Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 8(1): 37-42

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# Investigating Optimum Parameters Required for Drilling Brass using Response Surface Methodology

**Pius Bamidele Mogaji[1*], Israel Ajibola Famurewa[1]**
[1]Department of Mechanical Engineering,
School of Engineering and Engineering Technology, Federal University of Technology, P.M.B. 704, Akure, Ondo State, Nigeria.
**Corresponding Author: Pius Bamidele Mogaji**

**Abstract**
This research work determined the optimum parameters required for drilling brass using Response Surface Methodology (RSM) based on L9-A 34-2 fractional factorial design. The brass work piece is of dimension of Length of 200mm, Breadth of 80mm and Thickness of 1.5mm (200mm×80mm×1.5mm). The following process parameters namely, cutting speed, cutting feed, depth of cut and tool for minimizing surface roughness of brass were considered. Vertical pillar drilling machine of METALIK PK203 model was used for the drilling operation and coupling ultrasonic thickness meter of TM-8810 model was as well used to measure the surface roughness of the work piece after drilling. Analysis of Variance (ANOVA) was carried out to test for the significant level of the process parameters for optimizing surface roughness. The findings revealed that the process parameters has a high significant effect in influencing the response variable at 5% significant level except for tool on a zero variation and that optimum process parameters can be achieved at an intermediate level during drilling operation. It was also discovered that there exist a good agreement between the estimated and experimental results based on the mathematical model formulated.

**Keywords:** brass; process parameters; response surface methodology (rsm); surface roughness

## INTRODUCTION

Every machining operation requires recommended process parameters in minimizing or maximizing the response variables to be determined. This research study involves drilling a brass as work piece so as to minimize the surface roughness with the desired process parameters input.

Drilling which is a cutting process uses drill bit to cut hole of circular cross-section in solid materials. In deciding the quality of the drilled holes, the desired process parameters should highly be considered in order to avoid poor finishing after drilling. Brass is an alloy made of Zinc and Copper, which is very expensive material, has a number of benefits. Perhaps the most popular thing about brass is the beauty of the metal. Brass is golden coloured and the metal is very shiny and glossy when polished. Brass goes with any type of décor. Brass is suitable for use in modern houses and much traditional houses.

Brass is an extremely strong and hard wearing material which cannot become scratched or damaged easily. Due to the quality and characteristics of brass, it is therefore recommended to seek the required process parameters during drilling of the brass material so as to avoid rough in-depth drilling of the material which in turn will minimize surface roughness of the work piece which the study seeks to investigate.

## LITERATURE REVIEW

Azlan et al, 2009 investigated the effect of drilling parameters such as spindle speed, feed rate and drilling tool size on material removal rate [MRR], surface roughness, dimensional accuracy and burr for brass so as to find the optimum drilling parameter for HSS drilling tool in micro-drilling processes. Their findings revealed that surface roughness are mostly influenced by spindle speed and feed rate. Their findings revealed that the value of MRR decreases when the tool diameter, spindle speed and feed rate decreases, and that as drilling tool diameter, feed rate and spindle speed increase, the dimensional accuracy of drilled hole decreases. (Kannan et al, 2015) investigated on drilling 6mm hole in brass plate with the help of Artificial Neural Network [ANN] modelling and Genetic Algorithm [GA] optimization techniques. Their findings revealed that proper parameters selection plays a vital role in reducing surface roughness and ovality errors.

Ozay and Savas, 2012 investigated and analyzed the effect of tangential turning milling method on the surface roughness of the cutting parameters using cutter speed, work piece speed, axial feed rate, helix angle of cutting tool and depth of cut in the machining of MS58 brass material. Their finding revealed that as cutting tool speed and work piece speed increase, average surface roughness value decreases.

Vaibhav et al, 2015 investigated on micro holes drilling using electrical discharge machining on titanium wrought alloy. They employed grey relational analysis to determine the optimal machining parameters, among which the discharge current and the capacitance were found to be the most significant. It was also observed that as discharge energy increases, material removal rate [MRR] and electrode wear rate [EWR] increase.

Hossam et al, 2013 presented a real time simulation for virtual end milling process by using 60/40 brass as the workpiece with the application of neural network approach. Their findings established that the result obtained from neural model and of the experimental results confirm the efficiency and accuracy of the model for predicting the surface roughness.

The work of Shandilya et al, 2012 was on the parametric optimization of wire electrical discharge machining using response surface methodology in which the study was made to optimize the process parameters during machining of SiCp/6061 Al metal matrix composite by wire electrical discharge machining using RSM.

Despite the numerous works carried out on parametric optimization of material machining and the use of RSM, there is no author who has put in concerted effort in considering the effect of drilling on brass. Hence, the need for the present study in investigating the optimum parameters required for brass drilling without altering or changing its microstructure.

## Experimental Details

The present experimental investigation includes selection of drilling parameters, range of drilling parameters, formation of the design matrix using Response Surface Methodology (RSM) based on L9-A 34-2 fractional factorial design, selection of work piece material, experimental set-up and measurement of surface roughness.

### Section of Drilling Parameters and the Range of Drilling Parameters

The process parameters that were chosen for experimentation are:

i. Cutting speed (rpm);
ii. Feed rate (mm/rev);
iii. Depth of cut (mm); and
iv. Tool (mm).

These are the main drilling parameters that affect the surface roughness. However, machining expert can change these process parameters at any time of machining. The levels of each input parameter were decided by studying literature in detailed and according to machine limitations. Table 1 shows the levels of drilling parameters according to RSM based on L9-A 34-2 fractional factorial design.

Table 1. Drilling parameters and their levels.

| Factor | Process Parameter | Units | Type | Minimum (+1) | Maximu m (-1) |
|---|---|---|---|---|---|
| X1 | Cutting speed | (rpm) | Numeric | 1400 | 1700 |
| X2 | Feed rate | (mm/re v) | Numeric | 0.11 | 0.75 |
| X3 | Depth of cut | (mm) | Numeric | 0.25 | 0.75 |
| X4 | Tool | (mm) | Numeric | 6 | 10 |

### Trial Machining Experiment

Experiments were conducted using the design of experiments (DOE) technique of RSM based on L9-A 34-2 fractional factorial design and optimization of the results using Analysis of Variance (ANOVA) to find minimum surface roughness. The range of machining conditions was based on the industry practice for brass. A total of 9 numbers of experiments with triplicate was finalized according to RSM based on L9-A 34-2 fractional factorial design. Table 2 shows the design layout for the experimentation.

Table 2. Design layout for the machining experiment.

| Test No. | XI: Speed (rpm) | X2: Feed (mm/rev) | X3: Depth of cut(mm) | X4: Tool (mm) |
|---|---|---|---|---|
| 1 | 1400 | 0.11 | 0.25 | 6 |
| 2 | 1400 | 0.18 | 0.5 | 8 |
| 3 | 1400 | 0.75 | 0.75 | 10 |
| 4 | 1500 | 0.11 | 0.5 | 6 |
| 5 | 1500 | 0.18 | 0.75 | 8 |
| 6 | 1500 | 0.75 | 0.25 | 10 |
| 7 | 1700 | 0.11 | 0.75 | 6 |
| 8 | 1700 | 0.18 | 0.25 | 8 |
| 9 | 1700 | 0.75 | 0.5 | 10 |

## EXPERIMENTAL SETUP

Drilling operation was carried out on a vertical pillar drilling machine, METALIK PK203 model, with a speed range of 75rpm to 3200rpm driven by a motor of 1.5KW. A cutting High speed steel (HSS) drills of 6mm, 8mm and 10mm was used for the experimentation with the introduction of coolant.

### Surface Roughness Measurement

A coupling ultrasonic thickness meter, TM-8810 model was used to measure the surface roughness of the drilled holes in the brass work piece. Table 3 shows the values of the surface roughness measured in triplicate along with the average surface roughness and the experimental run order.

### Development of Surface Roughness Prediction Model

To develop the surface roughness prediction model in terms of cutting speed, feed rate, depth of cut and tool, the measured value of surface roughness along with the experimental run order must have been fed into the design data. For the development of prediction model, the first step is ANOVA analysis.

Table 3. Results measurements

| | Process Parameters | | | | Surface roughness of Brass(μm) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Test No. | XI: Speed (rpm) | X2: Feed (mm/rev) | X3: Depth of cut(mm) | X4: Tool (mm) | 1st | 2$^{nd}$ | 3rd | Mean surface roughness( μm) | Standard Error surface roughness |
| 1 | 1400 | 0.11 | 0.25 | 6 | 7.55 | 8.51 | 5.60 | 7.22 | 0.86 |
| 2 | 1400 | 0.18 | 0.5 | 8 | 8.32 | 7.83 | 7.60 | 7.92 | 0.21 |
| 3 | 1400 | 0.75 | 0.75 | 10 | 7.72 | 7.15 | 7.80 | 7.56 | 0.20 |
| 4 | 1500 | 0.11 | 0.5 | 6 | 8.57 | 6.89 | 9.00 | 8.16 | 0.64 |
| 5 | 1500 | 0.18 | 0.75 | 8 | 9.67 | 7.70 | 9.70 | 9.02 | 0.66 |
| 6 | 1500 | 0.75 | 0.25 | 10 | 5.02 | 4.79 | 6.10 | 5.30 | 0.40 |
| 7 | 1700 | 0.11 | 0.75 | 6 | 10.23 | 6.00 | 9.90 | 8.71 | 1.36 |
| 8 | 1700 | 0.18 | 0.25 | 8 | 6.11 | 4.60 | 8.20 | 6.30 | 1.04 |
| 9 | 1700 | 0.75 | 0.5 | 10 | 5.33 | 4.38 | 7.60 | 5.77 | 0.96 |

## ANOVA for Surface Roughness Prediction Model

The analysis of variance (ANOVA) is based on two assumptions:

i. The variables are internally distributed; and
ii. Homogeneity of variance. Significant violation of e ther assumption can increase the chances of error.

To check the assumption of normal distribution, the normal probability plot of the residuals for surface roughness plotted in Figure 1was used. Fig. 1 shows that the residuals fall on a straight line, which implies that the errors are distributed normally. Fig. 2 represents residuals versus the fitted surface roughness plot. It shows that there is no obvious pattern and unusual structure in the points. This implies that there is no reason to suspect any violation of the independence or constant variance assumption.

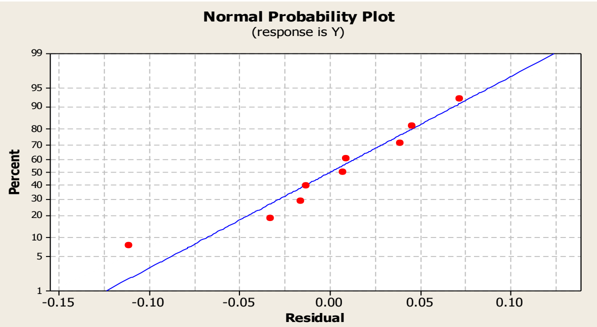


Fig.1. Normal Probability Plot of Residuals for Surface Roughness

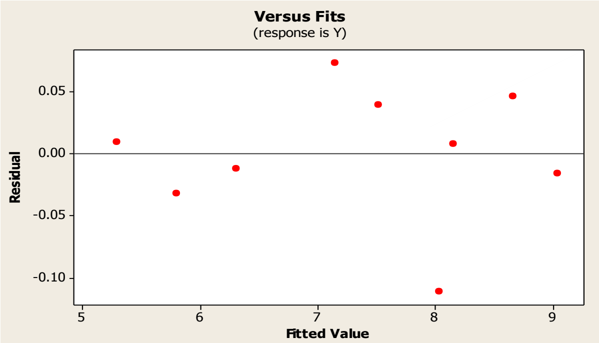


Fig. 2. Plot of Residuals vs. Fitted Value of Surface Roughness

### *ANOVA Surface Roughness Prediction Model*

The ANOVA was carried out using the measured or recorded data at a significance level of $\alpha = 0.05$, i.e. for a confidence level of 95%. The ANOVA analysis for surface roughness is as summarized in Table 4

Table 4. ANOVA for surface roughness of brass steel (Authors' computation from MINITAB 16)

| Factor | **Linear Regression Effect** | | | | | |
|---|---|---|---|---|---|---|
| | DOF | Sum of Square (SS) | Mean of Sum of Square (MSS) | F-Statistic | Predicted(P-value) | Remarks |
| X1: Cutting Speed | 1 | 0.6983 | 0.1217 | 21.38 | 0.010 | Significant |
| X2: Feed Rate | 1 | 5.7422 | 5.7422 | 1009.04 | 0.000 | Significant |
| X3: Depth of cut | 1 | 6.9768 | 6.9768 | 1225.99 | 0.000 | Significant |
| X4: Tool | 1 | 0.0378 | 0.0378 | 6.64 | 0.062 | Not Significant |
| Error | 4 | 0.0228 | 0.0057 | | | |
| Total | 8 | 13.4779 | | | | |
| $R^2$ = 99.83%; Adj. $R^2$ = 99.66% | *P-value < 0.05 or 5% is Significant | | | | | |
| Factor | **Linear Square Regression Effect** | | | | | |
| | DOF | Sum of Square (SS) | Mean of Sum of Square (MSS) | F-Statistic | Predicted(P-value) | Remarks |
| X1 | 1 | 0.6983 | 0.1217 | 150.03 | 0.007 | Significant |
| X2 | 1 | 5.7422 | 0.0727 | 89.03 | 0.011 | Significant |
| X3 | 1 | 6.9768 | 0.0794 | 97.83 | 0.010 | Significant |
| X4 | 1 | 0.0378 | 0.0378 | 46.60 | 0.021 | Significant |
| X2*X2 | 1 | 0.0118 | 0.1180 | 14.55 | 0.062 | Not Significant |
| X3*X3 | 1 | 0.0093 | 0.0093 | 11.51 | 0.077 | Not Significant |
| Error | 2 | 0.0016 | 0.0008 | | | |
| Total | 8 | | | | | |
| $R^2$ = 99.99%; Adj. $R^2$ = 99.95% | *P-value < 0.05 or 5% is Significant | | | | | |
| Factor | **Linear Interaction Regression Effect** | | | | | |
| | DOF | Sum of Square (SS) | Mean of Sum of Square (MSS) | F-Statistic | Predicted(P-value) | Remarks |
| X1 | 1 | 0.6983 | 0.0065 | ** | ** | Not Significant |
| X2 | 1 | 5.7422 | 0.0015 | ** | ** | Not Significant |
| X3 | 1 | 6.9768 | 0.0000 | ** | ** | Not Significant |
| X4 | 1 | 0.0378 | 0.0013 | ** | ** | Not Significant |
| X1*X2 | 1 | 0.0035 | 0.0022 | ** | ** | Not Significant |
| X1*X3 | 1 | 0.0052 | 0.0118 | ** | ** | Not Significant |
| X2*X3 | 1 | 0.0121 | 0.0054 | ** | ** | Not Significant |
| X2*X4 | 1 | 0.0019 | 0.0019 | ** | ** | Not Significant |
| Error | 0 | ** | ** | | | |
| Total | 8 | 13.4779 | | | | |
| $R^2$ = **; Adj. $R^2$ = ** | *P-value < 0.05 or 5% is Significant | | | | | |
| Factor | **Quadratic Regression Effect** | | | | | |
| | DOF | Sum of Square (SS) | Mean of Sum of Square (MSS) | F-Statistic | Predicted(P-value) | Remarks |
| X1 | 1 | 0.6983 | 0.0756 | ** | ** | Not Significant |
| X2 | 1 | 5.7422 | 0.0213 | ** | ** | Not Significant |
| X3 | 1 | 6.9767 | 0.0183 | ** | ** | Not Significant |
| X4 | 1 | 0.0378 | 0.0378 | ** | ** | Not Significant |
| X2*X2 | 1 | 0.0118 | 0.0106 | ** | ** | Not Significant |
| X3*X3 | 1 | 0.0093 | 0.0074 | ** | ** | Not Significant |
| X1*X2 | 1 | 0.0001 | 0.0008 | ** | ** | Not Significant |
| X1*X3 | 1 | 0.0016 | 0.0016 | ** | ** | Not Significant |
| Error | 0 | ** | ** | | | |
| Total | 8 | 13.4779 | | | | |
| $R^2$ = **; Adj. $R^2$ = ** | *P-value < 0.05 or 5% is Significant | | | | | |

The characterization of machined surface quality was limited only to surface roughness. Table 4 shows the computed ANOVA for surface roughness for brass based on the linear effect, linear square effect, linear interaction effect and quadratic effect respectively. It is observed that the linear effect and linear square effect showed a very high significant with the process parameters except for tool. However, the linear effect displayed a best fit in terms of the model performance for the experimental study.

Based on the linear effect, the coefficient of determination ($R^2$) is reasonably high with a value of 99.83% which explains the effect of the surface roughness on the considered factors (speed, feed, depth of cut and tool). The Adjusted $R^2$ of 99.66% explained the true behaviour of the $R^2$. The remaining 0.17% is been explained by the disturbance error which is unobservable during the experiment. Also, the P-values of the F-statistic calculated at 5% significance level, revealed that tool as a factor does not contributes significantly in explaining the surface roughness of brass after drilling operation.

**Surface Roughness Prediction Model**

The regression model for surface roughness in terms of linear effect is given in Eq. (1).

$$SR = 12.8627 - 0.0049X_1 - 2.7868X_2 + \\ + 4.3133X_3 - 0.4200X_4 \quad (1)$$

The model Eq. (1) is as well validated graphically to reveal the good agreement between the experimented and estimated value of the surface roughness as shown in Fig. 3.

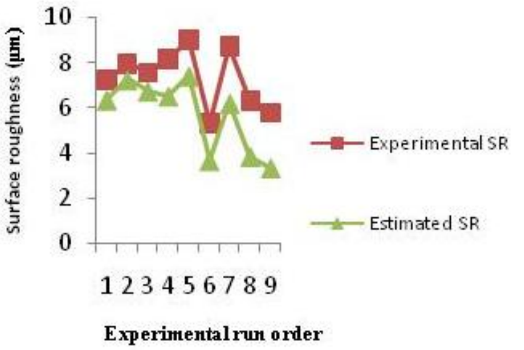


Fig. 3. Comparison between measured and predicted value for surface roughness of Brass

Figure 3 shows validation of the surface roughness values. The experimental and estimated results were similar and not a large difference in surface roughness values

**RESULTS AND DISCUSSION**

The result of the machining experiment for surface roughness as in Table 3 were inputted into a MINITAB 16 software based on the experimental plan for further analysis. The surface roughness was plotted against the process parameters based on the experiment measurements through surface plot graph.

**Effect Of Drilling Parameters On Surface Roughness**

From Fig. 4 to Fig. 8, all the observations recorded was at a speed of 1700rpm, with a feed rate of 0.75mm/rev, tool diameter of 10mm, depth cut of 0.75mm, and the surface roughness at a maximum value of (7.57µm). It was therefore deduced that the drilling bit size of 6mm at an intermediate level should be considered for drilling brass based on the measure of thickness of the plate considered

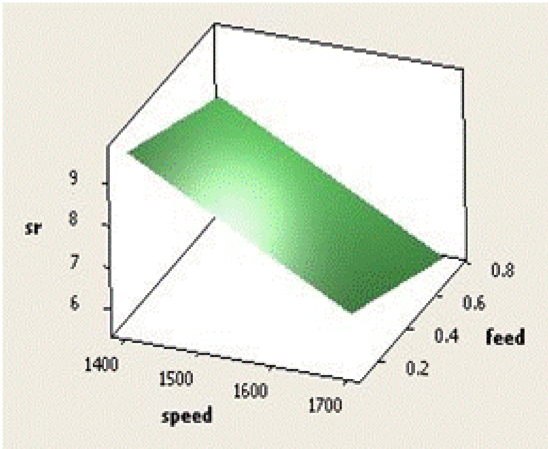


Fig. 4. Estimated surface roughness of brass at speed against feed rate

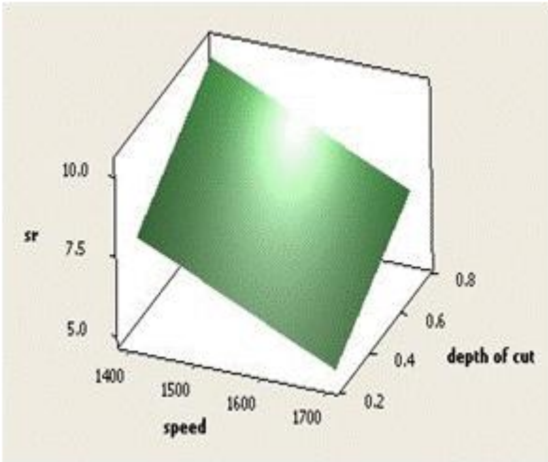


Fig. 5. Estimated surface roughness of brass at speed against depth of cut

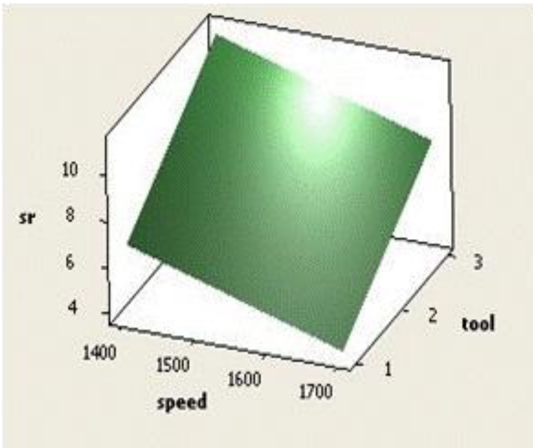


Fig. 6. Estimated surface roughness of brass at speed against tool

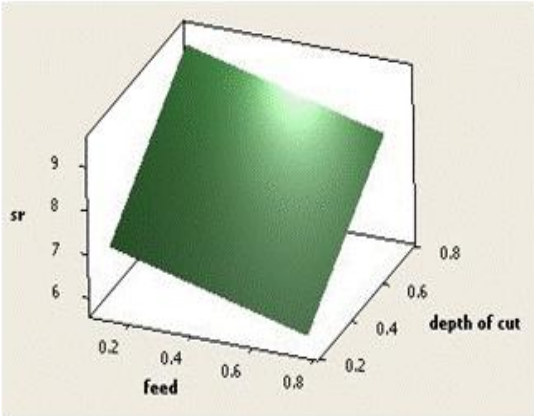


Fig. 7. Estimated surface roughness of brass at feed against depth of cut

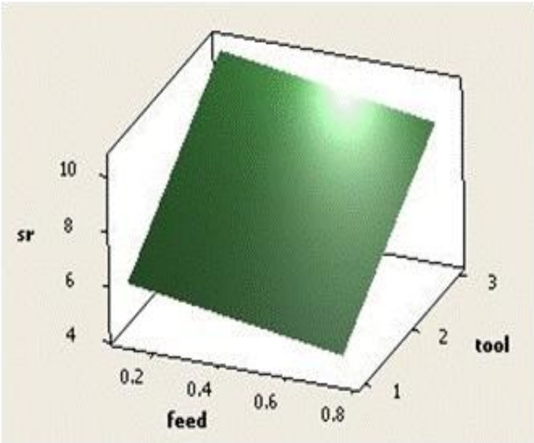


Fig. 8. Estimated surface roughness of brass at feed against tool

**Optimization Of Drilling Parameters For Minimum Surface Roughness**

The constraints used during the optimization process are summarized in Table 5 and the optimal solution is reported in Table 6.

Table 5. Constraints for optimization of drilling parameters for stainless steel

| Name | Goal | Lower limit | Upper limit |
|---|---|---|---|
| X1: Cutting Speed (rpm) | is in range | 1400 | 1500 |
| X2: Feed Rate (mm/rev) | is in range | 0.11 | 0.75 |
| X3: Depth of Cut (mm) | is in range | 0.25 | 0.75 |
| X4: Tool (mm) | is in range | 6 | 8 |
| Y: Surface Roughness (µm) | Minimize | 5.30 | 9.02 |

Table 6. Optimization results for surface roughness

| Cutting Speed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool (mm) | Surface Roughness (µm) | Desirability | Remarks |
|---|---|---|---|---|---|---|
| 1500 | 0.35 | 0.50 | 6 | 6.93 | 0.7321 | Selected |

**CONCLUSION**

The experimental investigation revealed that the optimal solution of the response variable cannot be actualized easily with a particular combination of process parameters settings because the optimum condition of the drilling process is concerned with minimizing surface roughness which requires varying process parameters during experimentation. It is observed that optimum surface roughness is obtained at an intermediate level of cutting speed, feed, depth of cut and tool respectively. To acquire a minimal surface finish of work piece based on the thickness of the brass, cutting speed, feed, depth of cut and tool should be set as intermediate level as possible. The linear interaction effect and quadratic effect does not contribute significantly to the experimental investigation due to lesser or no contributory effect of the process parameters in the analysis.

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