Machinability Studies On Copper Based Alloy- Optimization Of Control Parameters In Turning Operation Using Taguchi Method

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Abstract

Machinability is defined as the ease with which a material can be machined under specific conditions. It is an important parameter which establishes the power required to machine a component, obtain fairly good surface finish. In order to predict the machinability of materials, two main factors namely, the condition of work materials and physical properties of work materials are generally considered. They include mainly structure of the material, chemical composition, heat treatment employed, hardness and tensile strength of the material etc to name a few. Cutting conditions and cutting parameters also play a very significant role in the assessment of machinability. A thorough knowledge of the above is essential to determine the machinability.

In this study, an attempt has been made to arrive at the optimum cutting parameters for turning operations. Copper alloy (Aluminium bronze alloy with 88% Copper, 10% Aluminium, 1.5% Iron, and 0.5% Silicon) has been selected for the study. For this purpose, Spindle speed, feed rate and coolant usage has been taken into account to assess the machinability. Taguchi method, a powerful tool to design optimization for quality, was used to arrive at the optimal cutting parameters for turning operations. An orthogonal array, the signal to noise ratio (S/N), and analysis of variance (ANOVA) was employed to investigate the cutting characteristics of copper alloy using coated carbide tool insert. From the above study, the cutting parameters for turning operation have been optimized. Furthermore, the effect and contribution of main cutting parameters namely, Spindle speed, feed rate and usage of coolant on surface finish and dimensional accuracy of the component has been studied. The results of the investigation indicate improvement in surface finish with good dimensional accuracy. The machining time has reduced considerably thereby increasing the productivity.

***Keywords**: Turning process, Surface roughness, Dimensional accuracy, Taguchi method, ANOVA.*

1. Introduction

Copper alloy castings were among the earliest metallic objects made by man from molten metal, since copper was used as native metal. Its melting point and that of its alloys with gold, tin, and zinc are low enough to be within the range of temperatures which can be reached by wood and charcoal fires.

Copper is one of the Man’s oldest and most useful metal. It has been used since the beginning of the history for utensils, tools, and weapons, within the range of copper – based alloys materials are found to meet almost every conceivable requirement in respect of mechanical properties, high electrical and thermal conductivities, non – magnetic qualities and excellent resistance to both corrosion and wear. Copper being an excellent conductor of heat is used in cooking utensils, heating elements in furnace system.

Copper makes a number of alloys of commercial use with one or more of the elements such as Sn, Zn, Be, Cr, Mn, Pb, Al, Ni, Si, etc. Some of the commercial used copper based alloys are Tin bronze, Leaded Tin bronze, Aluminium bronze, leaded nickel bronze, Red brass, Yellow brass, Silicon brass, Gunmetal.

Copper alloys posses some distinct advantages such as appearance, electrical and thermal conductivities, resistance to corrosion, bearing qualities. Applications are electrodes of resistance welding machines, turbine runners, water meter housings, bearings, gears and corrosion resistance pumps, marine equipments, plumbing goods, valves and fittings and steam pipe fittings.

Machining is a material removal process where excess material is removed from the raw work piece. In order to produce any product with desired quality by machining, proper selection of process parameters is essential. This can be accomplished by Taguchi approach. The aim of the present work is to investigate the effects of process parameters on surface finish and dimensional accuracy to obtain the optimal setting of these process parameters. The Analysis Of Variance (ANOVA) is used to analyze the influence of cutting parameters during machining operation (turning operation).

2. Scope for Present work

Cutting parameters, surface roughness and dimensional accuracy of copper alloy has to be studied in this project. In machining operation, the quality of surface finish and dimension accuracy are an important requirements for many turned work pieces. This work presents a study of application of Taguchi method in the optimization of cutting parameter for surface roughness and accuracy in turning which allow it to be examined in more detail.

This study is aimed at finding out the answer for the following:

- The roles of optimized cutting parameters (spindle speed, feed rate and coolant usage) of the turning process for controlling the required surface roughness and dimension.
- Taguchi process approach to select and determine the optimum cutting conditions for turning process.
- Surface roughness studies in the evaluation of machining accuracy.

The following describes the methodology/procedure followed in the present investigation:

- Selection of copper alloys from all the groups (HCC–High conductivity copper, Al Br – Aluminum bronze, LB2–Leaded bronze. i.e., Selection of the parts which are in routine production)
- Prepare the material for turning operation.
- Selection of suitable parameters to be evaluated.
- Determine number of levels for the design parameters and possible interactions between them.
- Selection of appropriate orthogonal array and assigning of parameters to the array.
- Conducting experiment based on arrangement of orthogonal array.
- Analyses of the experimental results based on S/N and ANOVA.
- Verification of optimal parameters through confirmation experiment.

3. Materials and methodology

The work piece material selected for investigation is the copper alloy (Aluminium-bronze) rod with the composition given in the table 1. The size of the work piece used for experimentation is a circular rod with the dimension 32mm inner diameter and 40.6mm length.

Table 1: Chemical composition of the work piece material

Main element	Weight (%)	Impurities	Weight (%)
Copper	88 min	Tin	0.2 max
Aluminium	7.5 – 10.5	Lead	0.2 max
Iron	1.50 max	Zinc	0.2 max
Nickel	0.30 max	Others	0.5 max
Silicon	0.5 – 2.0		

The cutting tests were made on medium duty CNC lathe. A carbide insert with a general specification of TPUN 160308 EN H20TI coated with Tic and TiCN was used as the cutting tool insert. The experiments were conducted as per the orthogonal array and the surface roughness for various combinations of parameters was measured using surface roughness tester and the dimensions were measured using digital vernier calipers. The measurement accuracy meets the ISO standards. The experimentations were conducted for the inner diameter finishing operation keeping the depth of cut as a constant and varying the spindle speed, feed rate and the amount of cutting fluid (both dry and wet turning).

The average surface roughness (Ra) of machined work pieces was measured using a pocket surf stylus type instrument and the dimension of the finished component is measured using digital vernier caliper.

Figure 1: CNC machine

Figure 2: Work piece material

Table 2: Turning process parameters

Symbol	Parameters	Level 1	Level 2	Level 3
A	Spindle speed (rpm)	2200	2600	3000
B	Feed rate (mm/rev)	0.15	0.20	0.25
C	Coolant usage (Lpm)	0	2.5	5

Based on the selected factors and factor levels, a design matrix was constructed (Table 3) in accordance with the standard L_9 Taguchi orthogonal array (OA). The three levels of each factor were denoted by 1, 2 and 3.

Figure 3: Equipment for surface roughness measurement

Table 3: Taguchi's L_9 Orthogonal Array

Sl. no.	Spindle speed (rpm)	Feed rate (mm/rev)	Coolant usage (Lpm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4. Results and discussion

4.1 Surface roughness optimization

After raw data were collected S/N response ratios are calculated. The calculation of mean S/N ratios was based on the following procedure. For example, the mean effect for level one of spindle speed was computed using data from experimental numbers 1-3 of Table 4. The mean effect for level two of spindle speed was computed using experimental numbers 4-6 of Table 4. The mean effect for level three of spindle speed was computed using experimental numbers 7-9 of Table 4. Similarly, the mean effect of feed rate and coolant usage was computed for all other cutting levels. The mean S/N ratios for each level of cutting parameters are summarized and referred to in the S/N ratios response table for surface roughness (R_a) as shown in Table 5.

Table 4: Computation of S/N ratio for surface roughness

Trials	Factor 1	Factor 2	Factor 3	Avg. Ra	S/N
1	2200	0.15	0	55	-34.82
2	2200	0.20	2.5	48	-33.63
3	2200	0.25	5	70	-37.00
4	2600	0.15	2.5	66	-36.39
5	2600	0.20	5	46	-33.25
6	2600	0.25	0	95	-39.55
7	3000	0.15	5	32	-30.14
8	3000	0.20	0	61	-35.71
9	3000	0.25	2.5	88	-38.92

Factor 1: Spindle speed in rpm; Factor 2: Feed rate in mm/rev; Factor 3: Usage of coolant in Lpm; Avg. Ra: Average values of Surface roughness in µin.

Since the surface roughness should be less, select smaller- the -better (minimize) ratio,

$$\text{SMALLER - THE - BETTER} \quad S/N_s = -10\,\text{Log}_{10}\left[\frac{1}{n}\sum_{i=1}^{n} y^2\right]$$

Where ‘n’ is the number of observations per trial and ‘y’ is the observed data (output characteristic) in a run/row.

Table 5: Mean S/N ratio at individual parameter level for surface roughness

Symbol	A	B	C
Process parameters	Spindle speed	Feed rate	Coolant usage
Level 1	-35.15	-33.78	-36.69
Level 2	-36.39	-34.19	-36.31
Level 3	-34.92	-38.49	-33.46
Max-Min	1.47	4.3	3.23
Rank	3	1	2
Total mean S/N = -35.49			

4.1.1 Determination of the Optimum Factor-Level Combination for surface roughness

Figure 4 shows the graphs which contains curves representing the S/N ratio. The values of the graphs are from Table 5. The objective of using the S/N ratio as a performance measurement is to develop products and processes insensitive to noise factors. The S/N ratio indicates the degree of the predictable performance of a product or process in the presence of noise factors. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a higher value determines the optimum level of each factor. Consider, in figure 4, level three for spindle speed (A_3=3000rpm) has the highest S/N ratio value, which indicated that the machining performance at such level produced minimum variation of the surface roughness. Similarly, the level one of feed rate (B_1=0.15mm/rev) and the level three of coolant usage (C_3=5Lpm) have also indicated the optimum situation in terms of S/N ratio. Therefore, the optimum cutting condition will be spindle speed = 3000rpm (A_3), feed rate = 0.15mm/rev (B_1) and coolant usage = 5Lpm (C_3) and was determined to be able to produce the optimum surface roughness within the specific cutting condition range.

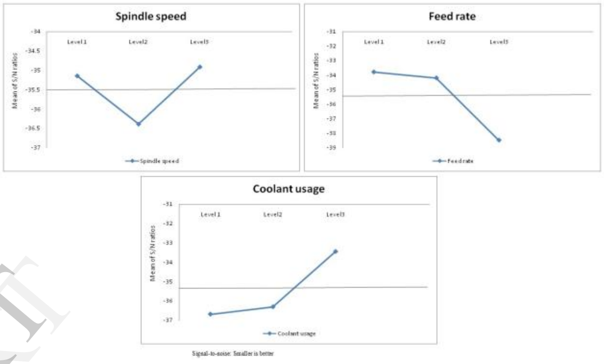


Figure 4: Response graph for surface roughness

Effect of Turning Parameters on Surface finish for S/N Ratio

Spindle speed: The effect of spindle speed on the surface finish values is shown above for S/N ratio. Its effect is decreasing with increase in spindle speed up to 2600 rpm, beyond that it increases and reaches the peak at 3000 rpm. So the optimum spindle speed is level 3 i.e., 3000 rpm.

Feed rate: The effect of feed rate on the surface finish values is shown for S/N ratio. Its effect is decreasing with increase in feed rate. So the optimum feed rate is level 1 i.e., 0.15 mm/rev.

Coolant usage: The effect of usage of cutting fluid on the surface finish values is shown above for S/N ratio. Its effect is increasing with increase in amount of cutting fluids. So the optimum usage of cutting fluid is level 3 i.e., 5 Lpm.

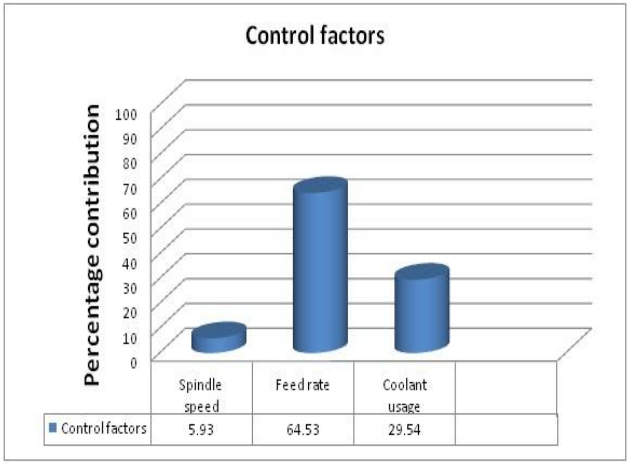
4.1.2 Analysis of variance (ANOVA)

The purpose of ANOVA is to investigate which of the process parameters significantly affect the performance characteristics. This is accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean of the S/N ratio, into contributions by each of the process parameters and the error. To find out contributing ratio of the control factors, Pareto ANOVA is used.

Table 6: Pareto ANOVA for surface roughness

Factors	A	B	C	Total
Sum at factor level	-35.15	-33.78	-36.69	-105.62
	-36.39	-34.19	-36.31	-106.89
	-34.92	-38.49	-33.46	-106.87
Sum of square of difference	3.7514	40.8422	18.6998	63.2934
Degree of freedom	2	2	2	6
Contribution ratio	5.93%	64.53%	29.54%	100%
Optimum level	A_3	B_1	C_3	

Figure 5: Individual control factor contribution to peak surface finish



4.2 Dimensional accuracy optimization

After raw data were collected (Table 7), S/N response ratios (Table 7) are calculated based on Table 7. The calculation of S/N ratios was based on the following procedure. The mean effect for level one of spindle speed was computed using data from experimental numbers 1-3 of Table 7. The mean effect for level two of spindle speed was computed using experimental numbers 4-6 of Table 7. The mean effect for level three of spindle speed was computed using experimental numbers 7-9 of Table 7. Similarly, the mean effect of feed rate and coolant usage was computed for all other cutting levels. The S/N ratios for each level of cutting parameters are summarized and referred to in the S/N ratios response table for dimensional accuracy as shown in Table 8.

Table 7: Computation of S/N ratio for Dimensional Accuracy

Trials	Factor 1	Factor 2	Factor 3	Avg. DA	S/N
1	2200	0.15	0	33.33	89.54
2	2200	0.20	2.5	33.33	89.54
3	2200	0.25	5	33.32	71.48
4	2600	0.15	2.5	33.32	71.48
5	2600	0.20	5	33.32	71.48
6	2600	0.25	0	33.34	69.54
7	3000	0.15	5	33.33	89.54
8	3000	0.20	0	33.33	89.54
9	3000	0.25	2.5	33.34	69.54

Factor 1: Spindle speed in rpm; Factor 2: Feed rate in mm/rev; Factor 3: Usage of coolant in Lpm; Avg. DA: Average values of Dimensional accuracy in mm.

Since the dimensional accuracy should be close to the target value, select nominal the best (ideal) ratio,

$$\text{NOMINAL THE BEST} \quad S/N_T = 10\log_{10}[\bar{y}^2/s_y^2]$$

Where '$\bar{y}$' is the observed mean data (output characteristic) and s_y^2 is the variance where it is given by $1/n \sum_{i=1}^{n} (y_i - \bar{y})^2$.

Table 8: Mean S/N ratio at individual parameter level for Dimensional accuracy

Symbol	A	B	C
Process parameters	Spindle speed	Feed rate	Coolant usage
Level 1	83.52	83.52	82.87
Level 2	70.83	83.52	76.85
Level 3	82.87	70.18	77.5
Max-Min	12.69	13.33	6.02
Rank	2	1	3
Total Mean S/N = 79.075			

4.2.1 Determination of the Optimum Factor-Level Combination for Dimensional accuracy

Figure 6 shows graphs which contain curves representing the S/N ratio. The values of the graphs are from Table 8. Process parameter settings with the highest S/N ratio always yield the optimum quality with minimum variance. Consequently, the level that has a higher value determines the optimum level of each factor. For example, in figure 6, level one for spindle speed (A_1=2200rpm) has the highest S/N ratio value, which indicated that the machining performance at such level produced minimum variation of the dimensional accuracy. Similarly, the level one of feed rate (B_1=0.15mm/rev) and the level one of coolant usage (C_3=0) have also indicated the optimum situation in terms of S/N ratio. Therefore, the optimum cutting condition will be spindle speed = 2200rpm (A_1), feed rate = 0.15mm/rev (B_1) and coolant usage = 0 (C_1) and was determined to be able to produce the exact dimension within the specific cutting condition range.

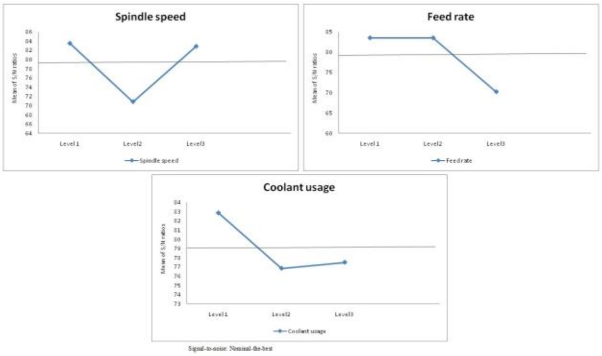


Figure 6: Response graph for dimensional accuracy

Effect of Turning Parameters on Dimensional Accuracy for S/N Ratio

Spindle speed: The effect of spindle speed on the dimensional accuracy values is shown above for S/N ratio. It can be seen from the response plot that its effect is peak at 2200 rpm and then decreasing with increase in spindle speed up to 2600 rpm, beyond that it increases again. So the optimum spindle speed is level 1 i.e., 2200 rpm.

Feed rate: The effect of feed rate on the dimensional accuracy values is shown for S/N ratio. It can be seen that its effect is constant with increase in feed rate up to 0.2 mm/rev and then it decreases with further increase in feed rate. So the optimum feed rate is level 1 i.e., 0.15 mm/rev.

Coolant usage: The effect of usage of cutting fluid on the dimensional accuracy values is shown for S/N ratio. Its effect is peak without use of cutting fluid and then decreases gradually with increase in amount of cutting fluids up to intermediate use. Then again effect increases with further use of cutting fluid. So the optimum usage of cutting fluid is level 1 i.e., without cutting fluid.

4.2.2 Analysis of variance (ANOVA)

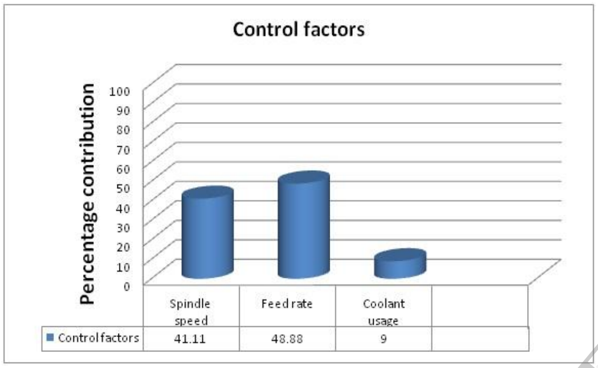
The S/N ratios of the parameters are used for ANOVA, applying the Pareto ANOVA to find the individual contribution of the control factors. In addition, percentage graph is plotted, making it easy to recognize the individual parameter contribution to achieve the exact dimension.

Table 6: Pareto ANOVA for dimensional accuracy

Factors	A	B	C	Total
Sum at factor level	83.52	83.52	82.87	249.91
	70.83	83.52	76.85	231.2
	82.87	70.19	77.5	230.56
Sum of square of difference	306.35	355.56	65.53	727.44
Degree of	2	2	2	6

freedom				
Contribution ratio	41.11%	48.88%	9%	100%
Optimum level	A_1	B_1	C_1	

Figure 7: Individual control factor contribution to exact dimensional accuracy



4.3 Predicting Optimum Performance

Once the optimal level of the design parameters has been selected, the final step is to predict and verify the improvements of the quality characteristic using the optimal level of design parameters. The estimated S/N ratio ή using the optimal level of the design parameters can be calculated as

Prediction of S/N:

$$ή = \eta_m + \sum_{i=1}^{0}(\eta_{im} - \eta_m)$$

Where, η_m is the total mean S/N ratio, η_{im} is the mean S/N ratio at the optimal level, and 0 is the number of the main design parameters that affect the quality characteristic.

$$ή = \eta_m + (\eta_{A3} - \eta_m) + (\eta_{B1} - \eta_m) + (\eta_{C3} - \eta_m)$$

$$ή = -35.46 + (-34.89-(-35.46)) + (-33.76-(-35.46)) + (-33.41-(-35.46))$$

Predicted S/N = -31.14 dB.

Therefore predicted Surface roughness=36µin.

With this prediction, one could conclude that the machine creates the best surface roughness (R_a = 36 µin) within the range of specified cutting conditions. A confirmation of the experimental design is necessary in order to verify the optimum cutting conditions.

4.4 Establishing the design by using a confirmation experiment

The confirmation experiment is very important in parameter design. The purpose of the confirmation experiment in this study was to validate the optimum cutting conditions ($A_3B_1C_3$) that were suggested by the experiment that corresponded with the predicted value. In this study, the confirmation runs with the optimum cutting condition $A_3B_1C_3$ resulted in response mean value of 28 µin and the S/N ratio calculated was -28.94 dB. Since the mean and S/N ratio of the confirmation run was all within the range, the optimum cutting condition has been verified. Therefore, the optimum surface roughness (R_a = 28 µin) can be obtained under the above mentioned cutting condition in the CNC machine. With the same condition, required dimension of 33.33mm can also be achieved.

Table 7: Results of the confirmation experiment for surface roughness

	Optimal Cutting Parameters	
	Prediction	**Experiment**
Level	$A_3B_1C_3$	$A_3B_1C_3$
Surface roughness (µin)	36	28
S/N ratio (dB)	-31.14	-28.94

Table 8: Improvement in the results

	Nominal	Optimum	% Improvement
Level	$A_1B_1C_1$	$A_3B_1C_3$	
Surface roughness (µin)	55	28	49.09
Dimensional accuracy	33.33	33.33	Target

(mm)			
Cycle time (s)	15	9	40

Thus from the table 8, it can be seen that there is considerable improvement in the surface finish of the component. The dimensional accuracy of the component is also maintained at the required target value (33.33mm). There is also improvement in the machining time. Thus the optimal parameters established using Taguchi approach helps in improving the productivity of the component with good customer satisfaction.

5. Conclusion

- Taguchi's robust orthogonal array design method is suitable to analyze the surface roughness of Aluminum-bronze alloy in turning operation.
- It is found that the parameter design of Taguchi method provides a simple, systematic and efficient methodology for the optimization of process parameters.
- Optimal parameter values i.e., Spindle speed of 3000 rpm, feed rate of 0.15 mm/rev and coolant usage of 5 Lpm were arrived at using Taguchi approach.
- ANOVA results for surface roughness shows that feed rate, coolant usage and spindle speed affects the surface roughness by 64.53%, 29.54% and 5.93% respectively. Spindle speed seems to have less significant contribution to surface roughness value.
- Also ANOVA results shows that spindle speed, feed rate and coolant usage affects dimensional accuracy by 41.11%, 48.88% and 9% respectively. Coolant usage seems to have less significant contribution to dimensional accuracy.
- A confirmation experiment was also conducted and verified the effectiveness of the Taguchi optimization method.
- The machining time was reduced considerably using Taguchi's optimal parameter settings thus improving the productivity.

6. References

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