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Research Paper

# Optimization of Cutting Parameters for Free Cutting Brass (CuZn35Pb3) Using Taguchi Method

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**Abstract**

The need of smooth surface finish produced during machining process plays a greater role to reduce wear of the part and corrosion protection. However, the cost of making good surface finish depends on selection of optimized parameters and use of precision machines. Dry turning operation is very important for saving cost of cutting fluid, contribute to clean environment and good for safety of machinist. Pure copper produces a long tubular or tangled chips which makes machining very difficult because chips are rolled on cutting tool causing tool wear. Machining of high ductility work material like copper can create high frictional forces between chip and cutting tool. This creates high tool wear due to poor chip formation. In this work, cutting parameters like cutting speed, depth of cut and feed are optimized for dry turning process using Taguchi Method. The optimum turning parameters in this study was obtained at higher cutting speed, lower feed and higher depth of cut. The minimum surface roughness at optimum turning parameters was obtained as 1.63 µm. Result of variance indicates the contribution of cutting speed, feed and depth of cut were 88.74%, 1.13% and 6.46% respectively. Among which cutting speed was the most significant factor for improving surface roughness.

## 1. Introduction

Machining is a material removal process where a cutting tool made of a harder material than the workpiece is used to remove materials in conventional machining process. It is not only performed for the overall forming of parts into their ultimate shapes, but also it is used to convert castings, forgings or preformed blocks of metal into desired shapes, with size and finish specified to fulfil design requirements (Singh et al., 2014). Operations that can be done on lathe machine are turning, facing, counter turning and tapering, boring and chamfering. Turning operation is very important material removal process in modern industry. At least one fifth of all applications in metal cutting are covered by turning operation. It is used to reduce the diameter of the work piece, usually to a specified dimension and to produce a smooth finish on the metal (Pedro et al., 2012; Saraswat et al., 2014).

Machinability, generally, is defined in terms of surface finish, tool life, force and power requirements and chip control. The machinability of materials depends on their composition, properties, and microstructure. Thus, proper selection and control of process variables

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are important (Sahoo, 2013). Optimization of machining processes is usually based on finding operating conditions, which minimize machining costs and maximize production rate. The three important process parameters in this study are depth of cut, feed and cutting speed. Surface roughness of a turned work-piece is dependent on these process parameters. In addition, it also depends on the several other exogenous factors such as work piece material and tool material type. Mechanical properties, quality and type of the machine tool used, auxiliary tooling, and lubricant used are also another parameter (Shaw, 1991; Chen, 2000; Pedro et al., 2012; Wang and Cheung, 2012; Singh et al., 2014; Zhang et al., 2015; Zhong et al., 2017).

Surface roughness remain the main indicator of machined component quality as it is related with surface quality. Achieving high surface quality by machining is a big challenge for machining industries at with more productivities and less machining time. Even rough surfaces wear more quickly and have high friction coefficient than smooth surfaces. As the surface roughness increases, quality of product goes on decreasing. Therefore, it should bridge the gap between quality and productivity (Ezugwu et al., 2005). Dry machining has got attention due to reduced cost of cutting fluid and less effect on causing environmental pollution which is generated from using metal cutting fluids. The optimization of turning process parameter in dry turning of SAE52100 steel by using carbide inserts was studied (Borse, 2014). The result showed that cutting speed is the most dominant factors which affects surface roughness and followed by feed and depth of cut. At low and moderate speed, feed marks observed whereas at higher speed feed marks were absent.

Researchers have investigated the effect of cutting speed, feed and depth of cut on the surface roughness of machined product of mild steel by using Taguchi method (Saraswat et al., 2014). Their result showed that the surface roughness was highly affected by feed and depth of cut has low significant effect on the surface roughness. The analysis also shows that the predicted values and calculated values are very close, that clearly indicates that the developed model can be used to predict the surface roughness in the turning operation of mild steel. The minimum average surface roughness obtained by Saraswat et al. (2014) was 2.22 μm.

Dry turning process is very important since it contributes to clean environment and safety for operator. Many scientists have suggested the optimization of dry turning process for different materials (Masounave et al., 1997; Thomas and Beauchamp, 2003; Diniz and de Oliveira, 2004; Filiz et al., 2007; Imran et al., 2014). The main objective of using cutting fluids in machining operations is the reduction of temperature in the cutting region to increase tool life. However, the advantages offered by cutting fluids have been strongly debated because of their negative effects on the economic aspect, the environment and the health of workers using them. A trend to solve these problems is cutting without fluid, a method named dry cutting, which has been made possible due to technological innovations. The study focuses on the surface integrity and wear mechanisms associated with mechanical microdrilling of nickel-base superalloy (Inconel 718) under dry and wet cutting conditions was investigated (Masounave et al., 1997). The result showed that the tool wear can be attributed to high chip contact length, higher temperatures, high adhesion and diffusion in wet cutting in comparison to dry cutting.

Mechanical properties makes a great contribution to surface roughness formation in ultra-precision machining due to the “size effect” and for different isotropic materials, the machined surface roughness under the same cutting conditions is different (Wang and Cheung, 2012; Zhang et al., 2015 ). The selection of appropriate tool materials depends not only on the material to be machined, but also on process parameters and the characteristics of the machine tool (Davis et al., 2014; Zhong et al., 2017). Surface roughness is highly affected by cutting parameters like cutting speed, depth of cut and feed rate during turning process on conventional lathe machine. These parameters must be within the recommended range depending on the type of material to be machined, tool geometry and tool material (Chen, 2000; Hayajneh, 2007; Zein and Irfan, 2018).

Micro-cutting experiments of copper grating were carried out using the self-developed polycrystalline diamond (PCD) micro tools and the effect of depth of cut, feed per tooth and spindle speed on dimensional accuracy and burr formation was investigated (Zhong, et al., 2017). Investigation surface roughness and stress modeling by finite element on orthogonal cutting of copper were studied (Thiele et al., 1990). In this study

Finite element (FE) method was applied to predict the stress during orthogonal cutting by simulating the machining process. Comparative study on optimization of surface roughness parameters in turning EN1A steel on a CNC lathe with coolant and without coolant was studied by a researcher (Selvaraj and Chandramohan, 2010). Their result shows that the best surface finish was occurred with coolant.

The main aim of this work is to fill the gap on practical cutting parameter of dry machining of free cutting brass (CuZn35Pb3) by Taguchi optimization method. It is also to justify practical case of dry machining advantages in saving cost of cutting fluids and environmental clean production method.

## 2. Experimental Procedures

The work piece materials used for this study was an alloy of copper, free cutting brass (CuZn35Pb3) which, is used in the applications of bolts, nuts, gears, pinions and high-speed screw machine parts with dimension of 25 mm x 50 mm. Free cutting brass (CuZn35Pb3) of 500 mm in length and 25 mm in diameter was prepared. Turning process at depth of cut 1 mm is used for removing any irregular parts on the surface for 450 mm of length. Nine different experiments with dimension of 23 mm x 50 mm at 1.5, 2.5 and 3.5 mm of depth of cut would be operated for experimental study with different cutting parameters which is selected using orthogonal array. Ceramic coated-carbide tool was used because of their chemical inertness, low thermal conductivity, resistance to high temperature, resistance to flank and crater wear since, ceramics are suitable coating materials for tools. The most commonly used ceramic coating is aluminum oxide ($Al_2O_3$) (Tilak, 2017).

### 2.1. Design of experiment

In the design of experiment (DOE), Taguchi method is used because it is a problem–solving tool which can improve the performance of the product, process design and system. The lathe machine with model of PSG A141 and power of 7 KW with spindle speed range of 15rpm to 2000 rpm was used in this work. The cutting force was calculated from the net machine power and the corresponding cutting speed that is dividing net machine power. The average surface roughness for each sample was measured by surface contact profilometer in which the result was in micrometers. The properties and chemical composition of the workpiece material was given in Table 1.

**Table 1:** Properties and composition of free cutting brass (Thiele Jr et.al 1990)

| Type and UNS number | Nominal composition | Ultimate tensile strength (Mpa) | Yield strength (Mpa) | Elongation in 50 mm (%) | Hardness (HV) |
|---|---|---|---|---|---|
| Free-cutting brass (CuZn35Pb3) | 61.5% Cu, 3.0% Pb, 35.5% Zn | 340–470 | 125–310 | 53–18 | 52 |

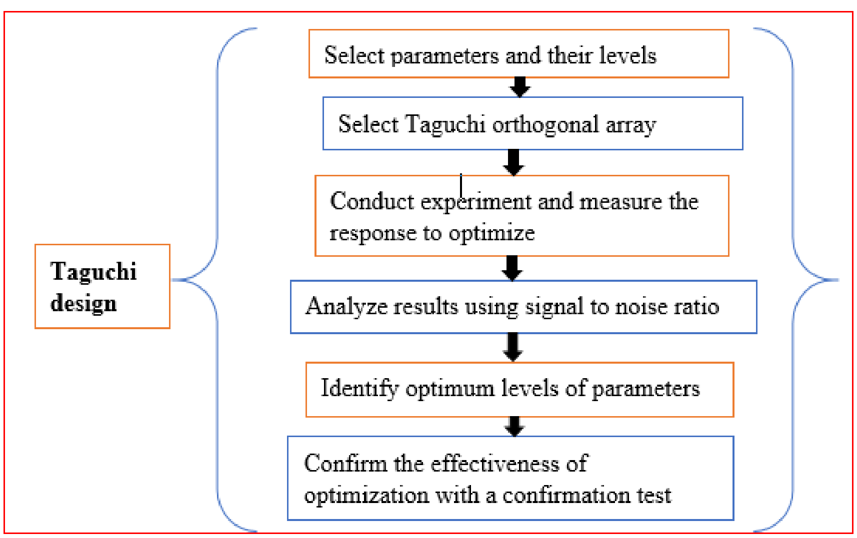


**Figure 1**: Taguchi design procedure

**Table 2**: List of parameters and their level

| Cutting Parameters | Parameters designation | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Cutting speed (m/min) | A | 30 | 40 | 50 |
| Feed (mm/rev) | B | 0.3 | 0.5 | 0.7 |
| Depth of cut (mm) | C | 1.5 | 2.5 | 3.5 |

To observe the most influential process parameters in the turning process among them cutting speed, feed and depth of cut each at three levels were considered in the experiment as given in Table 2. However, total number of experiments of the orthogonal array (OA) should be greater than or equal to the total DOF required for the experiment. Thus, $L_9$ orthogonal array was selected to make the further experiments are shown in the Table 3. This setup allows the testing of all three variables without having to run $27=3^{3.}$ Nine different samples were manufactured with different parameters and at different levels. In the Taguchi method the response variation was studied using signal-to-noise ratio and minimizing by optimizing the responses parameter. The smaller is the better S/N ratio used for these responses.

$$SN = -10\,log\left[\frac{1}{r}\sum_{i=1}^{1} y_i^2\right] \qquad (1)$$

where, $y$ is observation, $r$ is total number of observation and $y_i$ is $i^{th}$ response.

**Table 3:** Experimental layout using an L-9 Orthogonal array

| Ex. no | Cutting speed (m/min) | Feed (mm/rev) | Depth of cut (mm) |
|---|---|---|---|
| 01 | 30 | 0.3 | 1.5 |
| 02 | 30 | 0.5 | 2.5 |
| 03 | 30 | 0.7 | 3.5 |
| 04 | 40 | 0.3 | 2.5 |
| 05 | 40 | 0.5 | 3.5 |
| 06 | 40 | 0.7 | 1.5 |
| 07 | 50 | 0.3 | 3.5 |
| 08 | 50 | 0.5 | 1.5 |
| 09 | 50 | 0.7 | 2.5 |

Analysis of variance (ANOVA) is the statistical technique used to find the influence of all control parameters. Therefore, percentage contributions of each control factor was used to measure the corresponding effects on performance characteristics. The significance level of 5 %, i.e. for 95 % level of confidence was considered in this analysis.

## 3. Results and discussion

### 3.1. The effect of cutting parameters on the surface roughness

All nine experiments were conducted with different cutting parameters but at the same length of 50 mm. Samples of free cutting brass material are given in Figure 2. The diameter of the workpiece prepared for experimental work is 23 mm. Turning process was conducted with 1.5, 2.5 and 3.5 mm depth of cut. Sample number 1, 2 and 3 were operated by similar cutting speed of 30 m/min but, with different feeds (0.3, 0.5 and 0.7 respectively for sample 1, 2 and 3) and depth of cut (1.5, 2.5 and 3.5 respectively for sample 1, 2 and 3). By similar manner samples number 4, 5 and 6 were operated by similar cutting speed of 40 m/min but with different feed (0.3, 0.5 and 0.7, respectively) and depth of cuts (2.5, 3.5 and 1.5, respectively). The last three samples were also operated by similar cutting speed of 50 m/min, but with different feeds (0.3, 0.5 and 0.7, respectively) and depth of cuts (3.5, 1.5 and 2.5, respectively).

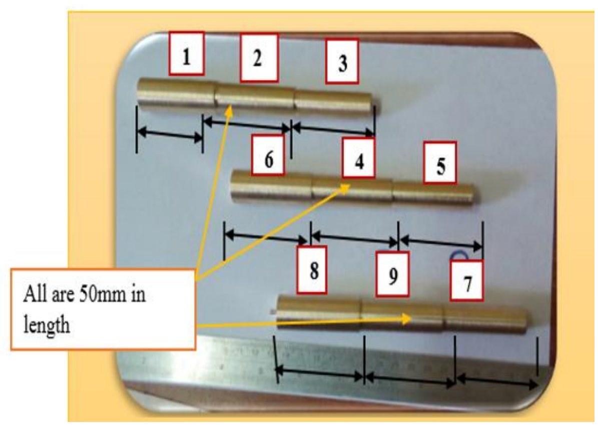


**Figure 2:** Samples after turning process

### 3.2. Optimization of cutting parameters

Taguchi's orthogonal arrays are highly fractional orthogonal designs. Orthogonal array designs focus primarily on main effects. These designs are used to estimate main effects using only a few experimental runs. Taguchi Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results. In Taguchi method, response variation is studied with the help of signal-to-noise (S/N) ratio.

**Table 4:** Experimental result for mean value of surface roughness

| Exp. No. | Cutting Speed (m/min) | Feed (mm/rev) | Depth of cut (mm) | Surface roughness (μm) | | | Avg. Ra (μm) | S/N ratios |
|---|---|---|---|---|---|---|---|---|
| | | | | Trial 1 | Trial 2 | Trial 3 | | |
| 1 | 30 | 0.3 | 1.5 | 3.5 | 3.47 | 2.83 | 3.27 | -10.29 |
| 2 | 30 | 0.5 | 2.5 | 3.22 | 3.93 | 3.35 | 3.50 | -10.88 |
| 3 | 30 | 0.7 | 3.5 | 3.29 | 2.81 | 2.12 | 2.74 | -8.76 |
| 4 | 40 | 0.3 | 2.5 | 2.75 | 3.67 | 2.2 | 2.87 | -9.16 |
| 5 | 40 | 0.5 | 3.5 | 3.15 | 2.7 | 2.85 | 2.90 | -9.25 |
| 6 | 40 | 0.7 | 1.5 | 3.01 | 3.22 | 2.95 | 3.06 | -9.71 |
| 7 | 50 | 0.3 | 3.5 | 1.58 | 1.97 | 1.34 | 1.63 | -4.24 |
| 8 | 50 | 0.5 | 1.5 | 1.8 | 1.92 | 1.75 | 1.82 | -5.2 |
| 9 | 50 | 0.7 | 2.5 | 1.9 | 2.19 | 1.93 | 2.01 | -6.06 |
| Average performance mean value | | | | | | | 2.64 | -8.17 |

3.2.1. Analysis of Mean for Surface Roughness

The average mean value of surface roughness for each factor i.e. Cutting speed (A), Feed (B) and Depth of cut (C) were calculated using the design of experiments. Table 4 presents the experimental results of surface roughness (Ra) values for each specimen and their mean values which are measured by surface contact profilometer. In this study each surface roughness trial value is the average of three trial reading.

Table 5 shows that cutting speed has more effect on surface roughness since the Delta value was 1.35 and ranking of 1. The factor with the least effect on the mean is feed (Delta = 0.15, Rank = 3). Those parameter levels with better surface finish value of specimens that means A3B1C3 will be taken as a possible parameter combination for better values. The significant factors in the order increasing by affecting surface roughness is feed, depth of cut and cutting speed as shown in Table 5.

**Table 5:** The response values of mean effect plot (smaller is better).

| Level | Cutting speed | Depth of cut | Feed |
|---|---|---|---|
| | Symbol | | |
| | A | B | C |
| 1 | 3.17 | 2.59 | 2.72 |
| 2 | 2.94 | 2.74 | 2.79 |
| 3 | 1.82 | 2.60 | 2.42 |
| Delta | 1.35 | 0.15 | 0.37 |
| Rank | 1 | 3 | 2 |

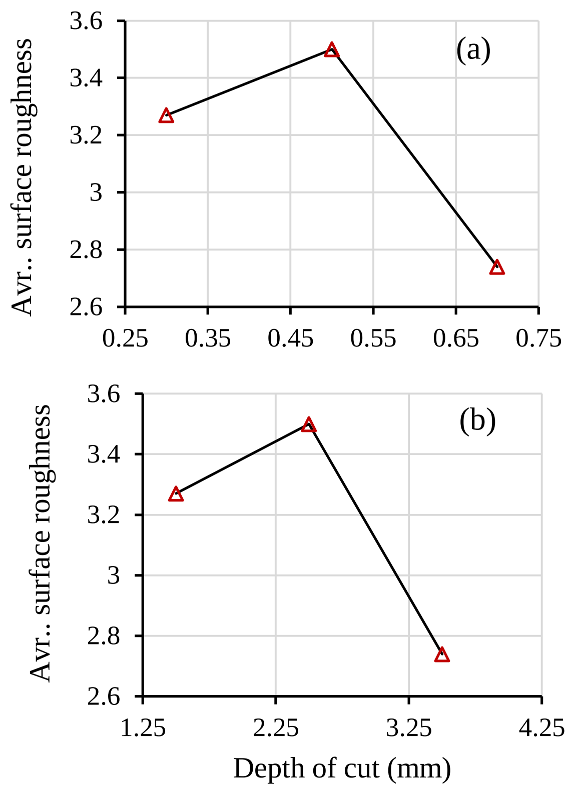


**Figure 3:** The effect of (a) feed and (b) depth of cut on surface roughness at cutting speed of 30 m/min

With increasing feed from 0.3 mm/rev to 0.5 mm/rev, surface roughness increased from 3.27 μm to 3.50 μm and then decreased to 2.74 μm when feed increased to 0.7 mm/rev at cutting speed of 30 m/min as shown in Figure 3(a). Similarly, as depth of cut is increased from 1.5 mm to 2.5 mm the surface roughness was also increased but surface roughness decreased when depth of cut was increased to 3.5 mm at cutting speed of 30 m/min as shown in Figure 3(b). For given feed and depth of cut shown in Figure 3(a, b), the optimum cutting parameters resulted in minimum surface roughness.

With increasing the feed from 0.3 mm/rev to 0.7 mm/rev, surface roughness increased to 2.90 µm at constant cutting speed of 40 m/min as shown in Figure 4(a). The surface roughness was increased with increasing depth of cut from 1.5 mm to 2.5 mm and then decreased when depth of cut was increased to 3.5 mm at cutting speed of 40 m/min as shown in Figure 4(b).

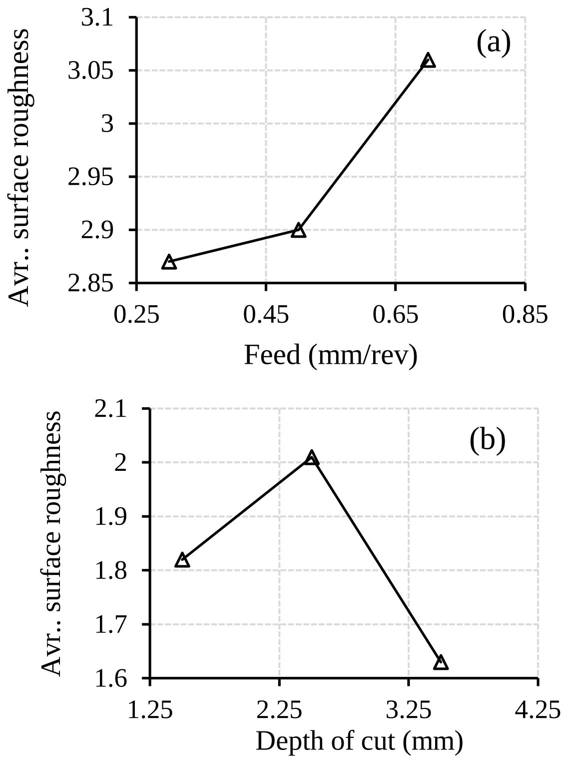


**Figure 4:** The effect of feed (a) and depth of cut (b) on surface roughness at cutting speed of 40m/min.

Surface roughness was increased from 1.63 µm to 2.01µm with increasing feed from 0.3 mm/rev to 0.7 mm/rev at cutting speed of 50 m/min as shown in figure 5(a). The surface roughness was increased when the depth of cut was increased from 1.5 mm to 2.5 mm and then decreased with increasing depth of cut to 3.5 mm at cutting speed of 50 m/min as shown in figure 5(b).

Figure 6 shows that with increasing cutting speed from 30 m/min to 50 m/min the surface roughness also increases at both constant feed 0.3 mm/rev and 0.5 mm/rev. But at 0.7mm/rev feed the surface roughness was increased initially with increasing cutting speed from 30 m/min to 40 m/min and then decreased when cutting speed was increased to 50 m/min as shown in Figure 6 (b). Generally, the surface roughness increased with increasing feed and decreased with increasing depth of cut and cutting speed within the scope of this investigation. The reason for decreasing of surface roughness is to reduce wear, corrosion resistance and friction as well as to get the product with high quality.

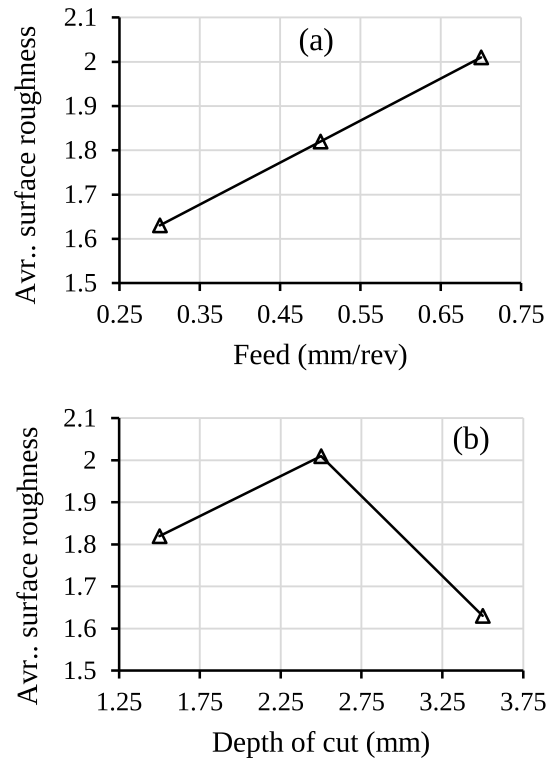


**Figure 5:** The effect of (a) feed and (b) depth of cut on surface roughness at cutting speed of 50 m/min.

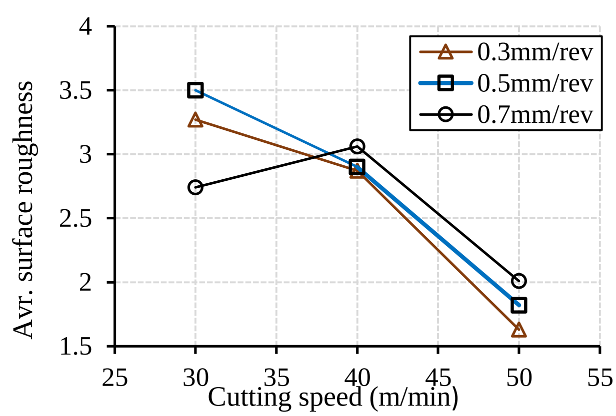


**Figure 6:** The effect of cutting speed on the surface roughness at 0.3 mm/rev feed, at 0.5 mm/rev and at 0.7 mm/rev.

For predicting the optimum response, three factors of parameters are selected by small mean value. A3B1C3 is the optimum levels of parameters mean value for surface roughness value. To find out predicted value of the responses (surface roughness value) the following linear regression equation is used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC3 - m) \quad (2)$$

where, $m$ = Average performance mean value for surface roughness, $mA3$ = optimum level value for parameter A, $mB1$= optimum level value for parameter B, $mC3$= optimum level value for parameter C.

$$y_{0pt} = 2.64 + (1.82 - 2.64) + (2.59 - 2.64) + (2.42 - 2.64)$$

$y_{0pt} = 1.55$ (Predict mean value for surface roughness value).

3.2.2. Analysis of S/N Ratios for Surface Roughness

The Taguchi method uses S/N ratio to measure the variations of the surface roughness value in experimental design. Table 6 presents the calculations of S/N Ratios for surface roughness value results using design of experiments.

**Table 6:** Response Table for Signal to Noise Ratios Smaller Is Better

| Level | Cutting speed | Feed | Depth of cut |
|---|---|---|---|
| | Symbol | | |
| | A | B | C |
| 1 | -9.98 | **-7.90** | -8.40 |
| 2 | -9.37 | -8.44 | -8.70 |
| 3 | **-5.17** | -8.18 | **-7.42** |
| Delta | 4.81 | 0.55 | 1.29 |
| Rank | 1 | 3 | 2 |

Surface roughness response shown in Table 6 shows that for signal to noise ratios of cutting speed weight percentage have the greatest effect (Delta = 4.81, Rank = 1). The factor with the least effect on the (S/N) ratio is feed (Delta = 0.55, Rank = 3). The optimal parameter combination on smaller is the better surface quality character is A3B1C3 are the possible parameter combinations for increasing the surface finish of the samples.

The numerical value of the maximum point in each graph shows the best value of particular parameter at that level. They also indicate the optimum conditions in the range of the experimental conditions. Since, S/N ratio used for this study is smaller is better and smallest S/N ratio was selected as it shown in the Figure 6 (a), (b) and (c). That is at 50 m/min cutting speed, 0.3 mm/rev feed and depth of cut at 3.5 mm (A3B1C3) was selected. For predicting the optimum response approximately, three factors of parameters are selected by low S/N ratio value. A3B1C3 is the optimum levels of parameters S/N ratio value for surface roughness value. To find out predicted values of the response (surface roughness value), linear regression equation was used:

$$y_{0pt} = m + (mA3 - m) + (mB1 - m) + (mC3 - m)$$

$$y_{0pt} = -8.17 + (-5.17 - (-8.17)) + (-7.90 - (-8.17)) + (-7.42 - (-8.17))$$

$y_{0pt} = -4.15$ (Predict S/N value for surface roughness).

3.2.3. Analysis of Variance (ANOVA) for Surface Roughness

Analysis of variance (ANOVA) is used to identify the most significant factors which affects the surface roughness of the machined part. The result is reported in Table 7. The percent contribution for each factor was also calculated. From Table 7, it was clearly observed that cutting speed weight percentage (88.74%), feed (1.13%), depth of cut (6.46%) and the residual error (3.67%) had significant influence on surface roughness of free cutting brass specimens. Therefore, cutting speed has high significant effect parameter on the surface roughness of free cutting brass in dry turning process by 88.74% of contribution. Depth of cut has significant influence on the surface roughness by 6.46% contribution. But feed has the least significant influence on the surface roughness of free cutting brass during dry turning process.

3.2.4. Confirmation Test

Once the optimal combination of process parameters and their levels was obtained, the final step was to verify the predicted result against experimental result. If the optimal combination of parameters and their levels coincidently match with one of the experiments in the Orthogonal Array, then no confirmation test is required. By considering this, Confirmation test was not required in this work, because the optimum combination of parameters and their levels (A3B1C3) have a correspondent

**Table 7:** Analysis of Variance for surface roughness value

| Source | DOF | SST | SSTR | MSE | *F* | *P* | Percent contribution | Significance ($\alpha$=0.05) |
|---|---|---|---|---|---|---|---|---|
| Cutting speed | 2 | 3.14 | 3.14 | 1.57 | 24.75 | 0.039 | 88.74% | Highly Significant |
| Feed | 2 | 0.04 | 0.04 | 0.02 | 0.33 | 0.754 | 1.13% | Less significant |
| Depth of cut | 2 | 0.23 | 0.23 | 0.11 | 1.81 | 0.356 | 6.46% | Significant |
| Residual error | 2 | 0.13 | 0.13 | 0.06 | | | 3.67% | |
| Total | 8 | 3.53 | | | | | 100% | |

**Table 8:** Comparison between predicted and experimental confirmation

| Response | Optimal parameter | Predicted value | | Experimental value | |
|---|---|---|---|---|---|
| | | Mean | S/N | Mean | S/N |
| Surface Roughness (μm) | A3B1C3 | 1.55 | -4.15 | 1.63 | -4.24 |

to an experiment of the orthogonal array of the trail 7 condition of the experiment. The obtained optimal factor combination is one of the trial conditions (Trial 7) of the experiment. Thus, the minimum average surface roughness in this study was 1.63 μm as it is showed in Table 4, which was at 50 m/min cutting speed, 0.3 mm/rev feed and 3.5 mm depth of cut. Table 8 presents the confirmation experiment and predicted results comparison for surface roughness measurements.

It can be seen from Table 8, the difference between experimental result and the predicted results are very small. The values predicted by using Taguchi approach is approximately near to the value which is experimentally obtained. This verify that, the experimental results of surface roughness are strongly correlated with the predicted results.

### 3.2.5. Observation of Chip Morphology

Discontinuous chips were observed due to heterogeneous microstructure of the free cutting brass, in dry turning operation of this study. Figure 8 shows the chips formed in dry turning process of free cutting brass for all nine different experiments. It was reported that, due to the presence of lead element in the free cutting brass alloy the chips produced were discontinuous type (Chiappini, 2014). The maximum and minimum length of these chips were identified. The chips of all samples can be observed as discontinuous type of chips. But samples No. 7, 8 and 9 have chips with smallest size due to high cutting speed during the turning process and samples No. 1, 2 and 3 have discontinuous chips with long length because of low cutting speed during the process. But samples No. 4, 5 and 6 have chips with small and long in size since it was operated with moderate cutting speed. The longest chip was 1.6 mm long which is for sample No. 3 because of low cutting speed of 30 m/min and high depth of cut 3.5 mm. The smallest is approximately the size of powder which is in micrometers for sample No. 8 due to speed of 50 m/min and low depth of cut. At optimum value of cutting parameters the chips produced was discontinuous which is preferable for turning operation without any difficulties during the operation. The chips produced at optimum cutting parameters were shown in Figure 7(c) which is for sample seven.

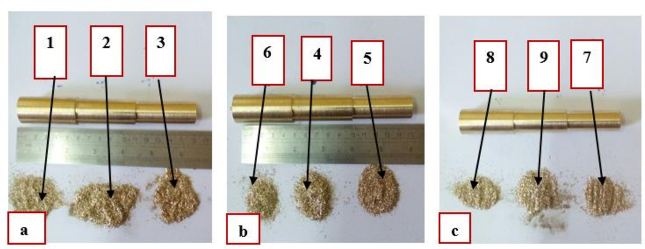


**Figure 7:** Chip morphology (a) for experiment 1, 2 and 3 (b) for experiment 4, 5 and 6 (c) for experiment 7, 8 and 9.

## 4. Conclusions

The present research consists of experimental investigation on the dry turning process of free cutting brass with different turning parameters like cutting speed, feed and depth of cut to study their effects on the surface roughness of finished product.

1. Optimization of the surface roughness was done using Taguchi method. In turning of free cutting brass for minimum surface roughness, use of higher cutting speed (50 m/min), lower feed (0.3 mm/rev) and higher depth of cut (3.5 mm) were selected. A3B1C3 are optimized to get low surface

roughness which is high surface finish of machined part.

2. The minimum average surface roughness during this study was 1.63 µm. The results of the ANOVA indicate that the percentage contribution of cutting speed, feed and the depth of cut on the surface roughness were 88.74%, 1.13% and 6.46%, respectively.
3. From the percentage contribution of the ANOVA, the cutting speed has highest significant effect on the surface roughness and feed has least significant. The possibility of dry machining for free cutting brass which save cost of machining and also contributes to green manufacturing was also a finding of this work.
4. This work has proved implementation of micro-manufacturing using conventional machining process due to the fact that the surface finish obtained was in microns.

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