Effect of Process Parameters on the Surface Quality of Machined Aluminum and Steel Products

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Abstract. In a turning process, surface roughness depends on machining process parameters. The aim in this work is to improve the quality of the machined surface of the by controlling the main input parameters of the turning process for aluminum and steel materials. The effect of the machining parameters on surface roughness was studied using the orthogonal L9 Taguchi method. Four process parameters chosen were the length of the specimen (L), diameter of the specimen (D), feed rate (F), and depth of cut (T). The optimization method was performed using the signal to calculate noise ratio (S / N) for the changing response of all experiments. The results were analyzed using the analysis of variance (ANOVA). The main conclusion of this work is that F and T are the most important factors and can influence the machined surface quality in terms of surface roughness, whereas the other factors are insignificant. The minimum surface roughness for aluminum is 1.03 μm and 5.02 μm for steel specimens, which were obtained using a more suitable set of parameters with values of T 0.5 mm, F 0.5 RPM., L1000 mm, and D 40 mm.

Keywords: Surface roughness; Machining parameters; S/N ratio; Taguchi method.

1. Introduction

The machining process is one of several manufacturing processes where a part of the raw material is cut into the final form required by the process of removing the controlled substance. Processes with this common theme are now collectively known as demonstrative manufacturing as distinct from the addition of controlled substances, known as incremental manufacturing [1]. Surface roughness has a vital role in evaluating and determining the quality of machining results applied to the product. Surface roughness and material removal rate have a significant effect on the quality of production in global manufacturing. As far as turned mechanisms are concerned, well-finished surfaces (low surface roughness) are significant as this can decrease or even completely remove the need for further machining. Surface roughness, sometimes shortened to roughness, is a constituent of surface tissue. It is measured by the deviations in the direction of the standard vectors of an actual surface of its ideal shape. If these deviations are significant, the result is that this surface is irregular, but if they are of lesser significance, the surface is plane [2].

Many researchers have worked in this area and investigated the relations between the surface roughness and input parameters. Suhail et al. [3] showed that surface finishing quality is an important requirement for many workpieces that are converted. The choice of optimal cutting parameters is extremely hard when it comes to
controlling the required surface quality. It was also found that the surface temperature of the workpiece can be effectively sensed and used as an indicator to control the cutting performance and improve the optimization process.

A common method of manufacturing parts was handled by the literature [4], which investigated removal of excess materials through automation with the help of the cutting tool. These authors found that it is possible to determine the optimal settings for processing transactions aimed at reducing production costs and achieving the quality of the required product. The result of cutting parameters in the feeding process mainly affects the roughness of the surface and the machining time of the product [2].

Bartarya and Choudhury [5] studied how to develop a force prediction model during EN31 steel finish manufacturing, using an unpolished edge sharpening tool for better performance within a selected set of cutting parameters. The surface quality proved to be highly influenced by cut parameters. Kumara et al. [6] investigated the effects of both spindle speed and feeding rate on the surface roughness in carbon steel parts, using a CNC machine to convert various types of alloy steel and carbide cutting tools. The results showed a decrease in roughness of the surface with increasing of rotation speed and feed rate. Other studies have demonstrated that the feeding rate was the main influencing factor affecting on the surface roughness [7, 8]. The work of Kombhar and others [9] has shown that the contamination of hand tools and roughness of the surface play an important role in the manufacture of machines for good planning and control standards to improve processing conditions and cutting. They used a Taguchi method to find the ideal process for transformation parameters using steel alloys and showed that the feeding rate was the most important factor on the roughness of the surface and the age of the tool.

Some researchers have investigated the relationships between cutting tool wear and the roughness of machined surfaces [10]. The selection of cutting parameters included cutting speed, feeding rate and depth of the cut, all of which were chosen to see their effect on surface roughness and tool wear. Findings showed that the roughness of the surface decreased when the cutting speed, the cutting depth and feeding rate increased. However, the tools were further corroded when all the cutting parameters increased.

The selection of input process parameters, namely, depth of cut (T), feed rate (F), specimen length (L), and specimen diameter (D) contributes to the process of surface quality improvement and minimization of the resulting defects. In this work, new input parameters, which are specimen length and specimen diameter, were applied, so the intent of this work is to improve the main input parameters (F, L, D, and T) of the turning process and thus improve the quality of the surface of the machined part. A Taguchi method was applied to experiments to obtain the best results for cutting operations.

2. Materials and Experimental Details
Two types of materials were used in the current work. The first was steel, of a type commercially called AISI 4140. The other material was aluminum alloy of grade is AA7075-T6. The materials used in the present study were purchased from domestic markets in the form of rod with a standard length of 6 m and with diameters of 10, 25 and 40 mm. They were cut into the following dimensions: 500, 750, and 1000 mm for both the steel and aluminum materials. The choice of the lathe machine depended on high accuracy. The lathe machine was used
to machine the specimens of AISI 4140 alloy steel and AA7075-T6. Spindle speed levels were kept as constant at 500 RPM. Figure 1 shows the lathe machine used in the current study, which was chosen because had a span of more than one meter. Roughness was measured after the device was calibrated and after installing the specimen on the magnetic envelope. After all test specimens were completed, the surface roughness test was applied to them using roughness tester PCE-RT 1200 as shown in Figure 1.

Design of experiments (DOE) is one of the most holistic approaches to product development. It is a numerical approach that is intended to provide predictive knowledge of multifaceted and multiple processes with few operations. Taguchi method is an influential tool for designing high-quality systems. It works consistently and ideally in a variety of situations. In this study, Taguchi was selected and created through the application of Minitab 17, which produces maximum information with as few experiments as possible. Four input parameters with three levels per parameter were used to form steel and aluminum alloy shafts as shown in Table 1. Using the Taguchi method to design the experiment with the Minitab program, the matrix contained nine running experiments. The parameters were executed by processing and their size levels are displayed in Table 2.

Figure 1. The lathe machine used in the present study.

Figure 2. Roughness measuring device PCE-RT1200
Table 1. Process input parameters and their levels

| Parameter       | Symbol | Unit  | Levels          |
|-----------------|--------|-------|-----------------|
| Length          | L      | Mm    | 500 750 1000    |
| Diameter        | D      | Mm    | 10 25 40        |
| Feed            | F      | mm/rev| 0.5 1.0 1.5     |
| Depth of cut    | T      | Mm    | 0.5 1.0 1.5     |

Table 2. Orthogonal array L9 using the Taguchi with levels of parameters

| Exp. No | L (mm) | D (mm) | F (mm/rev) | T (mm) |
|---------|--------|--------|------------|--------|
| 1       | 50     | 10     | 0.5        | 0.5    |
| 2       | 50     | 25     | 1          | 1      |
| 3       | 50     | 40     | 1.5        | 1.5    |
| 4       | 75     | 10     | 1          | 1.5    |
| 5       | 75     | 25     | 1.5        | 0.5    |
| 6       | 75     | 40     | 0.5        | 1      |
| 7       | 100    | 10     | 1.5        | 1      |
| 8       | 100    | 25     | 0.5        | 1.5    |
| 9       | 100    | 40     | 1          | 0.5    |

Taguchi developed a system to be used through orthogonal array experiments, thus reducing the "contrast" of experiments by using the "optimal settings" of control parameters. Thus, optimal test results can be achieved by applying a DOE grouping with improved control standards. One of the main tools used in the strong design is the signal-to-noise S / N ratio and a set of orthogonal arrays. Signal-to-noise ratio, and recording functions for output preferred, with a focus on quality contrast, orthogonal arrays, a set of balanced experiences well to accommodate the multiple at the same time design factors [11].

S / N is used as a measurable value instead of a standard deviation. The S / N equation is based on the quality improvement criterion. The S / N concept is useful in improving quality because it can reduce contrast and improve measurement. Performance characteristics can be divided into three categories, which are better and better and better. In this study, the objective is to determine the best performance characteristics for a smaller surface roughness. Experimental effects of surface roughness and S / N ratio are found by using the corresponding equation [12].

• Smaller is better characterized

\[
\frac{S}{N} = -10 \log_{10} \left( \frac{1}{n} \sum y^2 \right) \tag{1}
\]
• Nominal is the best characterized

\[
\frac{S}{N} = 10 \log \frac{\bar{y}}{s_y} \tag{2}
\]

• Larger the better characteristic

\[
\frac{S}{N} = -\log \frac{1}{n} \left( \sum \frac{1}{y^2} \right) \tag{3}
\]

Having evaluated degrees of freedom, serve the appropriate grade orthogonal specific purpose. Basically, the independence of the matrix orthogonal will be greater than or at least equal in the process of these parameters. This study used a set of orthogonal L9. The lesser is the Ra in the machining process, the improved is the machining presentation. Each experiment had the combination of the 4 input parameters. Length of the specimen, a diameter of the specimen, feed rate, and depth of cut, all having 3 levels, were changed according to the experimental plan in L9 orthogonal array. Table 2 shows the experimental design parameters for the three pieces using an L9 orthogonal array.

The S/N equation depends on the standard for the quality characteristic to be improved. There are three categories of performance characteristics: best in terms of level, the nominal best, best. In this study, it was designed at least the display quality property for a lower surface roughness. Table 3 and Table 4 show the experimental results are presented for the surface roughness and S/N ratio by using the corresponding equation (1).

| Exp. No | Input parameters | Response | S/N |
|---------|------------------|----------|-----|
|         | L    | D    | F    | T     | Ra(µm) | Ra    |
| 1       | 500  | 10   | 0.5  | 0.5   | 1.06   | -0.0506 |
| 2       | 750  | 25   | 1    | 1     | 9.59   | -1.9636 |
| 3       | 1000 | 40   | 1.5  | 1.5   | 18.09  | -2.5148 |
| 4       | 500  | 10   | 1    | 1.5   | 12.48  | -2.1924 |
| 5       | 750  | 25   | 1.5  | 0.5   | 10.87  | -2.0724 |
| 6       | 1000 | 40   | 0.5  | 1     | 1.42   | -0.3045 |
| 7       | 500  | 10   | 1.5  | 1     | 18.47  | -2.5329 |
| 8       | 750  | 25   | 0.5  | 1.5   | 1.03   | -0.0256 |
| 9       | 1000 | 40   | 1    | 0.5   | 2.04   | -0.6192 |
Table 4.19 machining orthogonal array of values and response variables for AISI 4140

| Exp. No | Input parameters | Response | S/N |
|---------|------------------|----------|-----|
|         | L    | D     | F    | T    | Ra(µm) | Ra   |
| 1       | 500  | 10    | 0.5  | 0.5  | 5.02   | -1.4014 |
| 2       | 750  | 25    | 1    | 1    | 11.44  | -2.1168 |
| 3       | 1000 | 40    | 1.5  | 1.5  | 18.23  | -2.5215 |
| 4       | 500  | 10    | 1    | 1.5  | 15.58  | -2.3851 |
| 5       | 750  | 25    | 1.5  | 0.5  | 11.75  | -2.1400 |
| 6       | 1000 | 40    | 0.5  | 1    | 6.03   | -1.5606 |
| 7       | 500  | 10    | 1.5  | 1    | 19.20  | -2.5666 |
| 8       | 750  | 25    | 0.5  | 1.5  | 7.64   | -1.7661 |
| 9       | 1000 | 40    | 1    | 0.5  | 7.67   | -1.7695 |

3. Analysis of Experimental Results
3.1 Effects of Main Parameter
Surface roughness is considered an indicator of quality in this study. Surface roughness facts were collected throughout the experiments and appear in Table 5 as a result of the analysis of the four main adjustment factors for each alloy. The study’s main neutral statistical analysis, ANOVA, determined the parameters that significantly affect the quality of the surface of the operating parameters. The F test can be used to determine the parameter that has the greatest impact on the response. From this preliminary analysis, it is possible to determine that the most important factor is F, with a contribution of approximately 77%, followed by T with a contribution of 12%. Whereas, the significant values for various input process parameters which yield the lowest roughness in the machining process are L of 1000 mm and D of 25 mm. Hence, F is the significant factor that affects the surface roughness because reduction in the feed rate reduces the average roughness amount. These effects can be seen clearly in Figure 3.

The ANOVA results for the surface roughness of steel specimens are shown in Table 6. The most important factor is the largest; F-value is the feed rate (F) with a contribution of 70%, shadowed by the depth of cutting factor with contrition of about 22%, on the roughness. These effects can be seen graphically in the main effect and interaction plots as shown in Figure 3. Figure 3 presents the interaction between the F and T vs Ra for the steel specimens. It is clear that the Ra increases when the F and T increase. From that figure, we can say that the lower level of the depth of cut and low level of feed rates lead to decreased surface roughness and produce machined specimens with a good quality surface. These results have been demonstrated by other researchers [52].
Figure 3. The interaction between the depth of cutting and feed rate versus surface roughness of Al

Table 5. Result of ANOVA for the surface roughness (AA7075-T6)

| Source | DOF | Seq. SS  | Adj. MS | F-value | P-value | Percent contribution |
|--------|-----|----------|---------|---------|---------|----------------------|
| L      | 1   | 8.664    | 8.664   | 2.11    | 0.220   | 2.08%                |
| D      | 1   | 18.330   | 18.330  | 4.46    | 0.102   | 4.39%                |
| F      | 1   | 322.212  | 322.212 | 78.36   | 0.001   | 77.20%               |
| T      | 1   | 51.726   | 51.726  | 12.58   | 0.024   | 12.39%               |
| Error  | 4   | 16.447   | 4.112   |         |         | 3.94%                |
| Total  | 8   | 417.379  | 4.112   |         |         | 100.00%              |

R-Sq. = 96.06%

The total error is a: - (Error/Total) = (16.447/417.379) * 100 = 3.94%

Figure 4. The interaction between feed rate and depth of cutting versus surface roughness of alloy steel
Table 6. Result of ANOVA for Ra (AISI 4140) versus input process parameters

| Source | DOF | Seq. SS | Adj. MS | F-value | P-value | Percent contribution |
|--------|-----|---------|---------|---------|---------|----------------------|
| L      | 1   | 0.003   | 0.003   | 0.00    | 0.974   | 0.00%                |
| D      | 1   | 10.278  | 10.278  | 4.56    | 0.100   | 4.61%                |
| F      | 1   | 155.337 | 155.337 | 68.96   | 0.001   | 69.73%               |
| T      | 1   | 48.127  | 48.127  | 21.37   | 0.010   | 21.61%               |
| Error  | 4   | 9.010   | 2.252   |         |         | 4.04%                |
| Total  | 8   | 222.755 |         |         |         | 100.00%              |

R-Sq. = 95.96%

The total error is a: \((\text{Error/Total} = (9.010/222.755) \times 100 = 4.04\%\)

Figure 5. The average of the Ra for turning specimens of Al and alloy steel

The results show that there is no evident effect generated by either F or L on the temperature reached during the machining process of either of the materials used. 'Figure ' presents the relation between temperature and F, while 'Figure ' shows the effect of L on the temperature. 'Figure ' presents the interaction between the depth of cut and specimen diameter versus machined specimen temperature for Al specimens. 'Figure ' presents the interaction between depth of cut and specimen diameter versus tool temperature of alloy steel. From these figures, it can be seen the temperature increases with increasing both the depth of cut and specimen diameter. This can be attributed to the direct relationship between the diameter and cutting speed. So that, at large specimen diameter the corresponding cutting speed is also large and hence the temperature raises. This increase in temperature can be explained in terms of the relationship between temperature and cutting speed. The temperature increased at a larger depth of cut (see Figures 8 and 9) and this can be attributed to the direct relationship between T and temperature. It is clear that the increase in depth of cut, the strength of the chips and
the friction capacity consumed on the surface of the tool increased with increasing temperature in the cutting area, this fact is consistent with the work of [14] and [15].

Figure 6. Interval plot of machining to temperature (C) of Al (a) feed rate (mm/rev) and (b) specimen length

Figure 7. Interval plot of machining to temperature (C°) vs (a) feed rate (mm/rev) and (b) specimen length of AISI 4140 alloy steel
3.2 Signal to Noise Ratios

The S / N ratio for surface roughness for AA7075-T6 and AISI 4140 was calculated through the set of parameters using the Taguchi method, as shown in Tables 7 and 8. We evaluated the S / N ratio of the total surface roughness detected from the delta values, where it was found that the ratio of feed rate was the most important factor, then the depth of the cut, the length of the sample and then the sample diameter.

Using the S / N values listed in Table 7s and 8, the main impact schemas were created using Minitab 17, as shown in 'Figure 6 and 'Figure 9’. When S / N values were calculated, smaller values applied to surface roughness. This is typical of the selected S/N ratio for all unwanted characteristics such as "defects” etc. for which the perfect value is zero. Similarly, when an ideal value is or minimal value is well-defined, then the change between measured information and ideal value is expected to be as irrelevant as possible [16]. The performance characteristics are determined to obtain the minimum surface roughness, because surface roughness requirements should be minimized.

Taguchi analysis: surface roughness (Ra) versus L (mm); D (mm); F (mm/rev); T(mm)

| Level | L (mm) | D (mm) | F (mm/rev) | T (mm) |
|-------|--------|--------|------------|--------|
| 1     | -15.083| -15.910| -1.189     | -9.126 |
Table 8. Response for (S/N) surface roughness for AISI 4140

| Level | L (mm) | D (mm) | F (mm/rev) | T (mm) |
|-------|--------|--------|------------|--------|
| 1     | -20.12 | -21.16 | -15.74     | -17.70 |
| 2     | -20.27 | -20.08 | -20.91     | -20.80 |
| 3     | -20.35 | -19.50 | -24.10     | -22.24 |

| Delta | 0.23 | 1.67 | 8.36 | 4.54 |
|-------|------|------|------|------|
| Rank  | 4    | 3    | 1    | 2    |

Notes: Delta: Measures the magnitude of the effect by taking the difference between the highest and the lowest property of the worker. The effect of this factor is then calculated by specifying the range:

\[ \Delta = \text{Max} - \text{Min} \]

Rank: Labels in the response table help you identify the factors that have the most impact quickly. The factor with the largest delta value is given a rank of 1; second largest factor is given delta 2, and so [16].

Figure 10. Main effect on the S/N ratio of surface roughness for AA7075-T6.
The optimal process parameters values for the turning process can be obtained by applying the main effect plots at the highest values of the S/N values for each of the corresponding variables. From Figure 1, it is noticed that the optimization process parameters for minimizing surface roughness are L3D3F1T1 (i.e. L = 1000 mm, D = 40 mm, F = 0.5 mm/rev, T = 0.5 mm). Yet from Figure 1, it is noticed that the optimization process parameters for minimizing surface roughness are L1D3F1T1 (i.e. L = 1000 mm, D = 40 mm, F = 0.5 mm/rev, T = 0.5 mm).

4. Conclusions

The current work focused on the effect of input parameters on surface quality in terms of surface roughness. The experiments were designed using a Taguchi method. A combination of four process parameters (diameter of the specimen, length of the specimen, feed rate, and depth of cut) with three levels were used to determine the surface roughness as a response parameter. Analysis of S / N ratio was used to determine the optimal level of process parameters, using ANOVA to investigate the effect of process parameters on the surface roughness. The main findings can be drawn from this study are:

1. The results for aluminum material showed that the most significant input parameters effect on the surface roughness was F (with a contribution of 77%) followed by T (with a contribution of 12%), whereas the length of the specimen and the diameter of a specimen had insignificant effect. The same results were conducted for steel material, but with a contribution of 69% for F and 21 for T.
2. The best-machined surface quality specimens were achieved with a minimum roughness of about 1.03 μm for aluminum and 5.02 μm for alloy steel specimens using set of the input parameters with T of 0.5 mm, F of 0.5 mm/rev, diameter 40 mm, and the length of 1000 mm.
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