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Investigate the effect of various cutting parameters on the surface roughness of aluminum alloy 5052 by using Taguchi method

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ABSTRACT

The characteristic surface finish of the machining is the mostly important characteristics of products quality and its indispensable customers' requirement. Taguchi robust parameters designs for optimizing for surface finish in turning of 5052 AL-Alloy using carbide cutting has been utilized in this paper. Using the Taguchi method for AA5052 aluminum alloy machining reveals that feed rate, cutting speed, and depth of cut significantly impact surface roughness, with feed rate often being the dominant factor, followed by speed, then depth. The results showed that lower feed rates (e.g., 0.1 mm/rev) and higher cutting speeds (e.g., 900 rpm) generally yield the best (lowest) surface roughness (Ra), while optimal depth of cut varies but often favors lower values. ANOVA and Signal-to-Noise (S/N) ratio analyses confirm parameter significance, allowing prediction of optimal settings for improved quality.

Finally, the relationship between the cutting parameters and the response variables was established using regression analysis implemented in MINITAB 16 software. The predicted values obtained from the developed regression models were compared with the corresponding experimental results. The comparison revealed a close agreement between the predicted and experimental values, indicating that the developed models are accurate and adequately represent the machining process.

KEYWORDS: Feeds, Speed, Depth of Cut Surface Finish, Surface Roughness, Taguchi method

1. INTRODUCTION

In today's highly competitive manufacturing environment, industries are increasingly focused on producing high-quality products while minimizing production costs and meeting delivery schedules. Among the various quality characteristics of machined components, surface roughness is considered one of the most critical performance indicators because it directly influences the functional performance, reliability, and service life of manufactured parts. Consequently, the prediction and optimization of surface roughness have become significant research topics in modern machining technology.



Surface roughness is strongly affected by machining parameters such as cutting speed, feed rate, and depth of cut. Selecting appropriate machining conditions is therefore essential for achieving the desired surface quality while maintaining productivity and reducing manufacturing costs. In addition to improving the functional characteristics of machined products, an appropriate surface finish enhances wear resistance, reduces friction, improves lubrication retention, and increases fatigue strength. Therefore, optimizing machining parameters has become an essential requirement for improving both product quality and process efficiency [1].

To achieve optimal machining performance, experimental design techniques combined with statistical modeling are widely employed for analyzing the relationship between process parameters and machining responses. Response Surface Methodology (RSM) is one of the most effective optimization techniques, enabling the development of mathematical models capable of predicting process performance and identifying optimal operating conditions with a reduced number of experiments.

In CNC turning operations, which represent one of the most widely used material removal processes in manufacturing industries, surface roughness remains one of the primary indicators used to evaluate machining quality. Increasing industrial demand for tighter dimensional tolerances and superior surface finish has encouraged researchers to develop reliable predictive models that correlate cutting parameters with surface roughness and other quality characteristics [2].

The present study focuses on optimizing the CNC turning process of Aluminum 5052 alloy by determining the optimal combination of machining parameters to minimize the arithmetic average surface roughness (Ra). The experimental design is based on Response Surface Methodology using a Central Composite Rotatable Design (CCRD). Furthermore, mathematical models are developed to describe the relationship between machining parameters and several surface quality characteristics, including different surface profile parameters, surface microhardness, and out-of-roundness. These models provide manufacturing engineers with a comprehensive understanding of the effects of machining conditions on the external surface integrity of machined components and facilitate the selection of optimal process parameters for improved product quality [3].

2.EXPERIMENTAL WORK

2.1 Work piece material:

The work piece in this study was aluminium alloy 5052, in the form of round bar with a diameter of 20 mm and length of 200mm as illustrate in the figure 1.



Figure 1: Illustrate the aluminium ally 5052 work piece

The turning tests on the work piece was conducted under wet conditions on a CNC (Computer Numerical Control) lathe (DX 200, JOBBER XL) having maximum spindle speed of 4000 rpm and maximum power of 7.5 KW. Prior to actual machining, the rust layers were removed by 0.5 mm depth of cut in order to minimize any effect of homogeneity on the final results. Machined components after machining were illustrated in the figure 2



Figure 2. Illustrated the machined Components of AA 5052

3. Procedure and Steps of Taguchi Parameters Design

The procedure of Taguchi design method can be divided into seven steps. The steps of Taguchi optimization are presented in as following; select the quality characteristic, select noise factors and control factors, select orthogonal array, conduct the experiments, analyse results: determine optimum factor-level combination, predict optimum performance and confirm Experimental Design

3.1. Software analysis

MINITAB statistical software is used in this study for selecting the types of design to be used for running the experiments, to display all possible combination controllable factors and analyzing data representing main and interaction



relationship between them. This software provides a wide range of basic and advanced data analysis capabilities.

4. RESULTS AND DISCUSSION

4.1. Selection of Quality Characteristic:

There are three types of characteristics in the Taguchi methodology, such as smaller-the-better, larger-the-better, and nominal-the-best. The goal of this research was to produce optimum surface roughness (Ra) in turning operation. Smaller Ra values represent better or improved surface roughness. Therefore, a smaller-the-better quality characteristic was implemented and introduced in this study [4].

4.2. Selection of Control Factors:

The previous studies [6], indicated that feed rate, cutting speed, and depth of cut had significant effects on surface roughness in the machining operation. In this study, the controllable factors are feed rate (A), cutting speed (B), and depth of cut (C), with one nose radius of tool, which were selected because they can potentially affect surface roughness performance in turning operations. Since these are controllable in the machining process, they are considered as controllable factors in the study. Table 1 listed all the Taguchi design parameters and levels.

Table 1. Illustrate the variable factor levels of aluminum 5052

| Factor | Level 1 | Level 2 | Level 3 |
|----------------------|---------|---------|---------|
| Feed rate (mm /rev) | 0.1 | 0.2 | 0.3 |
| Cutting speed (rpm) | 700 | 800 | 900 |
| Depth of cut (mm) | 0.5 | 1.0 | 1.5 |

4.3. Selection of Orthogonal Array

One of Taguchi method steps is selecting the proper orthogonal array (OA) according to number of controllable factors (parameters). Since three factor were selected to study in this research, three levels of each factor were considered. Therefore, L9 Taguchi method has used special design of orthogonal. arrays L9(3*3) to study the entire parameter with only a small number of experiments for surface roughness as illustrate in figure 2.

Table 2. Illustrate the L9 (3*3) Taguchi orthogonal array

| Experiment number | Feed rate A | Cutting speed B | Depth of cut C |
|-------------------|-------------|-----------------|----------------|
| 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 |

4.4. Conducting the Experiments

The Signal-to-Noise (S/N) ratio, commonly denoted as S/N or by the Greek letter (η), is a fundamental concept in the Taguchi method for evaluating process performance and robustness. In this approach, the signal represents the desirable value of the quality characteristic (mean response), whereas the noise represents the undesirable variation in the response, which is measured by the standard deviation (SD). This variation is primarily caused by uncontrollable factors, known as noise factors, whose effects cannot be directly regulated during the machining process [5].

Typical noise factors in machining include tool deflection, machine vibration, and workpiece deformation resulting from cutting forces. Although these factors influence machining performance, their effects are not the primary focus of this study. Therefore, the S/N ratio is employed as a statistical measure that simultaneously considers the average performance and the variability of the response, providing an effective indicator of process robustness [6].

The objective of the Taguchi method is to maximize the S/N ratio so that the desired signal is strengthened while the influence of noise factors is minimized. A higher S/N ratio indicates a more stable process with improved quality characteristics and reduced sensitivity to uncontrollable variations. Depending on the desired quality objective, Taguchi proposed three different categories of S/N ratios: Lower-the-Better (LB), Nominal-the-Best (NB), and Higher-the-Better (HB). The appropriate formulation is selected according to the nature of the response variable being optimized [7]. The smaller is better quality characteristic can be explained as:

$$S/N = -10 \log \text{MSD} \quad (1)$$

Where: MSD = the mean square deviation.

The mean square deviation for smaller-the characteristic is:

$$\text{MSD} = \frac{y_1^2 + \dots + y_n^2}{n}$$

Where n = number of measurements in trial / row, in this case, $n=3$ and y_i is the measured value in a run/row. We can rewrite the S/N equation as:

$$S/N = -10 \log \left| \frac{y_1^2 + \dots + y_n^2}{n} \right|$$

4.5. The results for Surface Roughness

The results for Surface Roughness in this experimental run illustrate in table 3.

Table 3. Illustrate the results of surface roughness

| EX Number | Feed rate A (mm/rv) | Cutting speed B (rpm) | Depth of cut C (mm) | R 1 | Ra2 | Ra3 |
|-----------|----------------------|-----------------------|---------------------|-------|-------|-------|
| 1 | 0.1 | 700 | 0.5 | 1.073 | 0.975 | 1.05 |
| 2 | 0.1 | 800 | 1.0 | 1.091 | 0.95 | 1.185 |
| 3 | 0.1 | 900 | 1.5 | 0.894 | 1.08 | 0.899 |
| 4 | 0.2 | 700 | 1.0 | 1.33 | 1.074 | 0.98 |
| 5 | 0.2 | 800 | 1.5 | 3.044 | 1.98 | 1.99 |



| | | | | | | |
|---|-----|-----|-----|-------|--------|-------|
| 6 | 0.2 | 900 | 0.5 | 1.012 | 0.878 | 0.893 |
| 7 | 0.3 | 700 | 1.5 | 2.109 | 1.69 | 1.46 |
| 8 | 0.3 | 800 | 0.5 | 0.844 | 1.0987 | 0.833 |
| 9 | 0.3 | 900 | 1.0 | 0.94 | 1.099 | 0.799 |

Table 3 illustrate that the best surface roughness value was at machining the sample No (6) under the cutting parameters (feed rate 0.2 mm/min, cutting speed =900 rpm and depth of cut = 0.5 mm). All these results data can be represented graphically illustrated in figure 3..

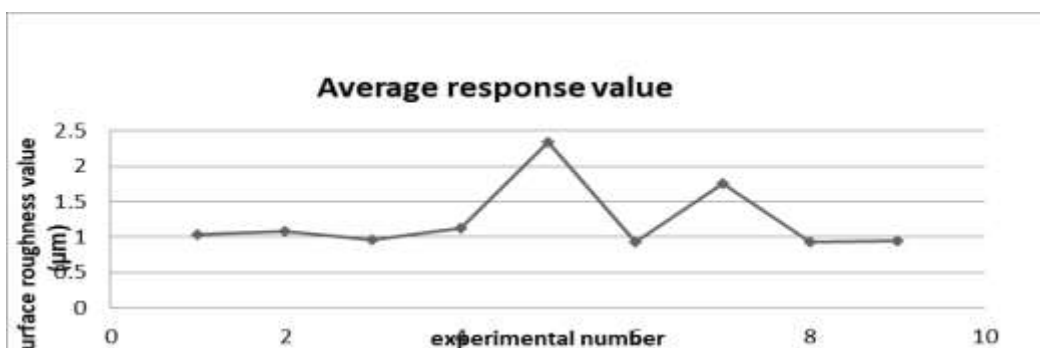


Figure 3. Illustrate the experimental Results of Surface Roughness

Table 4. Illustrate the experimental Results of aluminum alloy 5052

| Experiment number | Response value | | | Average response value | Sum of squares | MSD | S/N value |
|-------------------|----------------|--------|-------|------------------------|----------------|----------|-----------|
| | Ra 1 | Ra2 | Ra3 | | | | |
| 1 | 1.073 | 0.975 | 1.05 | 1.032666667 | 3.204454 | 1.068151 | -0.28633 |
| 2 | 1.091 | 0.95 | 1.185 | 1.075333333 | 3.497006 | 1.165669 | -0.66575 |
| 3 | 0.894 | 1.08 | 0.899 | 0.957666667 | 2.773837 | 0.924612 | 0.340403 |
| 4 | 1.33 | 1.074 | 0.98 | 1.128 | 3.882776 | 1.294259 | -1.12021 |
| 5 | 3.044 | 1.98 | 1.99 | 2.338 | 17.14644 | 5.715479 | -7.57053 |
| 6 | 1.012 | 0.878 | 0.893 | 0.927666667 | 2.592477 | 0.864159 | 0.634063 |
| 7 | 2.109 | 1.69 | 1.46 | 1.753 | 9.435581 | 3.145194 | -4.97647 |
| 8 | 0.844 | 1.0987 | 0.833 | 0.925233333 | 2.613367 | 0.871122 | 0.599209 |
| 9 | 0.94 | 1.099 | 0.799 | 0.946 | 2.729802 | 0.909934 | 0.409901 |

Table 5. Illustrate the Response of Means for S/N value

| Level | A | B | C |
|-------|----------|----------|----------|
| 1 | -0.20389 | -2.12767 | 0.315648 |
| 2 | -2.68556 | -2.54569 | -0.45869 |



| 3 | -1.32245 | 0.461456 | -4.06887 |
|-------|----------|----------|----------|
| Delta | 2.481666 | 3.007145 | 4.384514 |
| Rank | 3 | 2 | 1 |
| Level | A | B | C |
| 1 | 1.021889 | 1.304556 | 1.431967 |
| 2 | 1.464556 | 1.446189 | 1.049778 |
| 3 | 1.208078 | 0.943778 | 1.682889 |
| Delta | 0.442667 | 0.502411 | 0.633111 |
| Rank | 3 | 2 | 1 |

Table 6.

Illustrate the Means of surface roughness

4.6. Analyzing the experimental data to determine the optimum cutting conditions

For the process observing the effect influence degree of cutting parameters (feed rate (A), cutting speed (B), and depth of cut (C) - with one nose radius of tool, of aluminum alloy 5052 in CNC turning for better surface roughness. The effects process are parameters resulting from the optimization process are plotted in figure 4 (a,b,c) . these figure show many graphs, each of graphs contains a line representing the mean of the S/N ratio and curve representing the control factor. The values of the graphs are from table 4. The objective the objectives of using the S/N ratio as a performance measurement are to develop process insensitive to noise factors. The S/N ratio indicates of the predictable performance of process in the presence of noise factors. In this study, it is the smaller the better in surface roughness case, which means the smallest surface roughness, would be the ideal situation; this is criteria employed in this study to determine the optimal cutting condition. By following the criteria of smaller surface roughness and larger S/N ratio, the graphs in figures 4(a,b,c) and 5(a,b,c) were used to determine the optimal set of parameters from the experimental design.

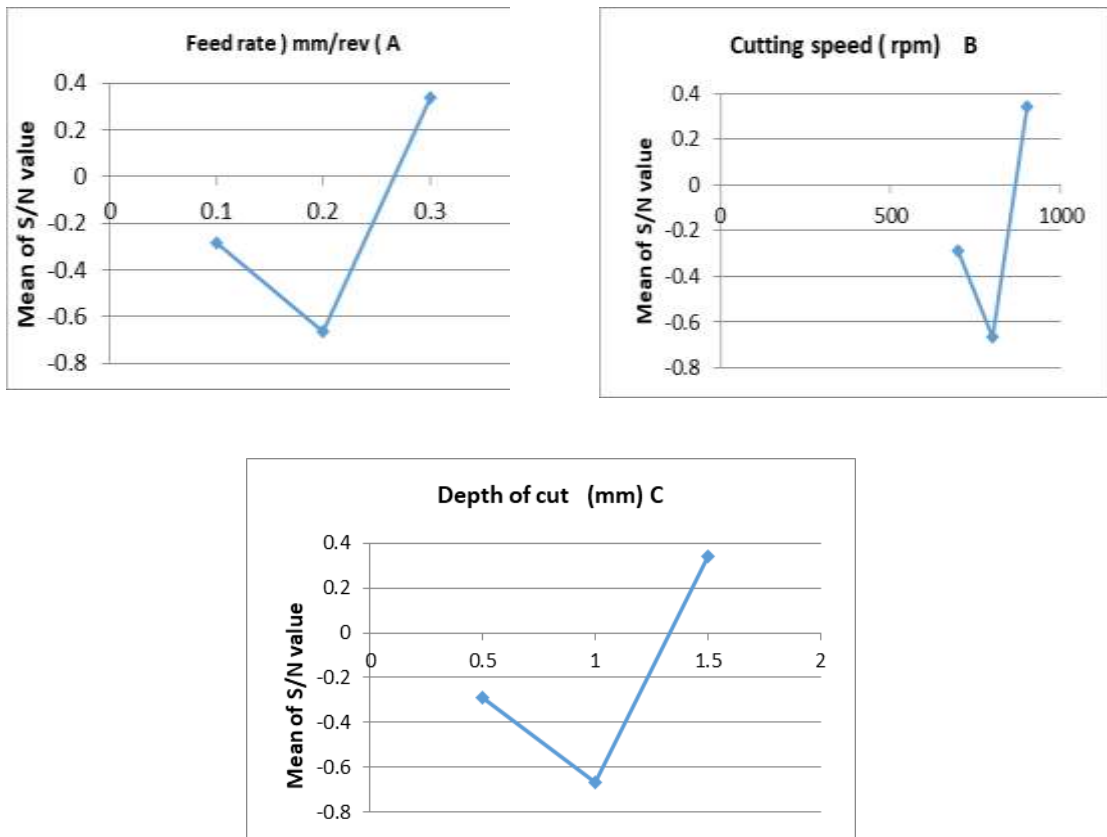
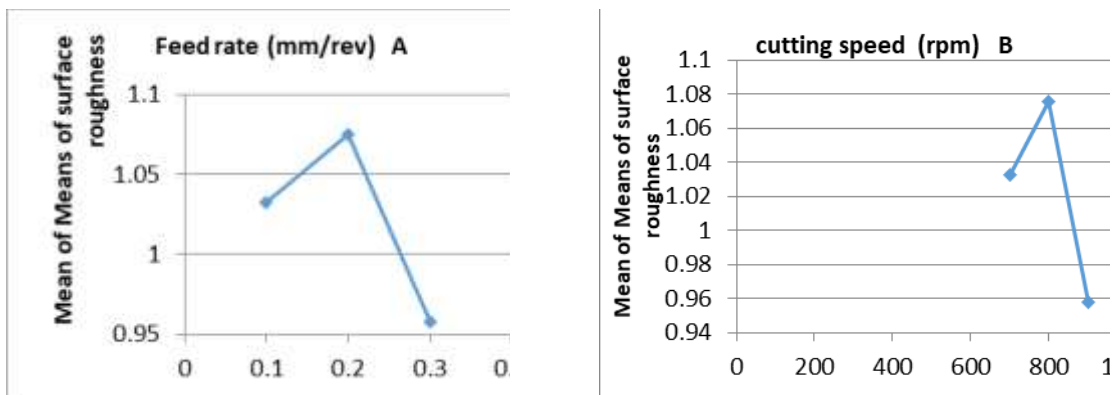


Figure 4: (A,B,C). Illustrate the plot of S/N value



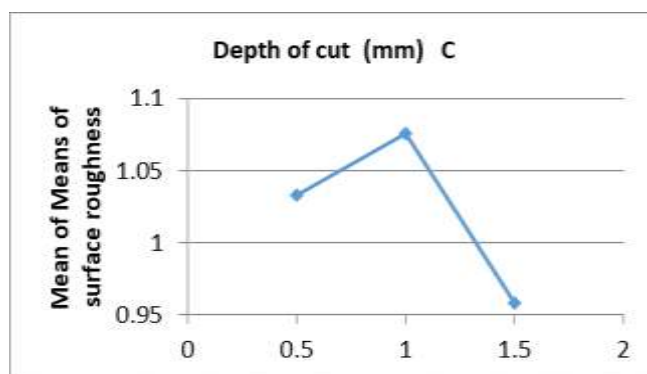


Figure 5 : (A,B,C). Illustrate the plot of means for surface roughness

Figures 5(a), 5(b), and 5(c) present the main effects plots of the Signal-to-Noise (S/N) ratios for the machining parameters. The results indicate that the feed rate (Factor A) at Level 1 (0.1 mm/min) yields the highest S/N ratio, indicating the lowest variation in surface roughness and, consequently, the best machining performance. Since the objective is to minimize surface roughness, a higher S/N ratio corresponds to improved process stability and superior surface quality.

Similarly, the optimum levels for the remaining machining parameters were identified as Level 3 (900 rpm) for the cutting speed (Factor B) and Level 2 (0.5 mm) for the depth of cut (Factor C), as these levels also produced the highest S/N ratios among their respective settings. Based on these findings, the optimal machining parameter combination is A1B3C2, corresponding to a feed rate of 0.1 mm/min, a cutting speed of 900 rpm, and a depth of cut of 0.5 mm.

A comparison between the optimum parameter combination obtained from the S/N ratio analysis and the experimental trials listed in Table 5 reveals that the optimal setting does not exactly correspond to any of the conducted experimental runs. Therefore, the expected performance under the optimum machining conditions must be estimated statistically. According to the Taguchi method, the predicted mean response for the optimal parameter combination can be calculated using the following equation [9].

$$\eta_{calc} = \eta_{avg} + (\bar{A}_i - \eta_{avg}) + (B_i - \eta_{avg}) + (C_i - \eta_{avg})$$

Where: The calculated S/N ratios at optimal machining conditions:

η_{avg} : The average S/N ratios of all control factors:

\bar{A}_i : average S/N ratio when the factor a (feed rate) is at level i.

B_i : average S/N ratio when the factor B (cutting speed) is at level i.

C_i : average S/N ratio when the factor C (depth of cut) is at level i.

The expression for surface roughness value is:

$$R_{calc} = 10\eta_{calc} / 20$$

The average S/N ratio for all control η average and the average S/N ratio for each control factor A2 , B2 , and C3 can be obtainable from the table 6.

Table 7: Illustrate the S/N ratios average value



| S/N average e | η_{avg} | \bar{A}_2 | B_2 | C_3 |
|---------------|--------------|-------------|----------|---------|
| Value | -1.4039 | -2.6855 | -2.54567 | -4.0688 |

Then the values of S/N ratios is substituted in Equation 4 and we obtain .

$$\eta_{calc} = -1.4039 + (-2.6855 - (-1.4039)) + (-2.54567 - (-1.4039)) + (-4.0688 - (-1.4039)); \quad \eta_{calc} = -1.16237 \text{ dB}$$

Substituting this value in Equation 5 we obtain the surface roughness value as: $R_{a_{calc}} = 1.143190 \mu\text{m}$

4.7. The conformation experiment results

In the engineering analysis, a conformation experimental is very important in validating the minimum surface roughness.

4.8. Surface Roughness:

The optimal machining parameters determined in this study were a feed rate of 0.1 mm/rev, a cutting speed of 900 m/min, and a depth of cut of 0.5 mm. To validate the optimization results, three additional machining experiments were conducted under these optimal cutting conditions as confirmation tests.

The results of the confirmation experiments demonstrated good agreement with the predicted values. The average surface roughness obtained from the three confirmation tests was $1.1531 \mu\text{m}$, which is very close to the predicted surface roughness value of $1.143190 \mu\text{m}$, as presented in Table 8. The small difference between the experimental and predicted values confirms the accuracy of the developed optimization model and verifies that the selected combination of machining parameters provides the minimum surface roughness. Therefore, the confirmation experiments validate the effectiveness of the proposed optimization approach in identifying the optimal cutting conditions for the CNC turning process.

Table 8: Illustrate the results of conformation experiment for Surface Roughness

| Sample Number | Mean of Ra (μm) |
|---------------|------------------------------|
| 1 | 1.143 |
| 2 | 1.201 |
| Mean | 1.1531 |

4.9. F Test Statistic

In this study, Analysis of Variance (ANOVA) and the F-test were employed to evaluate the statistical significance of the machining parameters and to determine their percentage contributions to the variation in surface roughness. ANOVA is a widely used statistical technique for identifying the influence of individual process parameters on the response variable and assessing whether these effects are statistically significant.

The F-value is calculated as the ratio of the mean square among variances (MSA) to the mean square within variances (MSW), as expressed by:

$$F = \frac{MSA}{MSW}$$

where MSA represents the mean square due to the factor under investigation, and MSW denotes the mean square of the experimental error.

The percentage contribution of each machining parameter is determined from its share of the total sum of squares (SST), providing a quantitative measure of the relative importance of each factor in influencing the response. Parameters with larger percentage contributions exert a greater effect on surface roughness.

Furthermore, the F-test is used to determine the statistical significance of each machining parameter. A larger F-value indicates that the corresponding process parameter has a more pronounced influence on the performance characteristic. Consequently, ANOVA enables the identification of the cutting parameters that significantly affect surface roughness and provides a reliable statistical basis for selecting the most influential machining conditions.

Table 9: Illustrate the ANOVA for Means surface roughness on of aluminum 5052

| Factor | DF | AdjSS | AdjMS | F- value | P- value | P % |
|--------------|----|--------|---------|----------|----------|-------|
| Feed Rate | 1 | 0.2372 | 0.23721 | 3.79 | 0.109 | 15.42 |
| Depth of Cut | 1 | 0.3641 | 0.36408 | 5.82 | 0.061 | 23.65 |
| CuttingSpeed | 1 | 0.6253 | 0.62533 | 10.00 | 0.025 | 40.62 |
| Error | 5 | 0.3127 | 0.06255 | | | 20.31 |
| Total | 8 | 1.5394 | | | | 100 |

Table 9 illustrate the results of ANOVA analysis of raw data for surface roughness on the aluminum alloy 5052. Form table 9 it is apparent that the F values of factor A (feed rate), factor C (Depth of cut) and factor B (Cutting speed), were all greater than $F_{0.05,2,2}=19$.

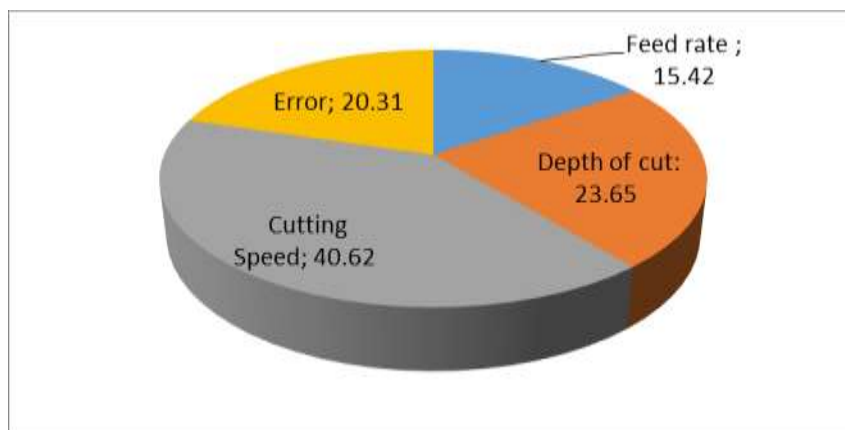


Figure 6. Illustrate the percent of control parameters on surface roughness of aluminum alloy 5052

Robust design performs an analysis of variables (ANOVA) of the experimental results in order to evaluate the relative importance of the process parameters and the error variances. The ANOVA analysis results can be seen in table 9 and figure 6 shows the influence of each factor on the performance of the turning process. According to ANOVA analysis of surface roughness on aluminum alloy 5052, the feed rate influences the performance by 15.42%, the depth of cut by 23.65% and cutting speed by 40.62

5. CONCLUSIONS

In this study the Taguchi orthogonal array is employed to optimize the machining parameters, with respect to surface roughness, which produced by CNC turning machine using one material (aluminum alloy 5052).

Taguchi method used to study effect of three factors, such as feed rate, cutting speed and depth of cut.

1. The optimum parameters for best surface roughness are obtained at a feed rate of 0.1 mm/min, cutting speed of 900 rpm, and depth of cut 1.0 mm. A2, B2 and C3. It has been observed that feed rate has got the most significant influence on the surface roughness.
2. A confirmation experiments were carried out to obtained the optimal conditions. The minimum surface roughness is calculated was 1.143190 μm , which is smaller than the 1.153 μm obtained in confirmation experiments.
3. Dry turning of Al 5052 using carbide inserts revealed following conclusions: in all experiments dominant wear mechanisms determined as abrasive and adhesion on flank and rake faces. Best surface finish recorded at highest cutting speed, and lowest feed rate.

6. REFERENCES

- [1] Kadrigama,, Surface roughness Prediction using Statistical Method, Euro Journal Publishing, 2009.
- [2] SakirTasdemir , 2008 , Prediction using artificial neural network, AISI 1040 steel in dry cutting condition, Surface roughness of Turning process.
- [3] N.E. Edwin Paul, P. Marimuthu and R. VenkateshBubu, "Machining Parameter Setting For Facing EN8 Steel with TNMG Insert, American International Journal of Research in Science, Technology, Engineering & Mathematics, vol. 3(1), pp.87-92,2013.
- [4] Funderburk, S.R. . (1999), "Key concepts in welding engineering"
- [5] Julie Z. Zh ang a, Joseph C. Chen b, E Daniel Kirby. 2006 "Surface roughness optimization in an end-milling operation using the Taguchi design method" . Journal of
- [6] Julie Z. Zhang a, Joseph C. Chen b, E Daniel Kirby. 2006 "Surface roughness optimization in an end-milling operation using the Taguchi design method" . Journal of Materials Processing Technology 184, 233-239.



- [7] DalgobindMahto and Anjani Kumar , 2008. Optimization of Process Parameters in Vertical CNC machine Using Taguchi's Design of Experiments".. Arab Research Institute in Sciences & Engineering,61-69.
- [8] K. Jinadah, K. El-Mahdy, M. Zaher, M. Abo-Tabikh, Tawfeik. "Taguchi Method". Production Engineering and Mechanical Design Department, Faculty of Engineering, Mansoura University.
- [9] cevdetGologlu, NazimSakarya, 2008. "The effect of cutter path strategies on surface roughness of material pocket milling of 1.2738 steel based on Taguchi method". Journal of materials processing technology 206, 7-15.