated under calculation was lesser than that of the F-Table's value.

3. EXPERIMENTAL WORK

Bronze and brass plates were taken as working materials and grinded in order to remove any surface irregularity. White chalk was applied on one side of the blocks. By using steel rule and scriber horizontal and vertical lines are drawn, such that 15 intersection points were obtained in order to make a hole using twist drill. Using radial drilling machine shown in figure 1, holes were made in accordance with the typical matrix shown in table 1 using 10 mm, 11 mm and 12 mm drill bit diameters.

Figure 1.Conducting the experiments on radial drilling machine

Figure 2 and figure 3 given below shows the figures of the brass and the bronze materials respectively.

Figure 2.Brass

Figure 3.Bronze

4. RESULTS AND DISCUSSION

4.1. Modal Calculation of MRR

The MRR can be calculated by the equation (4.1) given below.

$$\text{MRR} = \frac{\text{Original weight} - \text{Actual weight}}{\text{Time}} \quad (4.1)$$

$$\text{MRR} = \frac{0.423 - 0.414}{36.53}$$

MRR= 0.000246 Kg/Sec

4.2. Development of mathematical model

The important coefficients were found out and the concluding model was established with these coefficients. These coefficients were used to calculate the roughness surface of the drilled holes. All these process were done with the aid of a statistical software package named, MINITAB 14.

4.3. Examining the developed model's sufficiency

The sufficiency of the model created was verified using ANOVA. According to this methodology, the F_{ratio} calculation was performed and matched with the standard F_{ratio} with the confidence level of 95 percent as an usual value. The model was found to be sufficient if, the value generated under calculation was lesser than that of the F-Table's value. The results of this experiment given in the table A3 were sufficient at a confidence level of 95 percent. Figure B2 shows the surface roughness's scatter plot of the drilled holes. This shows that the tested and the forecasted values were closer to each within the stated bounds.

Figure B1 and figure B2 shows the scatter plot of MRR for bronze and the scatter plot of surface roughness for bronze respectively.

Figure B3 and figure B4 below shows the scatter plot of MRR for brass and the scatter plot of surface roughness for brass respectively.

4.4. Primary influence on surface roughness

The graphs are drawn for each drilling parameters separately. These graphs are shown in the figures B5 and B6 and the following observations are made: the drilled hole's surface roughness declines with the speed involved while being drilled. The drilled hole's surface roughness declines with the drilling feed rate. Surface roughness of the hole under the drilling process surges with the drill diameter. Surface roughness of the drilled hole in dry condition is more than the surface roughness in wet condition.

Figure B5 shows the primary influence plot of MRR for bronze and the figure B6 shows the primary influence plot for the surface roughness for bronze. Figures B7 and B8 shows the primary influence plot of MRR for brass and the primary influence plot of surface roughness for brass.

4.5. Interfacing effects on surface roughness

Interfacing plots are pointed for the examination of the consequence of all drilling factors at a time upon the surface roughness. Figures B9 and B10 express the interfacing plot of MRR for bronze and the interfacing plot of surface roughness for bronze respectively.

Figures B11 and figure B12 shows the interfacing plot of MRR for brass and the interfacing plot of surface roughness for brass respectively.

From the established model, surface roughness values are predicted by replacing the values of the drilling parameters in the established empirical mathematical model. Table A3 indicates the tested and predicted range of values of surface roughness for all the 16 combination of experiments performed. Regression co-efficient and ANOVA tables of MRR for Bronze Response Surface Regression: MRR (Kg/sec) versus Speed (rpm), Feed (mm/sec) examination was conducted with the help of coded units (Table A4). The calculations are performed with the fixed values of S to be 0.00002037, R-Sq to be 99.9 percentand R-Sq(adj) to be 99.6 percent. Here, DF denotes the Degrees of Freedom, SS denotes the Sum of Squares, MS denotes the Mean Square and F denotes the Fisher's Ratio. The regression co-efficient and ANOVA tables of surface finish for bronze are given below in the tables A5 and A6 respectively.

Table A5 shows the calculated coefficients of regression for surface finish in microns. The calculations are performed with the fixed values of S to be 0.2123, R-Sq to be 84.9 percent and R-Sq (adj) to be 57.6 percent.

Table A6 shows the ANOVA for surface finish. The regression co-efficient and ANOVA tables of MRR for brass are given below in the tables A7 and A8 respectively. The response surface regression: MRR versus SPEED (rpm), FEED (mm/sec) the examination was performed with the help of coded units.

The table A7 shows the calculated coefficients of regression for MRR. The calculations are performed with the fixed values of S to be 0.00004795, R-Sq to be 99.2 percent and R-Sq(adj) to be 97.6 percent. Table A8 shows the ANOVA for MRR. The regression co-efficient and ANOVA tables of surface finish for bronze are given below in tables A9 and A10 respectively. The response surface regression: surface finish versus speed (rpm), feed (mm/sec) examination was performed with the help of coded units. Table A9 shows the calculated coefficients of regression for surface finish. The calculations are performed with the fixed values of S to be 0.2123, R-Sq to be 84.9 percent and R-Sq(adj) to be 57.6 percent. Table A10 shows the ANOVA for surface finish. The tested and the forecasted values were almost closer to one another, which show the correctness of the established model. The sufficiency of the established model was examined with the help of analysis of variance maintained to be within 95 percent of the confidence level and it was identified to be sufficient. The plot of scatter clearly shows that tested and forecasted values are almost closer to one another. The primary influence plots show that, the surface roughness of the hole that underwent the drilling process declined with the speed of drilling, the drilling feed rate and from the shift of dry wet condition. The increase in the diameter of the drill's surface increases the roughness of the surface.

5. CONCLUSION

In this study, the application of RSM for examining the consequence of parameters under process on the surface finish and the MRR value in the radial drilling of bronze and brass materials was performed. RSM is handy to forecast the primary causes and the interfacing effects of various grouping of process parameters within the range of examinations. The established model was involved to forecast the peak surface finish and MRR for the sake of process parameters within the range of variables that were examined. The optimal level of surface finish and the MRR are maintained at Ra to be 1.70853μm and material removal rate to be 0.000220 Kg/Sec for bronze and Ra to be 0.74756μm and material removal rate to be 0.000243 Kg/Sec for brass. This was achieved by the drilling situation expressed earlier. It permits industry to lessen the process or the product's change and diminish the defectiveness in the products with the help of a comparatively smaller number of trial runs and expenditures to attain products of high quality. This work shows how to use RSM for improving machining behaviour with least cost and period to the industrialists and also explains how the industrial technology trainer, trains a project under development in any design-oriented programmes.

6. SCOPE OF FUTURE WORK

In the present investigation the influence of numerous process parameters such as the spindle rate, feed and drill bit diameter on surface finish and MRR were examined with their forecasted values. As a future enhancement, these experimentations will take place to find the consequence of other parameters included in the process like fluid involved in the cut, angle involved in the cut and the depth of the cut on the machinery surfaces involved in the machinery processes.

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APPENDIX A

Table A1.Design matrix for bronze

				Actual Values		Predicted Values	
S.No.	Speed (rpm)	Feed (mm/sec)	Drill diameter (mm)	MRR (Kg/sec)	Surface Finish (Microns)	MRR (Kg/sec)	Surface Finish (Microns)
1	180	0.13	11	0.000234	1.85	0.000220	1.70853
2	450	0.13	11	0.000528	1.82	0.000536	1.98517
3	180	0.33	11	0.000502	2.57	0.000498	2.45082
4	450	0.33	11	0.001350	1.63	0.001358	1.72549
5	180	0.21	10	0.000283	1.655	0.000307	1.71250
6	450	0.21	10	0.000733	1.833	0.000734	1.65983
7	180	0.21	12	0.000418	1.790	0.000410	1.99315
8	450	0.21	12	0.001068	1.885	0.001050	1.79751
9	280	0.13	10	0.000270	1.310	0.000257	1.36756
10	280	0.33	10	0.000708	2.460	0.000695	2.51811
11	280	0.13	12	0.000389	2.300	0.000406	2.21875
12	280	0.33	12	0.000919	1.845	0.000926	1.81058
13	280	0.21	11	0.000514	2.055	0.000554	1.89167
14	280	0.21	11	0.000515	1.905	0.000554	1.89167
15	280	0.21	11	0.000634	1.715	0.000554	1.89167

Table A2.Design matrix for brass

				Actual Values		Predicted Values	
S.No	Speed (rpm)	Feed (mm/sec)	Drill diameter (mm)	MRR (Kg/sec)	Surface Finish (Microns)	MRR (Kg/sec)	Surface Finish (Microns)
1	180	0.13	11	0.000246	1.23	0.00026	1.08853
2	450	0.13	11	0.000665	1.2	0.000655	1.36517
3	180	0.33	11	0.000611	1.95	0.000616	1.83082
4	450	0.33	11	0.00148	1.01	0.001471	1.10549
5	180	0.21	10	0.000253	1.035	0.000259	1.0925
6	450	0.21	10	0.00079	1.213	0.000809	1.03983
7	180	0.21	12	0.000428	1.17	0.000403	1.37315
8	450	0.21	12	0.00101	1.265	0.001011	1.17751
9	280	0.13	10	0.00026	0.69	0.000243	0.74756
10	280	0.33	10	0.000764	1.84	0.000756	1.89811
11	280	0.13	12	0.000385	1.68	0.000398	1.59875
12	280	0.33	12	0.000926	1.225	0.000938	1.19058
13	280	0.21	11	0.000542	1.435	0.000542	1.27167
14	280	0.21	11	0.000542	1.285	0.000542	1.27167
15	280	0.21	11	0.000542	1.095	0.000542	1.27167

Table A3.Calculated coefficients of regression for MRR (Kg/sec)

Term	Coef	SE Coef	T	P
Constant	-0.0051	0.00133	-3.81	0.012
Speed (rpm)	-0.0000	0.00000	-2.66	0.045
Feed (mm/sec)	-0.0019	0.00124	-1.56	0.178
Drill Diameter (mm)	0.00094	0.00023	4.019	0.010
Speed (rpm) *Speed (rpm)	0.0000	0.00000	4.135	0.009
Feed (mm/sec) *Feed (mm/sec)	0.003164	0.001114	2.840	0.036
Drill Diameter (mm) *Drill Diameter (mm)	-0.0000410	0.000011	-3.893	0.011
Speed (rpm) *Feed (mm/sec)	0.000009	0.000001	11.586	0.000
Speed (rpm) *Drill Diameter (mm)	0.000000	0.000000	1.441	0.209
Feed (mm/sec) *Drill Diameter (mm)	0.000068	0.000101	0.673	0.531

Table A4.ANOVA for MRR (Kg/sec)

Source	DF	Seq SS	Adj SS	AdjMS	F	P
Regression	9	0.00002	0.00002	0.0000	414.7	0.000
Linear	3	0.00001	0.00000	0.0000	9.95	0.015
Square	3	0.00000	0.00000	0.0000	14.32	0.007
Interaction	3	0.00000	0.00000	0.0000	45.58	0.000
Residual error	5	0.00000	0.00000	0.0000	*	*
Lack of fit	3	0.00000	0.00000	0.0000		
Pure error	2	0.00000	0.00000	0.0000		
Total	14	0.000002				

Table A5.Calculated coefficients of regression for surface finish (Microns)

Term	Coef	SE Coef	T	P
Constant	-16.999	13.9588	-1.218	0.278
Speed (rpm)	0.0076	0.0097	0.784	0.468
Feed (mm/sec)	45.0630	13.0057	3.465	0.018
Drill Diameter (mm)	2.1355	2.4550	0.870	0.424
Speed (rpm) *Speed (rpm)	-0.0000	0.0000	-0.299	0.777
Feed (mm/sec) *Feed (mm/sec)	10.5512	11.6150	0.908	0.405
Drill Diameter (mm) *Drill Diameter (mm)	-0.0513	0.1105	-0.464	0.662
Speed (rpm) *Feed (mm/sec)	-0.0186	0.0077	-2.422	0.060
Speed (rpm) *Drill Diameter (mm)	-0.0003	0.0008	-0.342	0.746
Feed (mm/sec) *Drill Diameter (mm)	-3.8968	1.0514	-3.706	0.014

Table A6.ANOVA for surface finish (Microns)

Source	DF	Seq SS	Adj SS	AdjMS	F	P
Regression	9	1.2641	1.26415	0.14046	3.12	0.112
Linear	3	0.3252	0.56246	0.18749	4.16	0.079
Square	3	0.0524	0.05504	0.01835	0.41	0.755
Interaction	3	0.8864	0.88640	0.29547	6.55	0.035
Residual error	5	0.2253	0.22538	0.04508		
Lack of fit	3	0.1673	0.16731	0.05577	1.92	0.360
Pure error	2	0.0580	0.05807	0.02903		
Total	14		1.48953			

Table A7.Calculated coefficients of regression for MRR

Term	Coef	SE Coef	T	P
Constant	0.000415	0.003153	0.132	0.900
Speed (rpm)	-0.000005	0.000002	-2.118	0.088
Feed (mm/sec)	-0.001298	0.002937	-0.442	0.677
Drill Diameter (mm)	-0.000021	0.000554	-0.038	0.971
Speed (rpm) *Speed (rpm)	0.000000	0.000000	0.155	0.883
Feed (mm/sec) *Feed (mm/sec)	-0.003007	0.002623	-1.146	0.304
Drill Diameter (mm) *Drill Diameter (mm)	-0.000002	0.000025	-0.076	0.943
Speed (rpm) *Feed (mm/sec)	0.000010	0.000002	5.831	0.002
Speed (rpm) *Drill Diameter (mm)	0.000000	0.000000	2.259	0.073
Feed (mm/sec) *Drill Diameter (mm)	0.000205	0.000237	0.862	0.428

Table A8.ANOVA for MRR

Source	DF	Seq SS	Adj SS	AdjMS	F	P
Regression	9	0.000001	0.00000	0.000000	65.36	0.000
Linear	3	0.000001	0.00000	0.00000	1.55	0.311
Square	3	0.000000	0.00000	0.000000	0.46	0.724
Interaction	3	0.000000	0.00000	0.000000	13.25	0.008
Residual error	5	0.000000	0.00000	0.000000		
Lack of fit	3	0.000000	0.00000	0.000000	0.14	0.929
Pure error	2	0.000000	0.00000	0.000000		
Total	14	0.000001				

Table A9.Calculated coefficients of regression for surface finish

Term	Coef	SE Coef	T	P
Constant	-16.379	13.9588	-1.17	0.293
Speed (rpm)	0.0076	0.0097	0.784	0.468
Feed (mm/sec)	45.063	13.005	3.465	0.018
Drill Dia (mm)	2.1355	2.4550	0.870	0.424
Speed (rpm) *Speed (rpm)	-0.000	0.0000	-0.299	0.777
Feed (mm/sec) *Feed (mm/sec)	10.551	11.615	0.908	0.405
Drill Dia (mm) *Drill Dia (mm)	-0.051	0.1105	-0.464	0.662
Speed (rpm) *Feed (mm/sec)	-0.0186	0.0077	-2.422	0.060
Speed (rpm) *Drill Dia (mm)	-0.0003	0.0008	-0.342	0.746
Feed (mm/sec) *Drill Dia (mm)	-3.8968	1.0514	-3.706	0.014

Table A10.ANOVA for surface finish

Source	DF	Seq SS	Adj SS	AdjMS	F	P
Regression	9	1.2641	1.2641	0.1404	3.12	0.11
Linear	3	0.3252	0.5624	0.1874	4.16	0.07
Square	3	0.0524	0.0550	0.0183	0.41	0.75
Interaction	3	0.8864	0.8864	0.2954	6.55	0.03
Residual error	5	0.2253	0.2253	0.0450		
Lack of fit	3	0.1673	0.1673	0.0557	1.92	0.36
Pure error	2	0.0580	0.0580	0.0290		
Total	14	0.000002				

APPENDIX B

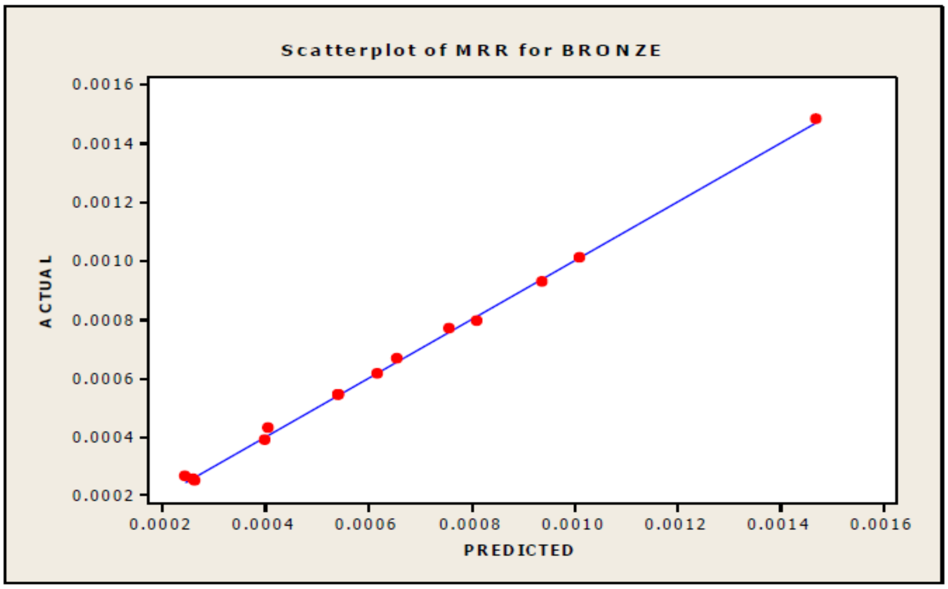

Figure B1.Scatter plot of MRR for bronze

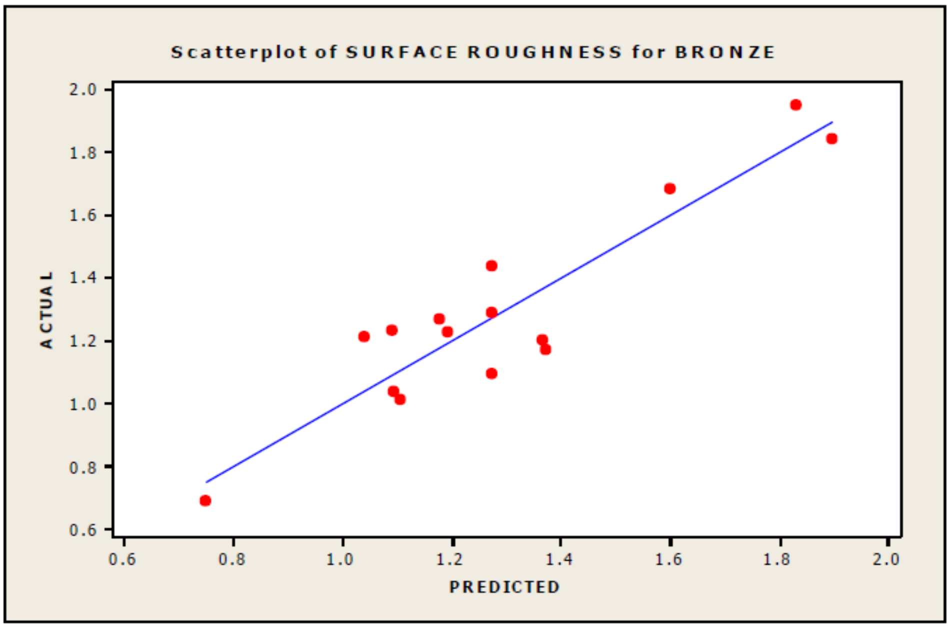

Figure B2.Scatter plot of surface roughness for bronze

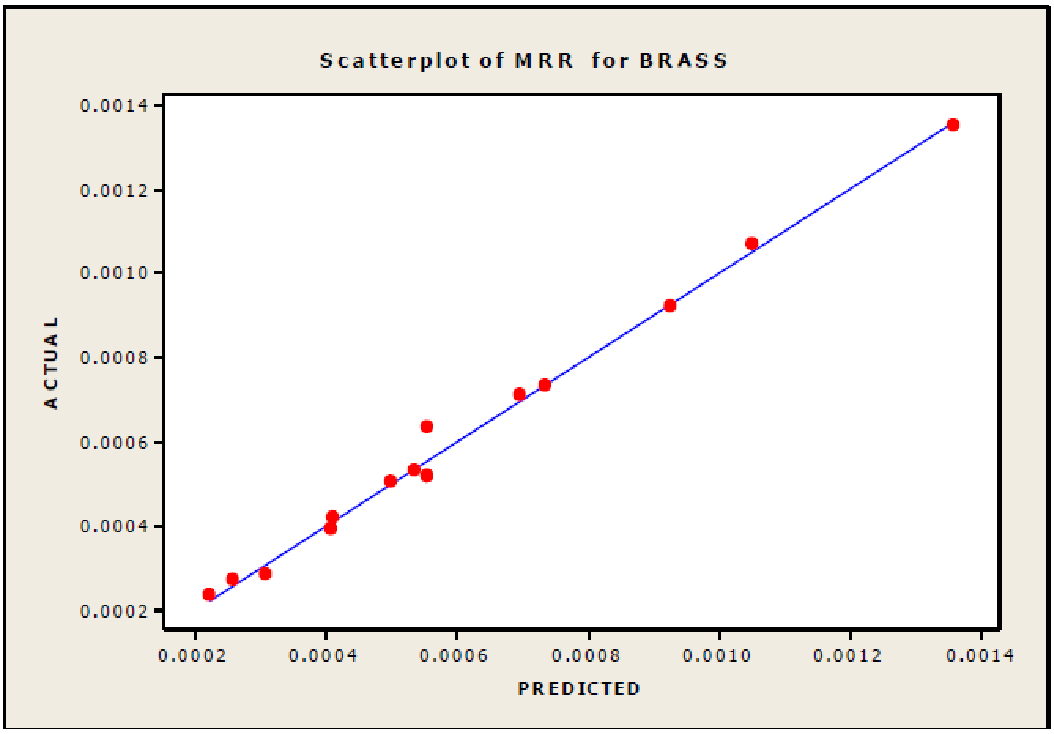

Figure B3.Scatter plot of MRR for brass

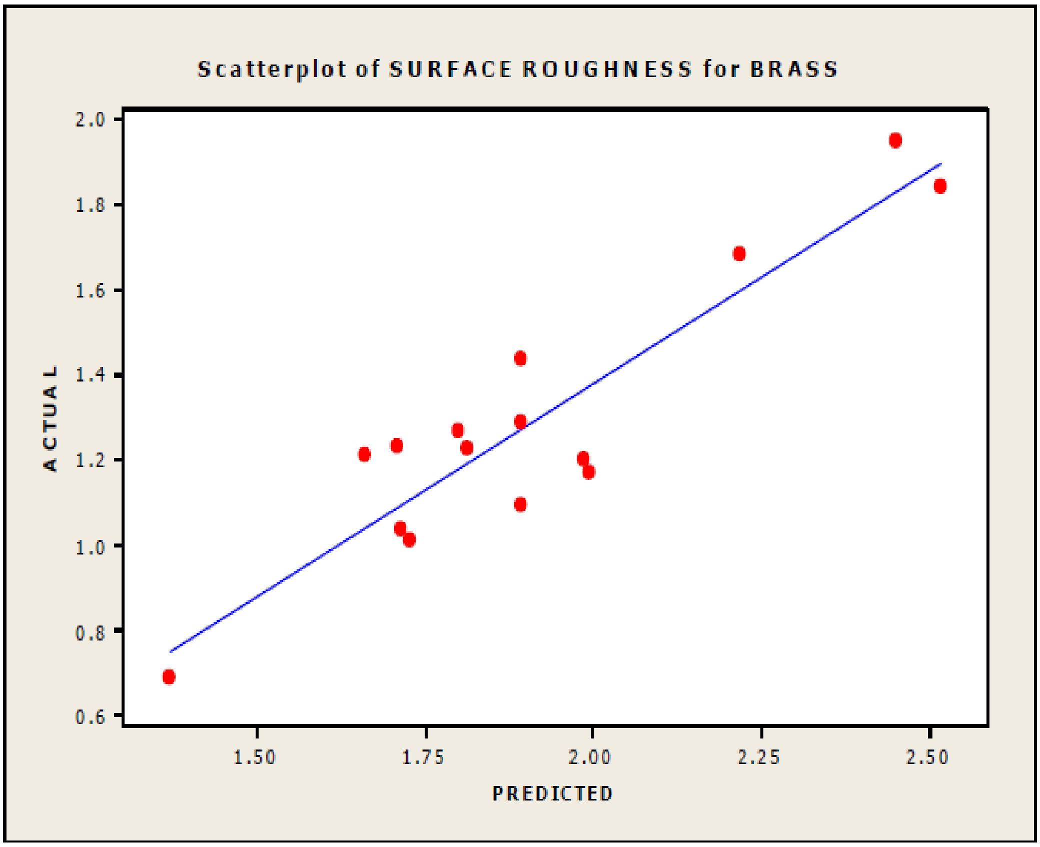

Figure B4.Scatter plot of surface roughness for brass

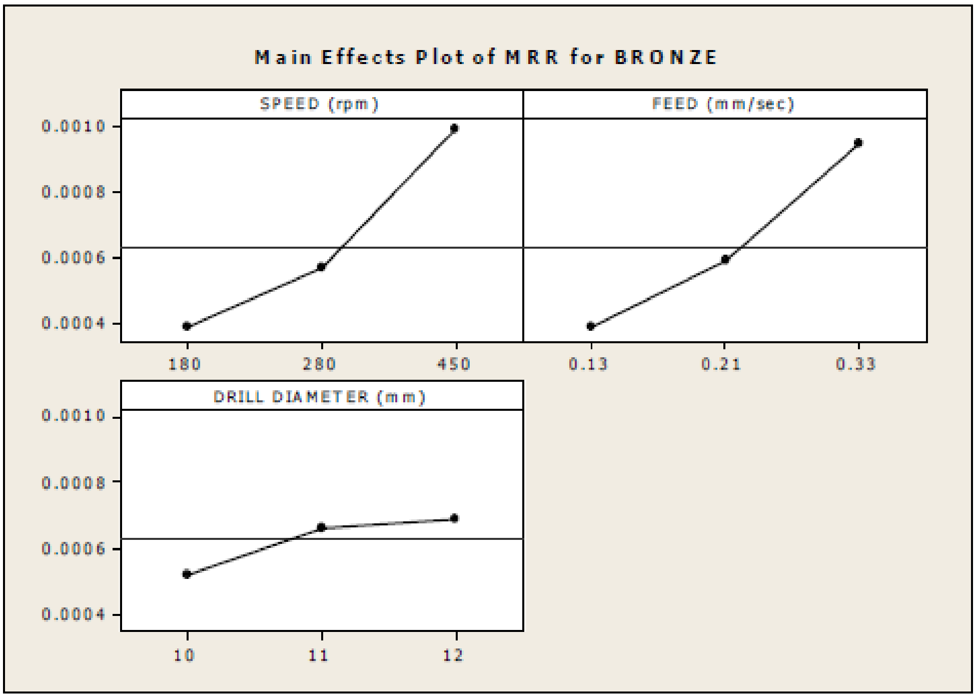

Figure B5.Primary influence plot of MRR for bronze

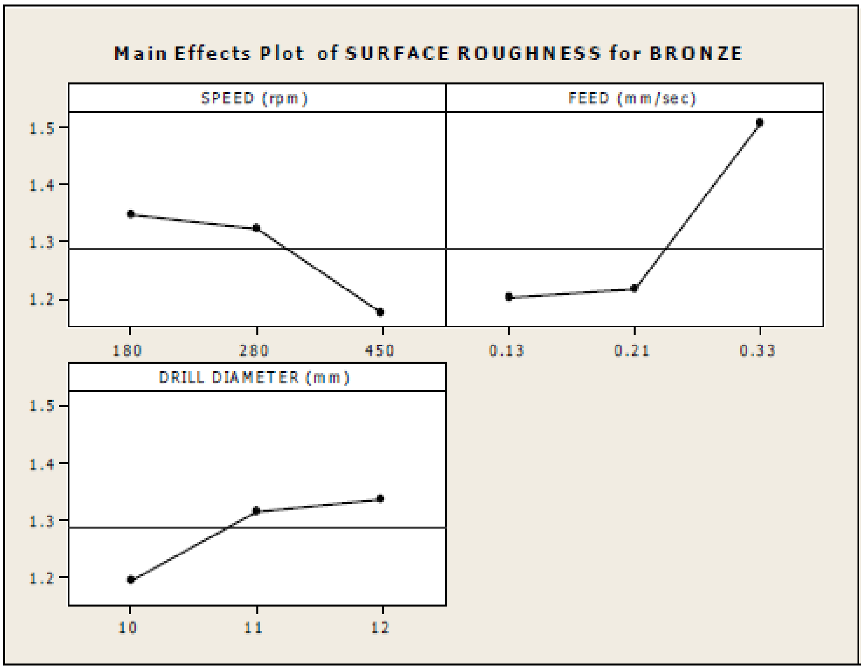

Figure B6.Primary influence plot of surface roughness for bronze

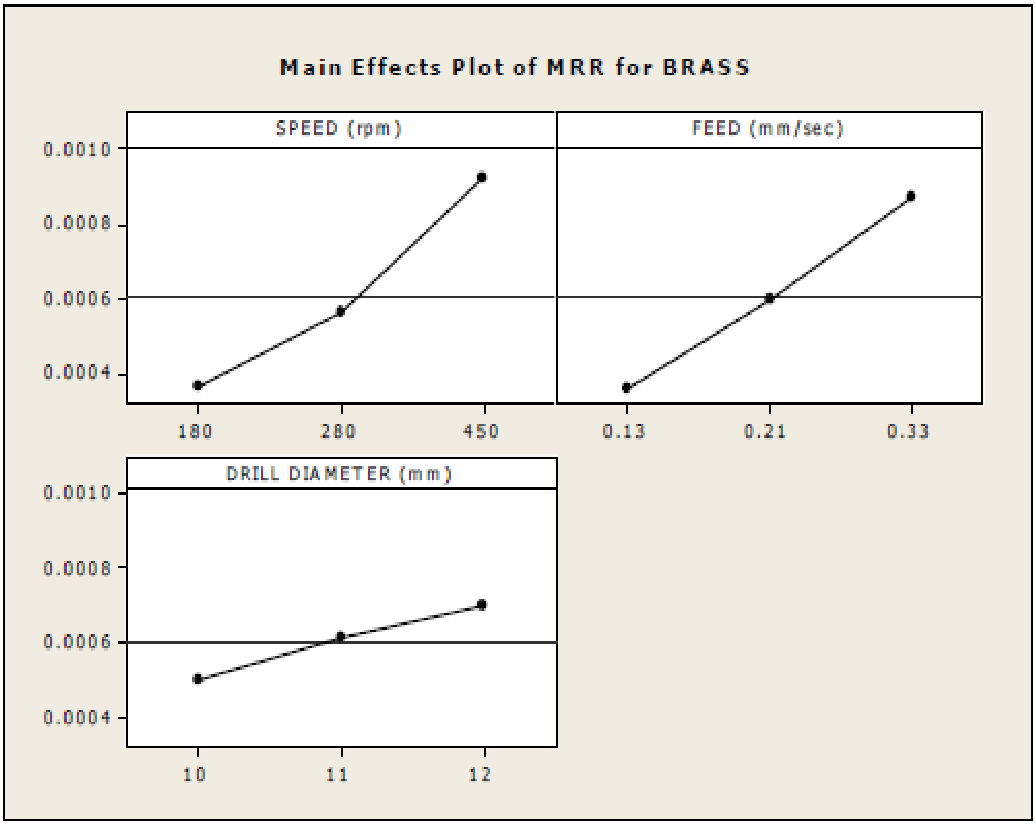

Figure B7.Primary influence plot of MRR for brass

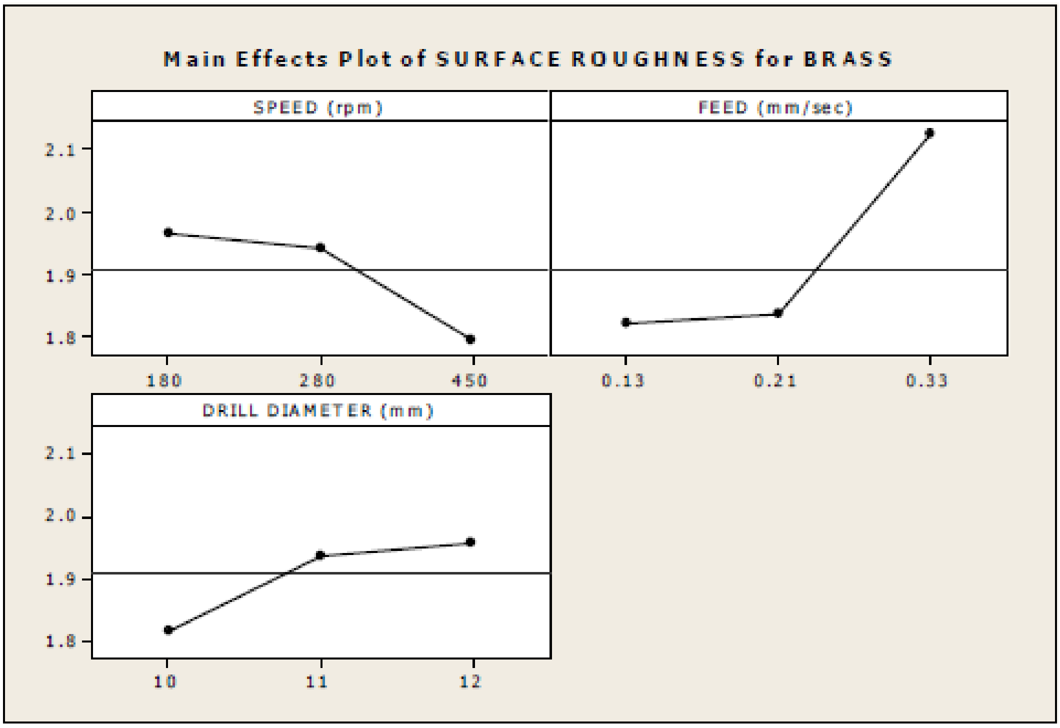

Figure B8.Primary influence plot of surface roughness for brass

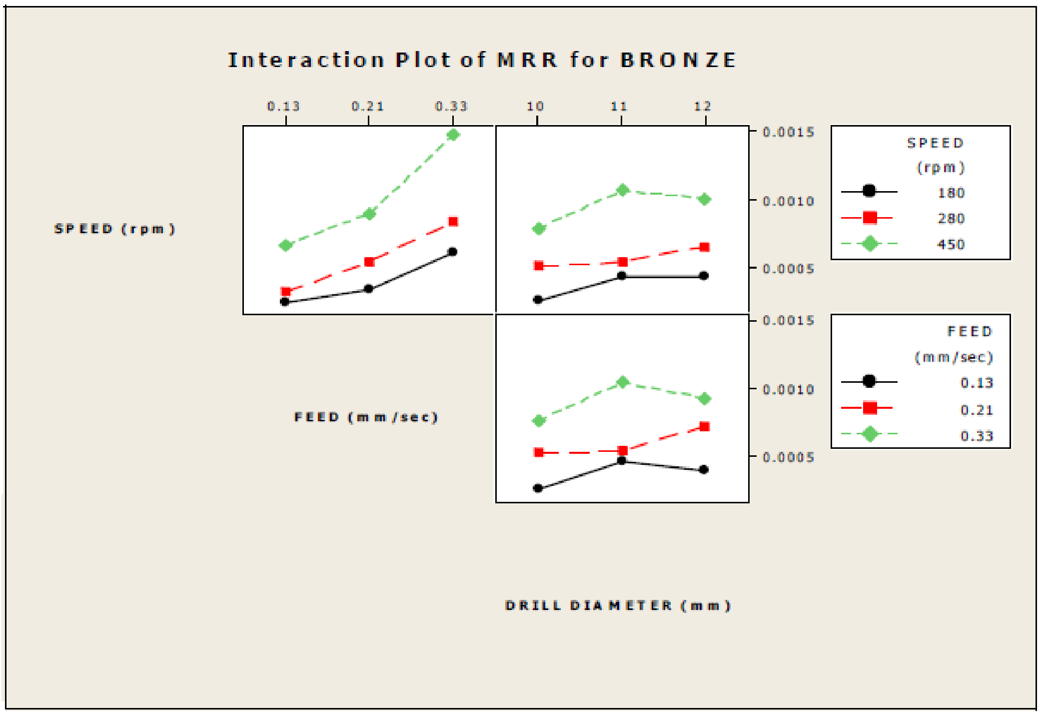

Figure B9.Interfacing plot of MRR for bronze

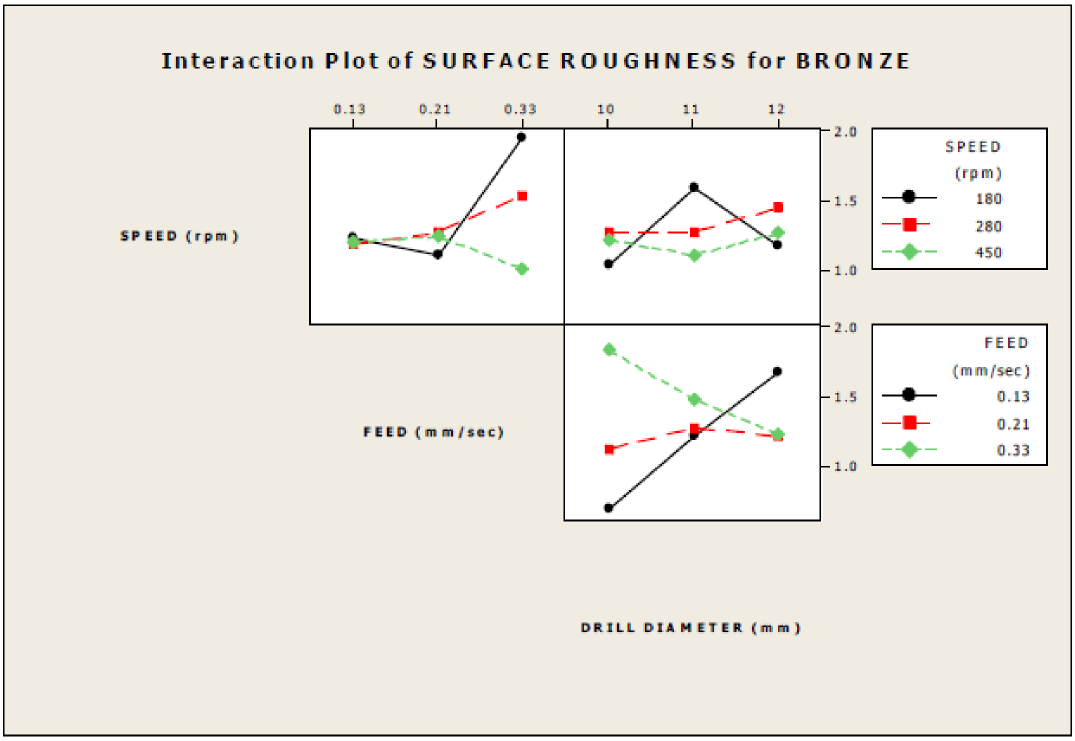

Figure B10.Interfacing plot of surface roughness for bronze

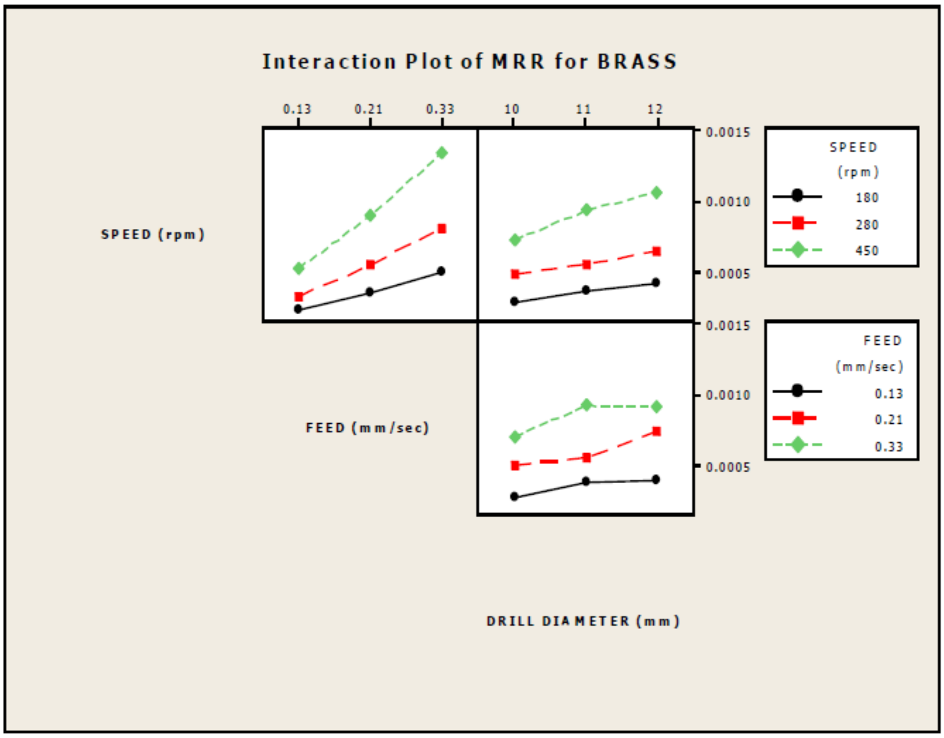

Figure B11.Interfacing plot of MRR for brass

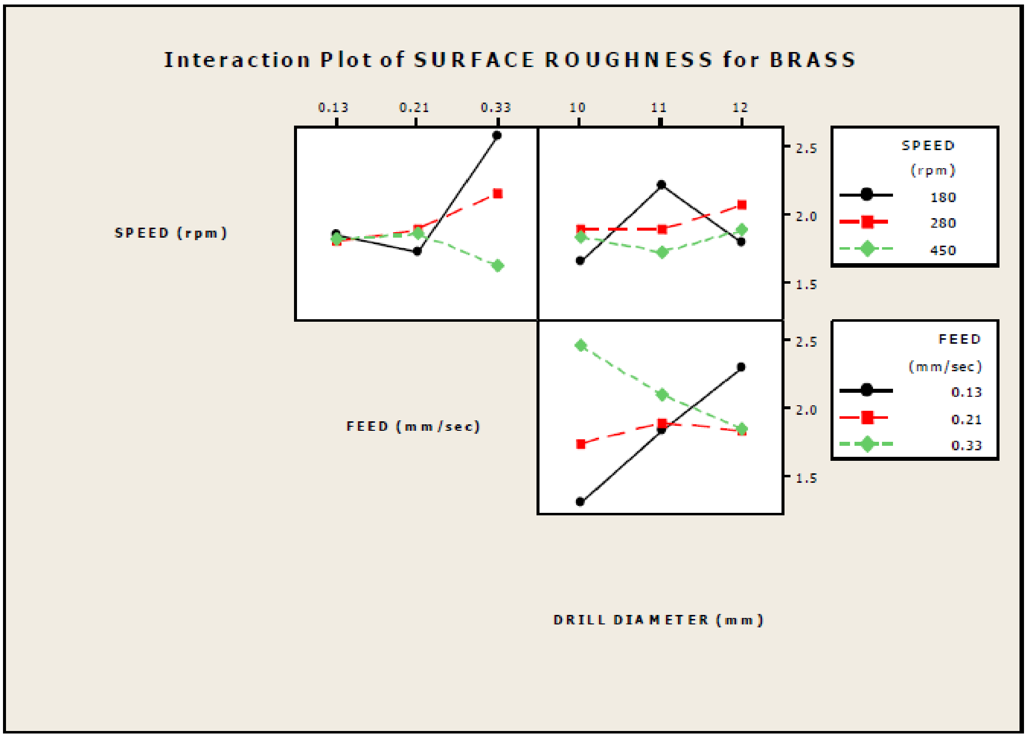

Figure B12.Interfacing plot of surface roughness for brass