# TAGUCHI BASED OPTIMIZATION OF CUTTING PARAMETERS ALUMINIUM ALLOY 6351 USING CNC

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**Abstract** - *Aluminum and its alloys are extensively used in wide variety of applications including domestic utensils, electronic circuits, structural applications, automobile industries etc. Aluminum alloys tend to lose their strength when they are exposed to temperatures of about 200-250°C. However strength of Aluminum alloys increases at freezing temperatures. They have high strength to weight ratio. Hence, the aluminum alloy6351 is used in manufacturing of tubes and pipes. Machining operation on Al 6351 are performed and cutting parameters i.e. feed rate, depth of cut and spindle speed have been optimized for Metal removal rate (MRR) and Surface Roughness by using Taguchi technique. CNC Lathe machine is used for turning operation in order to determine Metal Removal Rate (MRR) and Tele Surf tester is used to measure the surface roughness. It is observed that feed rate is the most influencing factor for metal removal rate (MRR) followed by depth of cut and speed. Whereas in case of surface roughness, feed is observed as most prompting factor with respect to the quality aspects of surface roughness followed by speed and depth of cut.*

***Key Words***: **Al 6351, CNC Lathe, TalySurf Tester, MRR, Surface Roughness, Machining time, Mini tab-17, ANOVA, S/N Ratio**

## 1. INTRODUCTION

The turning is the most widely used cutting process among all the processes. The increasing importance of turning operations is gaining new heights in the present industrial age, in which parts are made in round shape by a single point cutting tool on CNC lathe. Surface roughness is used to check the quality of a product, is one of the major quality characteristics of a turning product. In order to get better surface finish, the appropriate selection of cutting parameters is important before investigation. Material removal rate is also main characteristic in turning operation for high rate of production and high material removal rate is constantly required. The present exertion examines the effect of cutting parameters in turning aluminum alloy 6351. Aluminum alloy 6351 is a moderate strength alloy generally referred to as an architectural alloy. It is generally used in manufacturing complicated parts. It has a better surface finish, high corrosion fighting, good weld capability and it can be easily anodized. Aluminum alloy 6351 is usually used in architectural applications, extrusions, window frame works, entryways, shop fittings, watering system tubing. The experiments are considered utilizing Taguchi's technique with the three process parameters i.e. cutting speed, feed rate, and depth of cut at three levels. The outcomes are optimize according to parameter setting to gain minimum surface roughness and maximum material removal rate.

## 2. STEPS OF METHODOLOGY ADAPTED

1. Initial study to determine the various controlled and uncontrolled parameters
2. Selection of work materials, tool materials and their combination based on literature
3. Selection of process parameters, responses and their levels
4. Selection of experimental layout using Taguchi method
5. Conduction of experiment with different work tool material combination to study and measure various performance characteristics like surface roughness, material removal rate and machining accuracy
6. Measurement of response using standard equipments
7. Parameter optimization using Taguchi method and analysis of data using statistical tools.
8. Creating mathematical models by multiple regression analysis using Minitab-17 Software
9. Comparison of results of theoretical analysis with experimental results by conducting confirmation experiments.

## 3. WORK MATERIAL

Aluminum alloy 6351 is selected because of its low weight to strength ratio, better surface finish and its large number of applications in different areas such as extrusions, window outlines, entryways, shop fittings, watering system tubing etc.

**Fig -1**: Aluminum alloy 6351

**Table -1:** Chemical Composition of Al 6351

| Elements | Weights |
|---|---|
| Al | Remainder |
| Si | 0.83 |
| Cu | 0.037 |
| Mn | 0.49 |
| Mg | 0.67 |
| Cr | 0.01 |
| Zn | 0.02 |
| Fe | 0.2 |

## 4. DEGREE OF FREEDOM

Number of parameters = 3

Number of levels for each parameters = 3

Total degree of freedom (DOF) for 3 parameters = 3x (3-1) = 6

Minimum number of experiment = Total degree of freedom for parameters + 1

Minimum number of experiments = 6+1

Minimum number of experiments = 7

For the above process parameters and their levels, the minimum numbers of experiments to be conducted are 7. So that is why nearby$L_9$ orthogonal array is taken.

## 5. PROCESS PARAMETERS AND THEIR LEVELS

The cutting parameters and their levels are considered for the studies are set in the given table.

**Table -2:** Machining parameters and their levels

| Parameters | Levels | | |
|---|---|---|---|
| | level 1 | level 2 | level 3 |
| Speed (m/min) | 500 | 800 | 1100 |
| Feed (mm/rev) | 0.10 | 0.20 | 0.30 |
| DOC (mm) | 0.20 | 0.25 | 0.30 |

## 6. ORTHOGONAL ARRAY EXPERIMENT

**Table -3:** Experimental layout of L9 orthogonal array

| Experiment No | Machining parameters levels | | |
|---|---|---|---|
| | Speed | Feed | DOC |
| 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 |

## 7. PROCESS

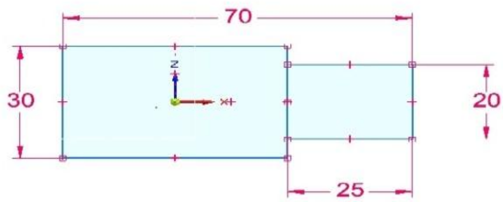


**Fig -2:** Dimensions of work piece after machining

1. On nine work pieces of Al 6351 the experiment is carried out.
2. All the work pieces are turned on CNC machine. The dimensions of each work piece is [Total length of work piece (L) =70 mm, Initial Diameter (D) =30 mm, Turned length of work piece (l) =25 mm & final diameter (d) =20 mm]
3. For each work piece time is measured with the help of stop watch.
4. By using the initial & final diameters and machining time, material removal rate is calculated by using the formula.

$$\text{MRR} = \frac{\frac{\pi}{4}}{\textit{Machining time in min}}(D^2 - d^2) \times L$$

Where, D =Work piece diameter before turning in mm, d = Work piece diameter after turning in mm, L =Work piece length in mm.

5. Surface roughness of all work pieces is measured by using surface roughness tester.
6. The analysis is carried out by using Taguchi method with the help of Minitab-17 software

## 8. ANALYSIS OF S/N RATIOS

The S/N ratio is the tool which measures the performance of particular process parameters with respect to the surface roughness and material removal rate. The S/N ratio for surface roughness and MRR has been calculated using smaller the better and larger the better characteristics.

$$\frac{S}{N_{Smaller}} = -10\ log_{10}[\frac{1}{n}\sum_{i=1}^{n} Y_i^2]$$
$$\frac{S}{N_{Larger}} = -10\ log_{10}[\frac{1}{n}\sum_{i=1}^{n} \frac{1}{Y_i^2}]$$

Table [4] and [5] shows the responses for S/N ratios of smaller the better and larger the better.

**Table -4:** Response table for S/N ratios, smaller is better

| Level | Speed | Feed | DOC |
|---|---|---|---|
| 1 | -5.638 | 2.762 | -6.854 |
| 2 | -3.301 | -4.01 | -4.983 |
| 3 | -7.895 | -15.587 | -4.998 |
| Delta | 4.594 | 18.349 | 1.87 |
| Rank | 2 | 1 | 3 |

**Table -5:** Response table for S/N ratios, larger is better

| Level | Speed | Feed | DOC |
|---|---|---|---|
| 1 | 63.58 | 62.16 | 65.61 |
| 2 | 65.81 | 66.34 | 66.69 |
| 3 | 70.17 | 71.05 | 67.25 |
| Delta | 6.59 | 8.89 | 1.64 |
| Rank | 2 | 1 | 3 |

Regardless of the category of the performance characteristics, a greater value of S/N ratio is always considered for better performance. From the table [4] it is obvious that feed has the highest effect on surface roughness followed by speed and depth of cut. Table [5] shows that feed rate is the parameter which mostly affect the value of MRR and is followed by spindle speed and depth of cut.

## 9. MAIN EFFECT PLOTS ANALYSIS FOR SURFACE ROUGHNESS & MRR

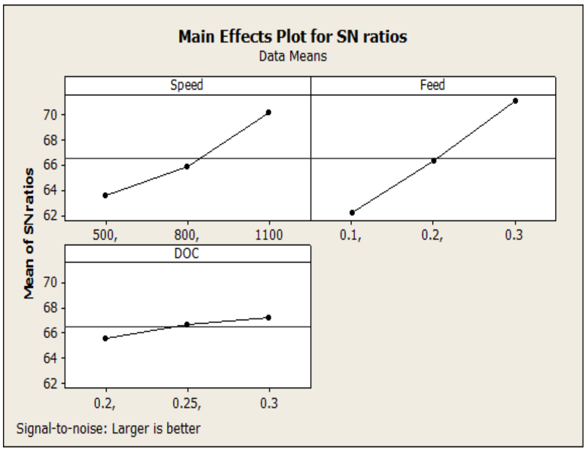


**Fig -3:** Main effect plots S/N ratios for surface roughness

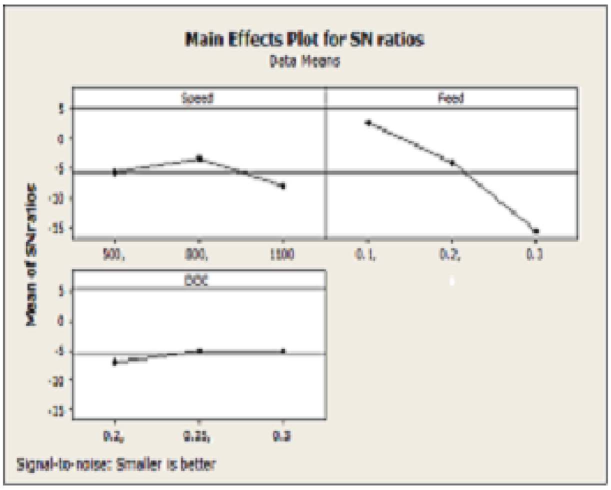


**Fig -4:** Main effect plots S/N ratios for material removal rate

The main effect plot for S/N ratios is indicated in fig [3] this figure demonstrates the variation of individual response with speed, feed rate, and depth of cut parameters respectively. The main effects plots are used to emphasis the optimal conditions for surface roughness. As showed by this main effect plot, the optimal conditions for least surface roughness are speed at level 2 (800 rpm), feed at level 1 (0.1 mm/sec) and depth of cut at level 3 (0.3mm).

The main influence plot for S/N ratios is specified in fig [4] this figure determines the difference of individual response with speed, feed rate, and depth of cut factors respectively. The main effects plots are utilized to emphasis the optimal conditions for material removal rate. As shown in this main effect plot, the best conditions for high material removal rate are speed at level 3 (1100 rpm), feed at level 3 (0.30 mm/sec) and depth of cut at level 3 (0.30 mm).

## 10. ANALYSIS OF VARIANCE (ANOVA)

The Analysis of variance (ANOVA) may be used to examine which plan factors and their relations affect the response considerably. The response data was obtained by various experiments for surface roughness and MRR are at 95% confidence level and the results of ANOVA for the response parameters are given in table [06] and [07].

**Table -6:** ANOVA table for S/N ratios of surface Roughness

| Source | DF | Seq SS | Adj SS | Adj MS | F | P |
|---|---|---|---|---|---|---|
| Speed | 2 | 2.302 | 2.302 | 1.151 | 0.81 | 0.552 |
| Feed | 2 | 48.386 | 48.356 | 24.193 | 17.08 | 0.055 |
| DOC | 2 | 0.108 | 0.108 | 0.054 | 0.04 | 0.963 |
| Error | 2 | 2.832 | 2.832 | 1.416 | | |
| Total | 8 | 53.629 | | | | |

**Table -7:** ANOVA table for S/N ratios of material removal rate

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | % C |
|---|---|---|---|---|---|---|---|
| Speed | 2 | 4474648 | 447464 | 2237324 | 103.81 | 0.001 | 0.010 |
| Feed | 2 | 7819922 | 781992 | 3909961 | 181.42 | 0.000 | 0.005 |
| DOC | 2 | 141507 | 141507 | 70754 | 3.28 | 0.023 | 0.233 |
| Error | 2 | 43104 | 43104 | 21552 | | | |
| Total | 8 | 12479181 | | | | | |

It is obvious from table [6] that feed (P=0.055) is the most effective parameter on the surface roughness followed by speed (P=0.552) and depth of cut (0.963) being recorded as the least effective parameter.

It is obvious from table [7] that the feed (P=0.005) have greatest impact on material removal rate, further speed (P=0.010) makes the second largest contribution and depth of cut (P=0.233) shows the least contribution towards material removal rate.

## 11. ANALYSIS OF EXPERIMENTAL RESULTS

The result is obtained from nine machining experiments for Al6351, designed by Taguchi method. In this study every one of the designs, plots and investigation have been finished applying Minitab-17software.

**Table -8:** Analysis of experimental results

| Trial No | Machining parameters | | | Machining Time (sec) | Surface Roughness (μm) | MRR ($mm^3$/min) | S/N ratios for Ra | S/N ratios for MRR |
|---|---|---|---|---|---|---|---|---|
| | Speed (rpm) | Feed (mm/rev) | DOC (mm) | | | | | |
| 1 | 500 | 0.1 | 0.2 | 13 min 50 sec | 0.713333 | 727.22 | 2.9342 | 57.2333 |
| 2 | 500 | 0.2 | 0.25 | 6 min 17 sec | 1.360000 | 1591.16 | -2.6708 | 64.0343 |
| 3 | 500 | 0.3 | 0.03 | 3 min 30 sec | 7.226667 | 2974.99 | -17.178 | 69.4697 |
| 4 | 800 | 0.1 | 0.25 | 7 min 58 sec | 0.666667 | 1295.18 | 3.5218 | 62.2466 |
| 5 | 800 | 0.2 | 0.3 | 5 min 35 sec | 0.960000 | 1835.04 | 0.3546 | 65.2729 |
| 6 | 800 | 0.3 | 0.2 | 3 min 14 sec | 4.886667 | 3126.58 | -13.780 | 69.9014 |
| 7 | 1100 | 0.1 | 0.3 | 4 min 38 sec | 0.810000 | 2241.43 | 1.8308 | 67.0105 |
| 8 | 1100 | 0.2 | 0.2 | 3 min 21 sec | 3.060000 | 3058.40 | -9.7144 | 69.7099 |
| 9 | 1100 | 0.3 | 0.25 | 2 min 01 sec | 6.166667 | 4884.31 | -15.801 | 73.7761 |

## 12. REGRESSION ANALYSIS FOR SURFACE ROUGHNESS & MRR

The regression equation is

Ra = -2.60747 + 0.000409(Speed) +26.81667(Feed) + 1.122223 (DOC)

MRR = -1590.49 + 2.717094(Speed) + 11203(Feed) +464.2(DOC)

**Table -9:** Predicted value for surface roughness

| Serial No. | (A3) Speed (m/min) | (B1) Feed (mm/rev) | (C3) Depth of cut (mm) | Ra Predicted ( µm) |
|---|---|---|---|---|
| 1 | 800 | 0.10 | 0.3 | 0.73806 |

**Table -10:** Predicted value for Material removal rate

| Serial No | (A3) Speed m/min | (B3) Feed (mm/rev) | (C1) Depth of cut (mm) | MRR Predicted ($mm^3$/min) |
|---|---|---|---|---|
| 1 | 800 | 0.1 | 0.3 | 4898.603 |

## 13. CONFIRMATION EXPERIMENT FOR SURFACE ROUGHNESS & MRR

The results after experimenting in three trials are shown in table [11] and table [12]. The mean Ra value = 0.7477 µm and the mean MRR value=4892.25 $mm^3$/min.

**Table -11:** Results of confirmation experiment for Ra

| Factor | Level | Value | Trial No | Ra in µm |
|---|---|---|---|---|
| Speed | A3 | 800 rpm | 1 | 0.7352 |
| Feed | B1 | 0.10 mm/rev | 2 | 0.8001 |
| DOC | C3 | 0.3 mm | 3 | 0.7038 |
| | | | | Mean = 0.7477 |

**Table -12:** Results of confirmation experiment for MRR

| Factor | Level | Value | Trial No | MRR in $mm^3/min$ |
|---|---|---|---|---|
| Speed | A3 | 800 rpm | 1 | 4860.32 |
| Feed | B3 | 0.10 mm/rev | 2 | 4913.65 |
| DOC | C3 | 0.3 mm | 3 | 4902.80 |
| | | | | Mean = 4892.25 |

When factor values are substituted in the mathematical model regression equation, it has given surface roughness (Ra) value = 0.73806µm and material removal rate (MRR) value = 4898.603 $mm^3/min$. The difference in surface roughness (Ra) and material removal rate (MRR) values observed is only 0.009µm and 6.35 $mm^3/min$ which is negligibly small and hence the model is validated.0.73806µm is the value of surface roughness (Ra) and4898.603 $mm^3/min$ is the value of material removal rate (MRR). Table [11] and table [12] showing optimal factors level A3B1C3 and A3B3C3 is more or less satisfied.

## 14. CONCLUSIONS AND FUTURE SCOPE

This presented work is an experimental approach to study the effect of input parameters i.e. spindle speed, feed rate and depth of cut on the surface roughness and material removal rate, the following conclusions can be made after performing experiments.

From response table rankings, it can be concluded that.

1. The feed rate has been found to be the most influencing factor on the quality attributes of surface roughness followed by speed and depth of cut.
2. Optimal parameters setting for surface roughness in turning of aluminum alloy 6351 are A2, B1and C3.
3. The feed rate has been found to have most extreme impact on the material removal rate than followed by depth of cut and speed.
4. Optimal parameters setting for material removal rate in machining of aluminum alloy 6351 are A3, C3 and B

## 15. FUTURE SCOPE

In this present work only three parameters i.e. speed, feed and doc have been optimized in accordance with their effects. View of future scope, other parameters i.e. nose radius, cutting tool angles etc. can be optimized for MRR and surface roughness. Likewise, the other output parameters i.e. power consumption, tool life, tool wear etc. can be added.

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