**Anbar Journal of Engineering Science ( AJES )** **Vol. 14 , No. 2 (2023) , pp. 1 ~11**
P-ISSN: 1997-9428 ; E-ISSN: 2705-7440 DOI: http://doi.org/10.37649/aengs.2023.140825.1053

Anbar Journal of Engineering Science©
journal homepage: https://ajes.uoanbar.edu.iq/
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# Investigation of Surface Quality in Bezier Technique for Machining Al7025 Alloy Using CNC Turning

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**PAPER INFO**

***Paper history***
Received: 10/06/2023
Revised: 22/09/2023
Accepted: 14/10/2023

***Keywords:***
Surface roughness,
CNC turning,
Prediction,
ANOVA analysis



**ABSTRACT**

Turning is the most popular machining operation. The quality of the product may be determined using a variety of metrics, such as the surface generation method and the surface roughness of the product. This work uses cutting variables to obtain the best surface quality through a mathematical model. The suggested surface generation in this work results from deriving it using the Bezier technique, with degree ($5^{th}$) having six chosen control points. One of the critical indicators of the quality of machined components is the surface roughness created during the machining process. Surface roughness improvement via machining process parameter optimization has been extensively researched. The Taguchi Method and actual tests were employed for evaluating the surface quality of complicated forms; regression models with three different variables for the cutting process, such as cutting speed, depth of cut, and feed rate, were also used. According to the experimental findings, the most significant effect of feed rate on the surface roughness is approximately (40.9%), and the more minor effect of depth of cut on the surface roughness is almost (16.23%). In addition, the average percentage error is 4.93%, the maximum error is 0.14 mm, and the minimum error is -0.143 mm for the prediction using the regression equation.

## 1. Introduction

CNC turning is a widely used machining process in modern manufacturing industries. This subtractive manufacturing technique involves rotating a workpiece while a cutting tool removes material to create the desired shape. CNC (Computer Numerical Control) technology enhances the precision, efficiency, and automation of the turning process., the product's quality, and the cost of the product. The ratio between product cost and quality at each production stage is important. Measuring surface roughness is crucial in several engineering applications [1].

Numerous studies investigated the effect of spindle speeds, feed rates, depths of cut, and surface roughness as the most important constraints for the selection of machines and cut conditions, as well as their effect on many designs, such as those involving fatigue loads, precision fitting, and aesthetic requirements. A higher depth of cut can reduce the surface roughness [2]. In recent times, there has been a growing recognition

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of the importance of Aluminium alloy-based materials (namely AA6061, AA5082, AA1100, AA359, and AA356) in the fields of automotive and aerospace applications. This recognition stems from their specific features, such as low density, exceptional thermo-mechanical capabilities, and favourable machinability. A comprehensive analysis was conducted to examine the effects of input machining parameters on aluminium alloy [3] and thoroughly examine their corresponding machining circumstances. Surface roughness may be predicted using a variety of sensors, including a force and torque dynamometer. Nevertheless, similar to any empirical investigation, this study possesses inherent constraints. Several limitations have often been reported in prior experiments. Much research has focused on a few factors that determine surface roughness, such as cutting speed, feed rate, and depth of cut. These variables are crucial, but tool geometry, cutting fluid, vibration, and workpiece material can all affect surface roughness. Neglecting these factors may restrict conclusions' generalizability.

Lack of optimization: Some research has examined the influence of factors on surface roughness but failed to optimize the mix of variables for the optimal finish. Optimization studies are necessary to find the parameter values that minimize surface roughness. Without optimization, research may not provide industrial applications. Sample size: some small experiments employ tiny samples, reducing statistical power and generalizability. A limited sample size may not capture process variability, leading to incorrect findings. Future studies could include more variables, improve parameter settings, raise sample numbers, add actual cutting circumstances, examine interaction effects, consider process dynamics, and undertake complete cost assessments to overcome these constraints. Addressing these restrictions will increase our understanding of CNC turning surface roughness and enable machining process improvements—a systematic framework comprising several essential elements. The particular structure of the study may vary. The raw data acquired from the studies encompasses surface roughness measurements at several varied settings. Utilize visual aids, such as graphs or diagrams, to depict the correlation between factors and surface roughness. This section will examine the statistical analysis findings, encompassing the use of analysis of variance (ANOVA) analysis, to ascertain the relevance of specific variables.

## 2. Literature Review

Prior studies investigating the impact of various factors on surface roughness in computer numerical control (CNC) turning operations have produced substantial advancements in the relevant domain. Basha et al. [4] used a second-order mathematical model constructed utilizing a regression approach, and the input parameters of spindle speed, feed rate, and depth of cut with a coated carbide tool, and the surface roughness on aluminium was possible to predict. The model was used to make this prediction. The optimization was conducted using Box-Behnken's response surface methodology. The purpose of this study is to utilize the design-expert 8.0 program to determine the cutting parameters that will yield the smoothest possible surface. Sonar et al. [5] used the Taguchi technique to develop the system and process parameters for turning an Al6061-T6 alloy by a CNC machine using different depths of cuts, feed rates, and cutting speeds. The orthogonal array (L9) was chosen from four parameters with three eligible levels. Three cutting tool inserts were used for nine orthogonal array runs. Regression modelling yielded polynomial equations and optimal machining settings. Surface roughness and material removal rate were predicted using these polynomial equations. Akhtar et al. [6] employed the Taguchi method to examine how the speed, cutting depth, and feed rate affected the surface roughness of an Al7075 alloy through a CNC machine. The findings revealed that the highest speed resulted in the largest material removal rate and the least surface roughness. At the same time, the lowest feasible cutting force was achieved with a modest cutting depth and feed rate. Hidayat et al. [7] utilized a programmed lathe and set it to three different settings, and the surface roughness of the aluminium sample was analysed. According to the findings, the feed rate produced the smoothest surfaces with the least amount of roughness. As mentioned above, the previous works used three levels of cutting parameters. One focused on using the cutting speed to achieve the best surface finishing of the workpiece, while the other concentrated on using those feed rates and depths of cut and their relationship with the surface quality. Faisal M. H et al. [8] Due to its strength, machinability, temperature and corrosion resistance, and automotive flexible shaft coupling applications, AA1100 aluminium alloy is widely utilized. In machining, cutting tool lifespan determines product quality. This study aims to extend tool life during sophisticated CNC turning of AA1100 alloy. A CBN-coated insert tool is used, and spindle speed (SS), feed rate (f), and depth of cut (DOC) are measured. The experimental analysis uses a Latin square design (L16) Experiment (DOE). The findings are analysed using ANOVA and RSM. The turning input parameters SS, f, and DOC are factors with various levels. SS is 900, 1100, 1300, and 1500 rpm, f is 0.1, 0.15, 0.2, and 0.25, and DOC is 0.1, 0.2, 0.3, and 0.4 mm. The study finds the best turning parameters for tool life using ANOVA and RSM. Sample 11 of 16 has the highest tool life and performs best under extended working hours. The optimal tuning parameters identified by RSM are 0.1 mm DOC, 0.2 to 0.25 mm/rev feed rate, and 1300 to 1500 rpm SS. These parameter combinations increase machining by increasing tool life to nearly 20 minutes. Mayur Verma et al. [9] Due to its strength, machinability, temperature and corrosion resistance, and automotive flexible shaft coupling applications, AA1100 aluminium alloy is widely utilized. In machining, cutting tool lifespan determines product quality. This study aims to extend tool life during sophisticated CNC turning of AA1100 alloy. A CBN-coated insert tool is used, and spindle speed (SS), feed rate (f), and depth of cut (DOC) are measured. 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Therefore, identifying the optimal parameters for cutting is challenging. These obstacles are sufficient to lead to an invalid model. Because of this, the Taguchi method for cutting variables into accurate models still needs to be developed by noticing the roughness of the surfaces. [10] In this paper the AISI P-20 tool steel underwent machining using a CNC turning machine, employing varying cutting speeds, depths of cut, and feed rates. The surface roughness and tool life were anticipated using Taguchi's aided fuzzy modelling approach. [11] This study optimization of the CNC truing machine for aluminium alloy, involving the manipulation of process parameters and evaluating surface roughness and tool life as output responses, was achieved through a simulated annealing approach. [12] The implementation of artificial neural network methodology in machine learning has been utilized to accurately forecast the lifespan of production equipment in real-time industrial scenarios. The analysis of tool life acquisition in production cycle data was conducted, and the findings about its optimal outcomes were provided. The user did not provide any text to rewrite. The tool life monitoring in single-point cutting operations was conducted using decision tree and principal component analysis techniques [13]. The implementation of neural network-assisted image processing was utilized to forecast the lifespan of turning tools throughout the turning operation. Additionally, it established three specified types of cutting-edge modes to conduct image processing analysis. This paper explains how to choose the cutting parameters, such as spindle speeds, feed rates, and cut depths, to limit the effect of surface roughness. The project aims to generate a complicated form using the settings of a CNC lathe and then evaluate the results to settle on an approach that is effective for creating surfaces

## 3. Theoretical Background

### *3.1 Shape Configuration by CAD-CAM Modelling*

The Bezier curve is well-known and often utilized in practice. A crude grid of (n + 1) control points will be used as a starting point. The fundamental idea behind establishing a Bezier curve is first to allow a point to trace a Bezier curve before allowing this curve to sweep out. A straightforward extension to a two-dimensional free-form curve may be accomplished by adding the parameter u to the vector equation of the curve to get the curve equation

$$P(u) = [x(u), y(u)] \quad \ldots (1)$$

Where: $0 \le u \le 1(u)$ are independent variables [14]

### *3.2. Taguchi Method*

The fundamental idea behind this technique is that the level of production quality should be evaluated in terms of the degree of variation from the parameters that have been specified.

The Taguchi method analyses the results using a statistical measure of performance known as the signal-to-noise ratio, which is derived from the field of control theory [15]. In this context, "noise" refers to the standard deviation, whereas "signal" refers to the acceptable values of the mean for the output characteristics.[16]

### 3.3 CNC Turning Machine

The traditional production lathes are quickly replaced by computer numerically controlled (CNC) lathes due to their superior ease of setting, operation, repeatability, and precision. They are produced to take full advantage of cutting-edge technology like carbide tools. After being established and trialed, the machine can continue to make parts with just occasional supervision from an operator, who may have developed the component and programmed the tool paths using the computer-aided design (CAD) or computer-aided manufacturing (CAM) process or manually [17].

## 4. Methodology

The work steps of the current research methodology are depicted in Figure 1. CAD/CAM modelling was created and applied to develop and reconstruct the surface, utilizing a bundle of design tools. This was done so that the modelling could be performed digitally. The Bezier curve can be identified for a given parameter value. In the present study.

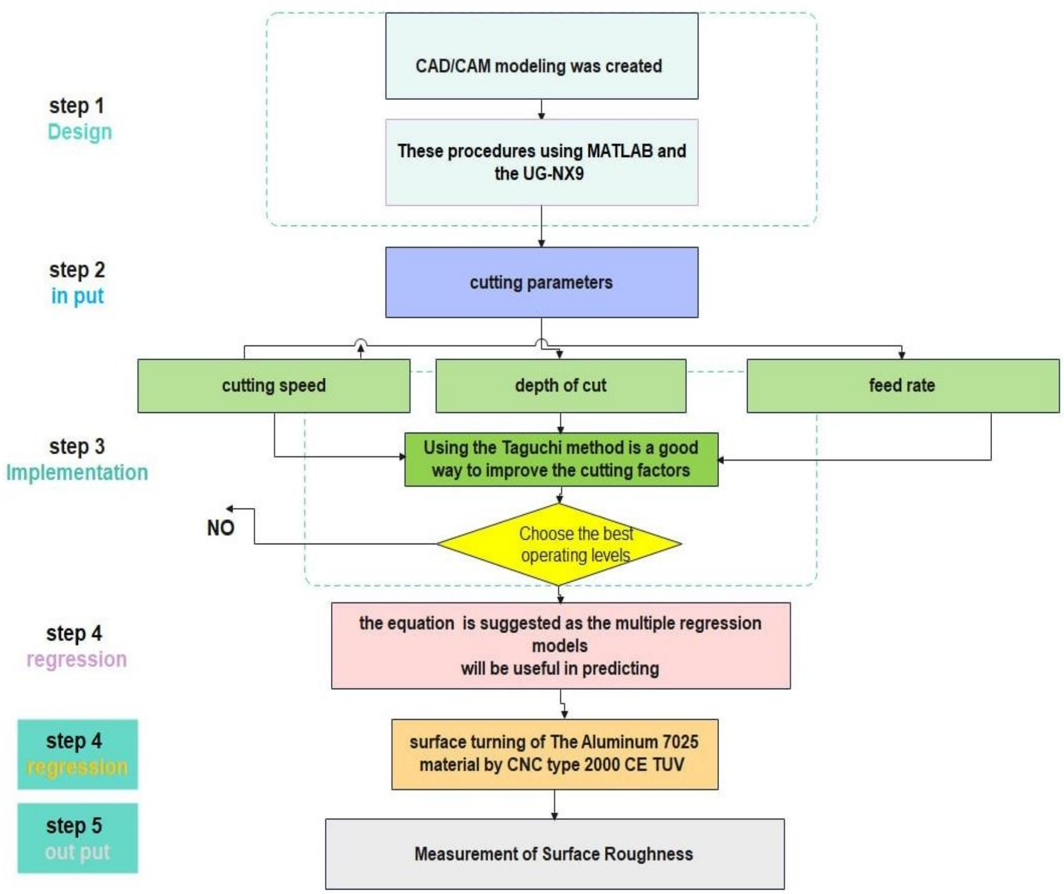


**Figure 1.** Research techniques.

The transfer of CAD data, as well as the generation of tool paths and post-processing are necessary to carry out the machining process. These procedures are demonstrated using MATLAB and the UG-NX9 application. The MATLAB program allows for matrix manipulation, algorithm implementation, and plotting. Curves have been modelled using the Bezier technique containing the control point matrices. As depicted in Figures 2 and 4, UG-NX is a program and advanced CAD/CAM development that provides the integrated design administration of parametric models and machining.

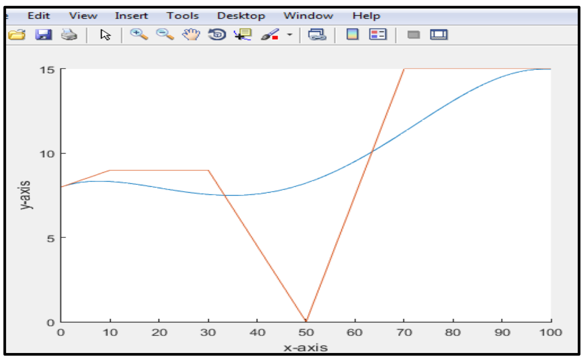


**Figure 2.** Bezier curves using MATLAB.

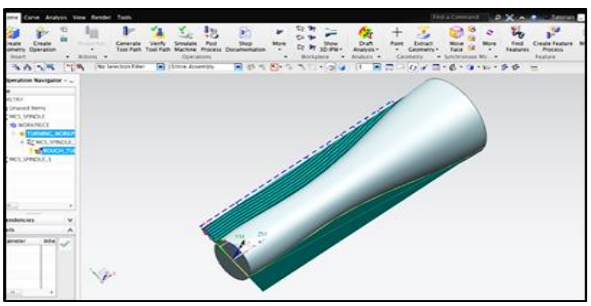

**Figure 3.** Achieving the model using UG-N.

**Figure 4.** Workpieces CAD vs. CAM

The workpiece is a rod dimension of an aluminum 7025 rod, depicted in Figure 1, are as follows: major diameter = 120 mm, minor diameter = 30 mm, and 300 mm in length as figure 4 and 7. Because one of the most crucial output components of the machining process is the surface roughness, it is advised to measure the quality of the surface's roughness using the Taguchi Method and practical work.

### *4.1 Cutting Parameters and Taguchi Method*

The procedure of turning that was carried out for this work using a CJK6132 standard turning machine type 2000 CE TUV is seen in Figure 5. Table 1 contains the detailed specifications of the machine. The device may be found in the Training and Workshops Center at the University of Technology.

**Figure 5.** Research techniques.

**Table 1.** Specifications of the used machine.

| | |
|---|---|
| Swing over bed | 320 mm |
| Range of speed (variable) | 100-2500 r\min |
| Maximum x-axis travel | 160 mm |
| Maximum z-axis travel | 500mm |
| x-rapid traverse | 5m\min |
| z-rapid traverse | 10 m\min |
| Min input unit | 0.001 mm |

Table 2 elucidates the three machining variables (speeds, depths of cut, and feeds) used in the experimental work for the (9) workpieces using the Minitab program.

**Table 2.** Machining variables.

| PARAMETERS with levels | | | |
|---|---|---|---|
| Cutting speed (rpm) | 2000 | 1700 | 1400 |
| Depth of cut (mm) | 0.7 | 0.5 | 0.3 |
| Feed rate(mm/min) | 0.26 | 0.2 | 0.14 |

The Taguchi method is an excellent way to improve the cutting factors that affect the manufacturing process. Using this method to plan an experiment leads to decrease in the number of tests and the least amount of time lost. In this paper, L9 was used, and the S/N value can be obtained by equation (2).

$$S/N = -10 \log \left[\frac{1}{n}\sum_{i=1}^{n}\frac{1}{(y^2)}\right] \qquad i = 1, 2, 3, \ldots \quad (2)[20]$$

## 4.2 Surface Roughness

The roughness of a surface is an irregularity in its texture that emerges on a workpiece as a result of mechanical processes. Surface roughness symbols are presented in Figure 6. The mean height of roughness incorporates the sample length ($L_m$) and the average line (m). The surface roughness can be calculated by equation (3).

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i| \qquad \ldots (3)\ [21]$$

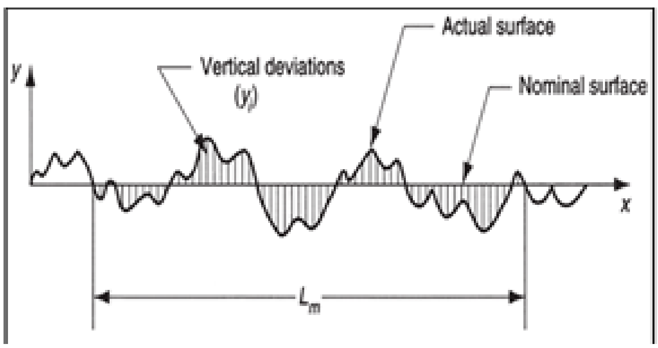


**Figure 6.** Work surface photographic.

## 5. Experimental work

### 5.1 Workpiece Preparation

Al7025 alloy has been used in this project because of its quality and how it is used in the manufacturing business. For the L9 tests, 9 black rolled rods with a diameter of 30 mm and a length of 120 mm were prepared, as illustrated in Figure 7. Table 3 shows the chemical composition of the Al7025 alloy.

**Table 3.** Chemical composition of the Al7025 alloy

| | | | | |
|---|---|---|---|---|
| Si% | Mn% | Cu% | Mg% | Pb% |
| 0.16 | 0.216 | 2.14 | 1.55 | 0.07 |
| Cr% | Ni% | Zn% | Ti% | V% |
| 0.09 | 0.012 | 4.93 | 0.038 | 0.007 |
| Fe% | Ca% | Al% | Other% | |
| 0.42 | 0.01 | 90.21 | 0.132 | |

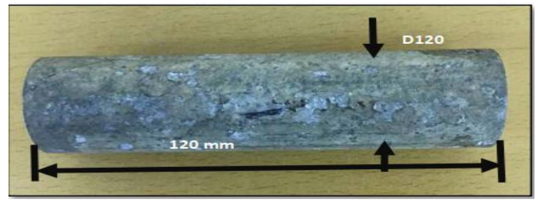


**Figure 7.** Workpiece before turning.

### *5.2 Cutting Tools*

Due to their high hardness, high thermal conductivity, wide temperature range, and high Young's modulus, carbides are excellent tools for various applications. The carbide-cutting tool was used in this work, as viewed in Figure 8. Various surface roughness values have been achieved, depending on the varied circumstances used to produce the samples for each experiment. Figure 10 explains how the Pocket Surf probe measures the surface roughness.

**Figure 8.** Carbide cutting tool used in this work

### *5.3. Measurement of Surface Roughness*

A Pocket Surf instrument has been used to gauge how rough a part's surface is after turning, as displayed in Figure 9. It is an affordable instrument that provides accurate surface roughness measurements. Table 4 lists the instrument's specifications.

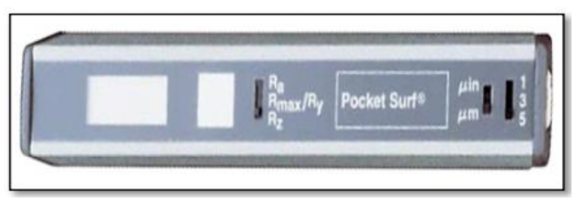


**Figure 9.** Measuring the surface roughness.

**Figure 10.** Probe surface roughness.

**Table (4):** Results after machining and predicting

| No. | Speed (rpm) | depth of cut (mm) | Feed (mm/min) | R3 | R2 | R1 | Ra | S/N | predicting | error |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 1400 | 0.3 | 0.14 | 1.12 | 1.12 | 1.1 | 1.11 | -0.90646 | 0.97 | 0.14 |
| **2** | 1400 | 0.5 | 0.20 | 1.52 | 1.59 | 1.56 | 1.56 | -3.86249 | 1.55667 | 0.00333 |
| **3** | 1400 | 0.7 | 0.26 | 1.39 | 1.31 | 1.33 | 1.34 | -2.54210 | 1.48333 | -0.14333 |
| **4** | 1700 | 0.3 | 0.20 | 1.11 | 1.08 | 1.09 | 1.09 | -0.74853 | 1.23333 | -0.14333 |
| **5** | 1700 | 0.5 | 0.26 | 1.68 | 1.59 | 1.62 | 1.63 | -4.24375 | 1.49 | 0.14 |
| **6** | 1700 | 0.7 | 0.14 | 1.08 | 1.05 | 1.06 | 1.06 | -0.50612 | 1.05667 | 0.00333 |
| **7** | 2000 | 0.3 | 0.26 | 1.1 | 1.02 | 1.01 | 1.04 | -0.34067 | 1.03667 | 0.00333 |
| **8** | 2000 | 0.5 | 0.14 | 0.83 | 0.77 | 0.76 | 0.79 | 2.04746 | 0.93333 | -0.14333 |
| **9** | 2000 | 0.7 | 0.20 | 1.29 | 1.36 | 1.33 | 1.33 | -2.47703 | 1.19 | 0.14 |

Table 5. Pocket Surf device.

| | |
|---|---|
| Measuring Ranges | Ra (0.03)-(6.35) µm<br>Ry (0.2)-(25.3) µm<br>Rz (0.2)-(25.3) µm |
| Weight | 435 g |
| Totally dimension | 140*76*25 mm |
| Display Resolution | 0.01 µm |

## 6. Result and Discussion

This part manifests and discusses how the surface roughness values are affected by the three-level factors of depth of cut (pitch), cutting speed, and feed rate. The output result was analyzed using the analysis of variance approach to locate the optimum machining variables with the assistance of the Minitab program. After the implementation, the experimental portion, including nine components and three parameters, is presented in Table 5.

### *6.1 Various Regression Models*

Data from any primary quantitative research designs, including c correct and experiment, may be analyzed using a multiple regression model to find the correlation between a criterion variable and a set of prediction variables. Value and correlation estimations can be supplied in this manner as well. As a result, multiple regressions will be helpful in predicting the criterion variable. Consequently, multiple regressions may predict the criterion variable with more accuracy. A three-way interaction equation 4 is suggested as the multiple regression model. The table shows the values obtained as well as the average error (4.93), the maximum error (0.14) mm, and

The minimum error (-0.143) mm for the regression equation prediction.

$$Ra = 1.23 - 0.000472\ Speed + 0.408\ depth + 2.92\ Feed \quad (4)$$

### 6.2 Effect of Cutting Speed, Depth of cut, and Feed rate on the Surface Roughness

It should be noted that raising the cutting speed reduces surface roughness; this indicates that increasing the cutting speed results in an improvement in surface roughness, as elucidated in Figure 11.

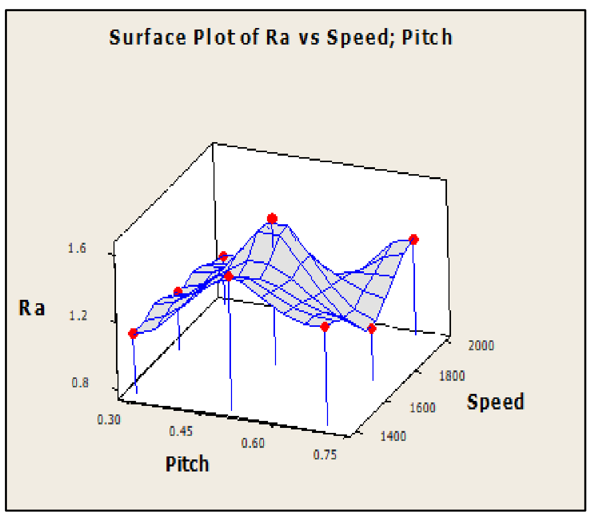


**Figure 11.** Effect of cutting speed and depth of cut on the surface roughness.

**Table 6.** ANOVA analysis findings

| Source of variance | DOF | Sum of square s | Variance | P (%) |
|---|---|---|---|---|
| Speed, (mm/min) | 2 | 0.1289 | 0.0644 | 22.14 |
| Side step, (mm) | 2 | 0.0945 | 0.0472 | 16.2 |
| Feed speed, (mm/min) | 2 | 0.2382 | 0.1191 | 40.93 |
| Error, e | 6 | 0.120 | | 20.6 |
| Total | 8 | 0.5820 | | 100 |

The increases in feed rate and depth of cut increased surface roughness as portrayed in Figure 12, and cutting speeds have an effect on friction, which decreases as the cutting speeds increase.

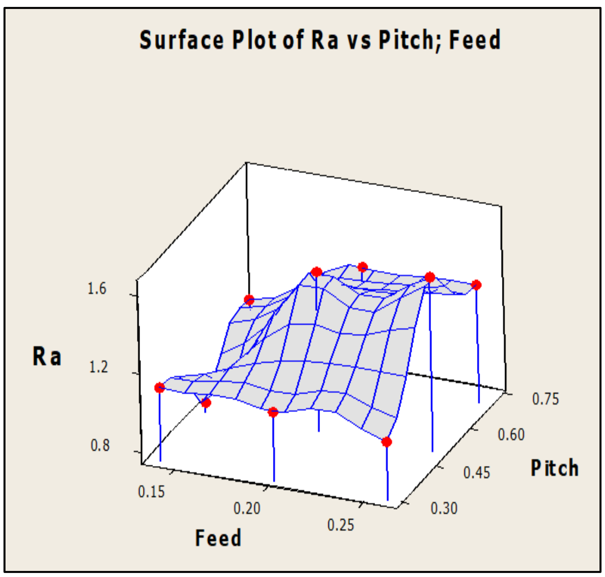


**Figure 12.** Effect of feed rate and depth of cut on the surface roughness.

## *6.3 Analysis of Variance (ANOVA)*

The analysis of variance (ANOVA) method was used to analyze the results of experiments to determine the impact of turning factors on surface finish that is dependent on cutting variables (cut depths, Surface roughness is affected by many things during the turning process, such as spinning speed, speeds, and feed rates). Table 6 exhibits the findings of the analysis of variance for surface finish.

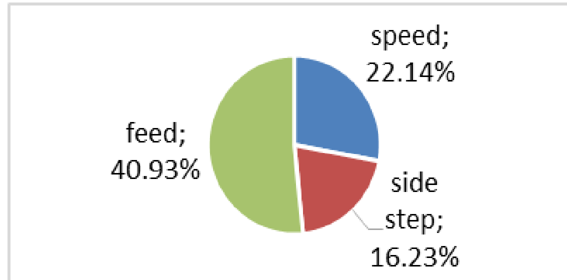


**Figure 13.** The influence of SOD(mm), Feed rate(mm/min), and Pressure(mpa) on MRR

Consequently, the most influential variable is the feed rate (40.9%), which is about twice the cutting speed (22.14%), while the pitch or depth of cut has a negligible effect (16.23%), as shown in Figure 13.

## *6.4 Optimal Condition*

Regarding machining quality parameters, the reduced surface roughness indicates optimal performance.

### *6.4.1 Main effect plots*

Using the software tool Minitab 17, the data was further examined using main effect graphs. The figures depict the variance of individual reactions for three machining parameters: Spindle speed, feed rate, and depth of cut. The x-axis in the graphs represents the value of each machining parameter, while the y-axis represents the response value (surface roughness). The primary impact plots are used to establish the best design conditions for achieving a low surface roughness, as seen in Figure 14. Cutting at level 3 (2000 rpm), a depth of cut (pitch) of level 1 (0.3 mm), and a feed rate of level 1 (0.14 mm/min) were found to produce the best surface finish.

feed rate, and side step, also called depth of cut or radial depth of cut. Let's talk about how each of these things affects surface roughness:

**Rotational Speed:** The rotational speed, also called cutting or spindle speed, is the speed at which the item spins when it is being turned. It is generally measured in RPM, which is "turns per minute." Surface roughness is affected by the speed of the spin in the following ways: When the spinning speed is faster, the surface tends to be smoother. This is because a speedier speed makes it easier to get rid of chips and makes it less likely that built-up edges will form, making the surface uneven. But spinning speeds that are too high can cause shaking and chatter, hurting the surface finish. You must find the right mix between speed and security to get the surface roughness you want.

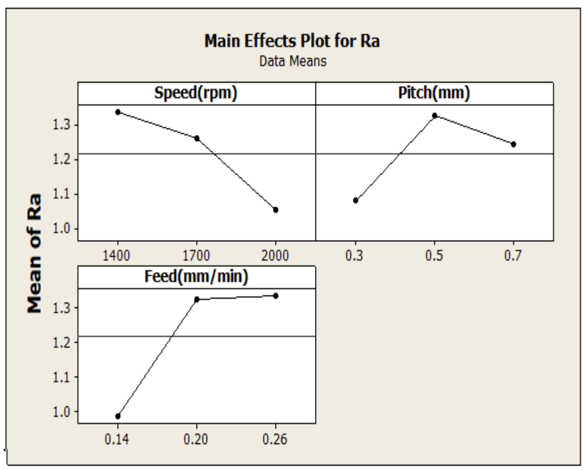


**Figure 14.** Effects of process parameters on the surface roughness.

**Feed Rate:** The feed rate is the speed of the cutting tool as it goes along the surface of the workpiece. It is usually recorded in millimeters per turn (mm/rev) or inches per turn (IPR). The flow rate has the following effects on surface roughness: A better surface finish usually comes from a slower feed rate. Slower feed rates give the cutting tool more time to slowly remove material, making errors less likely to be made. However, too low of a feed rate can cause rubbing and insufficient chip removal, leading to a sour surface finish and possible tool wear. Finish the turning process, which could increase the total time and cost of machining.

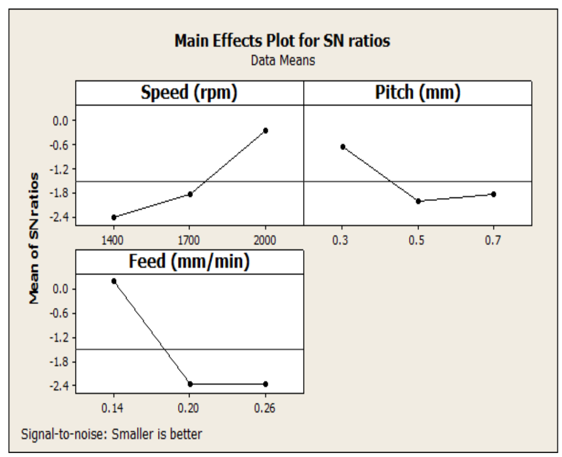


**Figure 15.** Signal-to-noise ratio

### *6.4.2 Signal-to-Noise (S/N) ratio plots*

A higher signal-to-noise ratio (S/N) indicates superior performance across the board. Therefore, the best option is the highest value setting for the machining parameters. The surface roughness was minimized based on the projected ideal parameter value noted in Figure 15.

## 7. **Conclusions**

**Side Step (Depth of Cut):** The side step, also called the depth of cut or the radial depth of cut, is the distance between the item's original surface and the cut's end surface. It tells how much stuff is taken away with each pass. The side step has the following effects on surface roughness: A smoother surface finish usually comes from a more petite side step. By taking smaller amounts of cut, the cutting forces are lessened. This leads to less tool movement and vibration, which can help make a better surface finish. But reducing the side

This research aims to optimize the turning processes using the Taguchi method's parameter design. The study's findings suggest the following inferences:

The robust orthogonal array design method of Taguchi is appropriate for the surface roughness analysis during the turning operations. The parameter design of the Taguchi method provides a straightforward, systematic, and effective way for optimizing the machining parameters. For minimum surface roughness, a higher spindle speed (2000 rpm), a lower input rate (0.14 mm/rev), and a higher depth of cut (0.3 mm) can be used.

According to the experimental findings, the effect of feed rate on surface roughness is approximately 40.9%. Among the three controllable factors (spindle speed, input rate, and depth of cut), these are the primary parameters influencing the surface texture. It's important to remember that rotational speed, feed rate, and side step effects on surface roughness can change based on the specific machining conditions, workpiece material, cutting tool shape, and other process factors. So, it's best to do test cuts and find the best settings for these factors based on how rough the surface needs to be and how the machine is set up.

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