OPTIMIZATION OF MACHINING PARAMETERS IN TURNING OF AL6063T6 THROUGH DESIGN OF EXPERIMENTS

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ABSTRACT

An attempt has been made in the paper to carry out an experimental investigation on Aluminium alloys by using Taguchi technique to find and correlate the technological factors to the economics of machining process. Improvement of one parameter leads to degradation of other parameters and optimization of multiple parameters is much more complicated. In this paper, the effect of variation in the machining parameters like speed, feed, depth of cut and nose radius on Al6063T6 has been studied and presented. Firstly, the optimum arrangement of the four turning parameters has been determined using the L9 configuration of the Taguchi technique with a variation in three levels. After the machining is completed, the values are documented and compared using statistical analysis software.

Key words: Machinability; Taguchi technique; cutting parameters; machining environment.


1. INTRODUCTION

Traditionally, the machinability of materials involves tool life, cutting forces, productivity or chip formation, with less attention paid to particle emission. In this work, the authors address the machinability of aluminium alloys from several points of view, including cutting forces, chip formation and segmentation and metallic particle emission. The main properties which make aluminium a valuable material are lightweight, strength, recyclability, corrosion resistance, durability, ductility, formability and conductivity. Due to this unique combination of properties, the variety of applications of aluminium continues to increase.
The analysis of the data during manufacturing by using suitable statistical designs is of high importance for precise evaluation to be obtained from the process. Design and methods such as factorial design, response surface methodology and Taguchi methods are now widely in use in place of one-factor-at-a-time experimental approach which is time consuming and exorbitant in cost. Lalwani et al., [1] studied the effect of cutting parameters in turning on cutting forces and surface roughness. Dickinson, Grieve et al., and Fischer and Elrod developed a turning model in which tool nose radius and feed rate are taken into account but cutting speed is ignored. Thomas et al., used built up edge formation occurring during dry turning mild carbon steel and a full factorial design, taking into account the three-level interactions between the independent variables. Yang and Tarng [3] have conducted study on optimal cutting parameters using Taguchi method in turning. Nian et al. [7] investigated the optimization of CNC turning operations by Taguchi method with multiple performance characteristics. Lin et al., developed an objective network model to estimate the surface roughness and cutting forces. Wang et al.,[9] investigated the effect of tool nose vibration on surface roughness during turning theoretically and experimentally.

Surface finish is one of the most important quality characteristics in manufacturing industries which influences the performance of mechanical parts as well as production cost. In order to improve the product quality and efficiency in machining, recently, there has been intensive computation focusing on surface roughness at international level. This computation can be observed in turning processes especially in aerospace and automotive industry by increasing the alternative solution for obtaining better surface roughness. A good quality turning surface can lead to improvement in strength properties such as fatigue strength, corrosion resistance and thermal resistance. In addition, the final surface roughness also affects several function attributes of parts like friction, wearing, light reflection, heat transmission, coating and ability of distributing and holding a lubricant. According to Kromanis, A. and Krizbergs, the quality of surface plays a very important role in functionality of produced part. Therefore, it is necessary to develop methods, which can be used for the prediction of the surface roughness according to technological parameters.

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Another way to define MRR is to imagine an “instantaneous” material removal rate as the

![Figure 1](image-url) Basic operations performed on turning equipment. (a) Facing. (b) Straight turning. (c) Taper turning. (d) Grooving and cutoff. (e) Threading. (f) Tracer turning. (g) Drilling. (h) Reaming. (i) Boring

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rate at which the cross-section area of material being removed moves through the work-piece. Since the depth of cut is changing the material removal rate changes continuously during the process. In some cases, this may be important. For example, if cutting forces and the resulting work-piece and tool deflections are of interest. The changing amount of material being removed along the tapered shaft means the cutting force and so the deflections will change during the process.

Let, \( D_i \) = initial diameter of the workpiece, mm,
\( d \) = Depth of cut, mm and
\( f \) = Feed, mm/revolution.

Then, material removed per revolution [15] is the volume of chip whose length is \( \pi D_i \) and whose cross-sectional area is \( d \times f \). That is,

\[
\text{Volume of material removed in one revolution} = \pi D_i \times d \times f \times mm^3
\]

Since the job is making \( N \) r.p.m., the MRR in \( mm^3/min \) is given by

\[
\text{MRR} = \pi D_i \times d \times f \times N \times mm^3/min
\]

The time during which a piece of equipment like machine, lathe, unit, or apparatus without direct participation of an operator, produces a change in the dimensions, shape, or state of a work-piece. The machining time depends on the characteristics of the manufacturing process; on the qualitative features of the raw material, semi-finished product, or stock; on the type of equipment and tool; and on the mechanization and automation of labour.

The machining time can be calculated by using the equations

\[
L = l + l_1 + l_2
\]

\[
l = \text{length of surface tube machined}
\]

\[
l_1 = \text{Distance required for feeding the tool cross wise to increase the depth of cut in mm}
\]

\[
l_2 = \text{Over travel of the tool at the end of each cut in mm}
\]

\[
L = \text{Distance travel led by the tool in the direction of the feed in single cut}
\]

\[
f = \text{feed mm/rev, N=rpm}
\]

\[
l_1 = 5 \text{ mm}, l_2 = 5 \text{ mm}
\]

\[
l = 35 \text{ mm}, L = 45 \text{ mm}
\]

\[
\text{Machining time} = \frac{L}{N} \text{ min}
\]

To machine metal at a specified speed, feed, and depth of cut, with a specified lubricant, cutting tool material, and geometry, generates cutting forces and consumes power. A change in any of the variables alters the forces, but the change is indirect in that the engineer does not specify the forces, only the parameters that generate those forces. Forces are important in that they influence the deflections in the tools, the work pieces, and the work holders, which in turn affect the final part size. Forces also play a role in chatter and vibration phenomena common in machining.

Obviously, the manufacturing engineer would like to be able to predict forces (and power) so that he can safely specify the equipment for a manufacturing operation, including the machine tool, cutting tool, and work holding devices. The relation to calculate force is given in equation

\[
F = k \times d \times f \times N
\]

\[
d = \text{depth of cut (mm)}
\]

\[
f = \text{feed per rotation (mm)}
\]

\[
k = \text{specific cutting energy coefficient}
\]
Although one may wish to describe the energy per unit volume needed to form the chip, machine tools are typically rated in terms of power. Unit (or specific) power values can be calculated by dividing the power input to the process, \( F \nu \), by the volumetric rate at which material is removed and then dividing this quantity by 33,000 to convert to horsepower. The specific power, \( P_s \), is a measure of the difficulty involved in machining a particular material and can be used to estimate the total cutting power, \( P \).

The required cutting power \( P \) (\( W \)) can be estimated using the following formula:

\[
P = \frac{F \nu}{60000} \text{ W} \quad (6)
\]

\( v = \text{cutting speed in mm/min} \)

\( F = \text{cutting force (N)} \)

2. OBJECTIVES OF THE WORK

The objective of the work is to discuss the various methods of Taguchi technique and strategies that are adopted in order to find the following parameters by both experimentally and Taguchi techniques.

- To develop relationship between the control parameters and response parameters during machining.
- To optimize turning operation parameters for surface roughness, material removal, machining force and power consumption.
- To optimize unit production cost and it is established on the basis of actual machining time, setup time, tool re-use time, tool life and tool changing time.

3. EXPERIMENTAL STUDY

The as-received Al6063T6 alloys were used in this study shown in Fig. 1 and its chemical composition are given in the Table 1. Al6063T6 alloy is the least expensive and most versatile of the heat treatable among the aluminium alloys. It offers a range of good mechanical properties and also good corrosion resistance. Its strength to weight ratio is excellent and it is ideally used for highly stressed parts. It may be formed in the annealed condition and subsequently heat treated.

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Ti</th>
<th>Mg</th>
<th>Cr</th>
<th>Zn</th>
<th>Others</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al6063T6</td>
<td>0.2-0.6</td>
<td>0-0.35</td>
<td>0-0.1</td>
<td>0-0.1</td>
<td>0.45-0.9</td>
<td>0-0.1</td>
<td>0-0.1</td>
<td>0-0.05</td>
<td>Bal</td>
<td></td>
</tr>
</tbody>
</table>

4. TAGUCHI TECHNIQUE

4.1. L9 Technique

Experimental design was done using Taguchi method. Hence, it has been possible to reach more comprehensive results with doing fewer experiments. In this sense, time and money have been used more efficiently [7-8]. In the determination of the characteristics of the quality as the rates of surface roughness to be measured, MRR, cutting time, and cutting force were required to be minimum, “less is more” principle has been applied among the quality values expected to be reached at the end of the experiments.

The control parameters were cutting speed (V), feed rate (f). Three levels were specified for each of the factors as indicated in Table 2. The orthogonal array chosen was L9, which has 9 rows corresponding to the number of parameter combinations (8 degrees of freedom). The first column was assigned to the cutting speed (V), the second column to the feed rate (f).
Table 2 Assignment of the Levels to the Factors

<table>
<thead>
<tr>
<th>CUTTING PARAMETERS</th>
<th>UNIT</th>
<th>NOTATION</th>
<th>LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Level 1</td>
</tr>
<tr>
<td>Feed rate</td>
<td>mm/min</td>
<td>f</td>
<td>10</td>
</tr>
<tr>
<td>Cutting speed</td>
<td>rpm</td>
<td>V</td>
<td>500</td>
</tr>
<tr>
<td>Depth of cut</td>
<td>mm</td>
<td>d</td>
<td>0.3</td>
</tr>
<tr>
<td>Tool nose radius</td>
<td>mm</td>
<td>r</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Table 3 Physical Layout for L9

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Nose radius (mm)</th>
<th>Feed (mm/min)</th>
<th>Speed (RPM)</th>
<th>DOC (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.400</td>
<td>10.000</td>
<td>500</td>
<td>0.300</td>
</tr>
<tr>
<td>2</td>
<td>0.400</td>
<td>40.000</td>
<td>1000</td>
<td>0.500</td>
</tr>
<tr>
<td>3</td>
<td>0.400</td>
<td>70.000</td>
<td>1500</td>
<td>0.800</td>
</tr>
<tr>
<td>4</td>
<td>0.600</td>
<td>10.000</td>
<td>1000</td>
<td>0.800</td>
</tr>
<tr>
<td>5</td>
<td>0.600</td>
<td>40.000</td>
<td>1500</td>
<td>0.300</td>
</tr>
<tr>
<td>6</td>
<td>0.600</td>
<td>70.000</td>
<td>500</td>
<td>0.500</td>
</tr>
<tr>
<td>7</td>
<td>0.800</td>
<td>10.000</td>
<td>1500</td>
<td>0.500</td>
</tr>
<tr>
<td>8</td>
<td>0.800</td>
<td>40.000</td>
<td>500</td>
<td>0.800</td>
</tr>
<tr>
<td>9</td>
<td>0.800</td>
<td>70.000</td>
<td>1000</td>
<td>0.300</td>
</tr>
</tbody>
</table>

4.2. Taguchi Analysis for Al6063T6 Alloy

The experimental results of the machining characteristics obtained for the turning parameters mentioned in table 3 are given in table 4.

Table 4 Experimental Results for Al6063t6 Alloy

<table>
<thead>
<tr>
<th>Expt. No.</th>
<th>Surface Roughness (Ra) (µm)</th>
<th>MRR (mm³/min)</th>
<th>Machining Time (min)</th>
<th>Machining Force (N)</th>
<th>Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.016</td>
<td>235.619</td>
<td>11.475</td>
<td>3.000</td>
<td>1.963</td>
</tr>
<tr>
<td>2</td>
<td>7.141</td>
<td>1570.796</td>
<td>1.650</td>
<td>10.000</td>
<td>13.090</td>
</tr>
<tr>
<td>3</td>
<td>7.682</td>
<td>4398.230</td>
<td>0.632</td>
<td>18.667</td>
<td>36.652</td>
</tr>
<tr>
<td>4</td>
<td>1.764</td>
<td>628.319</td>
<td>4.480</td>
<td>4.000</td>
<td>5.236</td>
</tr>
<tr>
<td>5</td>
<td>7.024</td>
<td>942.478</td>
<td>3.222</td>
<td>4.000</td>
<td>7.854</td>
</tr>
<tr>
<td>6</td>
<td>7.213</td>
<td>2748.894</td>
<td>0.849</td>
<td>35.000</td>
<td>22.907</td>
</tr>
<tr>
<td>7</td>
<td>1.580</td>
<td>392.699</td>
<td>7.168</td>
<td>1.667</td>
<td>3.272</td>
</tr>
<tr>
<td>8</td>
<td>4.927</td>
<td>2513.274</td>
<td>1.282</td>
<td>32.000</td>
<td>20.944</td>
</tr>
<tr>
<td>9</td>
<td>7.648</td>
<td>1649.336</td>
<td>1.415</td>
<td>10.500</td>
<td>13.744</td>
</tr>
</tbody>
</table>
5. RESULTS AND DISCUSSION

The main objective of the experiment is to optimize the turning parameters (cutting speed, feed rate, speed and nose radius) to achieve low value of the cutting parameters.

Figure 2 gives the main effects plot for surface roughness vs cutting parameters to determine the optimum value. It is also clear that higher surface finish has a high impact on the life of the machined components and hence the cutting parameter selection should result in a very low surface roughness value. From figure 2 it can be seen that the nose radius value of 0.8mm, Feed of 10mm/min, speed of 500 RPM and a depth of cut of 0.8mm result in the lowest surface roughness values.

![Figure 2 Main effects plot for surface roughness vs cutting parameters](image)

Figure 3 gives the main effects plot for material removal rate vs cutting parameters to determine the optimum value. It is also clear that higher material removal rate has a high impact on the processing time of the machined components and hence the cutting parameter selection should result in a very high material removal rate value. From figure 3 it can be seen that the nose radius value of 0.4mm, Feed of 70mm/min, speed of 1500 RPM and a depth of cut of 0.8mm result in the highest material removal rate values.

![Figure 3 Main effects plot for Material Removal Rate vs cutting parameters](image)

Figure 4 gives the main effects plot for machining time vs cutting parameters to determine the optimum value. It is also clear that lower machining time has a high impact on the processing time of the machined components and hence the cutting parameter selection should result in a very low machining time value. From figure 4 it can be seen that the nose radius value of 0.6mm, Feed of 70mm/min, speed of 1000 RPM and a depth of cut of 0.8mm result in the lowest machining time values.
Figure 4 Main effects plot for Machining Time vs cutting parameters

Figure 5 gives the main effects plot for Machining force vs cutting parameters to determine the optimum value. It is also clear that lower machining force has a high impact on the life of the machined components, surface finish of the final product and hence the cutting parameter selection should result in a very low machining force value. From figure 5 it can be seen that the nose radius value of 0.4mm, Feed of 10mm/min, speed of 1000 RPM and a depth of cut of 0.3mm result in the lowest machining force values.

Figure 5 Main effects plot for Machining Force vs cutting parameters

Figure 6 gives the main effects plot for machining power vs cutting parameters to determine the optimum value. It is also clear that lower machining power has a high impact on the life of the machined components and also on the total cost of machining and hence the cutting parameter selection should result in a very low machining power value. From figure 2 it can be seen that the nose radius value of 0.6mm, Feed of 10mm/min, speed of 1000 RPM and a depth of cut of 0.3mm result in the lowest machining power values.

Figure 6 Main effects plot for Machining Power vs cutting parameters
6. CONCLUSION
An experimental design was carried out using Taguchi technique to reduce the number of experiments done for 4 factors and 3 levels. The experiment was conducted to optimize the cutting parameters for turning of aluminium alloy Al6063T6 on a CNC machine. The Taguchi analysis for each of the parameters (i.e., Surface roughness, Material removal rate, machining time, machining force and machining power) was done to determine the optimum machining parameter setting. From the main effect plots obtained from statistical analysis software, we can conclude that

- The lowest surface roughness value is obtained for a parameter setting of nose radius value of 0.8mm, Feed of 10mm/min, speed of 500 RPM and a depth of cut of 0.8mm.
- The highest material removal rate value is obtained for a parameter setting of nose radius value of 0.4mm, Feed of 70mm/min, speed of 1500 RPM and a depth of cut of 0.8mm.
- The lowest machining time value is obtained for a parameter setting of nose radius value of 0.6mm, Feed of 70mm/min, speed of 1000 RPM and a depth of cut of 0.8mm.
- The lowest machining force value is obtained for a parameter setting of nose radius value of 0.4mm, Feed of 10mm/min, speed of 1000 RPM and a depth of cut of 0.3mm.
- The lowest machining power value is obtained for a parameter setting of nose radius value of 0.6mm, Feed of 10mm/min, speed of 1000 RPM and a depth of cut of 0.3mm.

The Taguchi analysis using Signal to Noise Ratios for each parameter (i.e., Surface roughness, Material removal rate and machining time) was done to find the optimum parameter setting. From the data collected we can say that surface roughness was minimum for a speed of 500 rpm and a feed of 0.09 mm/rev, material removal rate was maximum for a speed of 2000rpm and a feed rate of 0.09 mm/rev and machining time was minimum for a speed of 500 rpm and a feed of 0.09 mm/rev.

REFERENCE


