Comprehensive Journal of Science
Volume (9), Issue (36), (Sept 2025)
ISSN: 3014-6266

مجلة العلوم الشاملة
المجلد(9) ملحق العدد (36) (سبتمبر 2025)
ردمد: 3014-6266

# Optimization of CNC Milling Parameters Using Surface Roughness as a Response Variable

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Received: 2-08-2025; Revised: 08-09-2025; Accepted: 13-09-2025; Published 22 -09-2025

**ABSTRACT**
The present study focused on the effect of the main milling parameters such as rating feed ,speed and depth of cutting , and other factors were constant such as cooling condition were air cooling and milling tool type were four cutting edge tool with carbide coated insert and the study was carried out by machining C60 .Also in the presents study of the Taguchi method were applied to optimize surface quality in a CNC milling machine .An orthogonal array of L9 and MINTTAB16 were applied .The surface roughness values were obtained from the regression model are very close to the true values.

## 1. Introduction

The surface roughness is the criterion for the irregularity in the smooth surface. The surface roughness is determined as an arithmetic mean deviation of the surface depressions and peaks, which are expressed in the form of micro inches or micrometers, and the international measurement system (ISO) Center Line Average (CLA) is used[1-3]. The ability of manufacturing processes to produce a certain roughness on the surface depends on many factors such as rotational speed, feed rate depth of cut, cutting speed, and the mechanical properties of the specimen such as microstructure, cutting tool geometry and the rigidity of the machine, when the parameters study were not selected properly, the tool wears quickly and broken and directly effect on the economic losses of the specimen [4-6]. Any change in these factors may have a significant impact on the surface produced[7]. Computer numerical control milling machines have become one of the most effective manufacturing machines and are widely used in the field of industrial operations and are used in many diverse industries, including the aerospace industry[8]. Surface quality affects the wear resulting from surface friction, and therefore the surface to be finished is usually determined[9]. And choosing the appropriate processes to achieve the required quality level. In the case of cutting with a milling machine, the final surface depends on the rotational speed, feed rate, depth of cut, cutting speed, and mechanical properties of the work piece, and any change to these factors affects the produced surface[10-13].

## 2. Research Methodology:

Medium carbon steel was chosen for its versatility in many industrial products the samples with 50mm length,50mm width and 25mm height, milling tool consist four insert carbide was using , and air cooling , the MINITAB 16 program was used and using the Taguchi methodology as showing in fig.(1) , then the number of experiments used was determined, and the main variable and fixed factors that were also determined at three levels with fixed type of tool milling and cooling for all experiments.

## 3. Equipment and material.

### 3.1 Specimen material

Cutting test were performed on medium carbon steel (C60)[14]. The application of this metal could be applied on automotive and heavy equipment machines. In this study the die mention of specimen were 50mm in length, 50mm width and 25mm as height.

**Table 1: Chemical composition**

| Elements | Fe | C | Si | Mn | P | S | Cr | Mo |
|---|---|---|---|---|---|---|---|---|
| Percent | 98.8 | 0.58 | 0.211 | 0.694 | 0.0007 | 0.0030 | 0.0306 | 0.0051 |
| Elements | Ni | Al | Co | Cu | Nb | Ti | V | W |
| Percent | 0.0665 | 0.0153 | 0.0078 | 0.125 | 0.0024 | 0.0009 | 0.0032 | 0.01 |

**Table 2: Mechanical properties**

| Tensile Strength (MPa) | Yield point (MPa) |
|---|---|
| 700−850 | 400−600 |

### 3.2Milling machine

In this study (Bridge port CNC) were applied, and for the cutting tool was carbides insert type quadrant and in this case (PCE-RT 2000) device were used for surface roughness measure.

## 4. Design of experiments.

The cutting speed, feed rate and depth of cut have a very important effect on the surface roughness in milling operations, then choose these three main factors as variable factors, provided that they are at three levels as shown in table (3). And then constant the milling tool type and cooling method in all experiments[15, 16]. One of the steps included in Taguchi design is to choose the known orthogonal array (OA) according to the factors, as there were three factors, according to the following equation (1). And each of them was at three levels, then choose nine columns and each column has three levels as shown in table (4).

$$L_N(3^k)\text{……………………………………………..}(1)$$

**Where:**

**$L_N$: the total number of runs**

**3: number of level per factor**

**K: number of factors**

**Table (3) Levels and parameters.**

| Symbol | Control factor | Unit | Level I | Level II | Level III |
|---|---|---|---|---|---|
| A | Feed rate | mm/min | 50 | 100 | 150 |
| B | Cutting speed | rpm | 500 | 750 | 1000 |
| C | Depth of cut | mm | 0.2 | 0.4 | 0.6 |

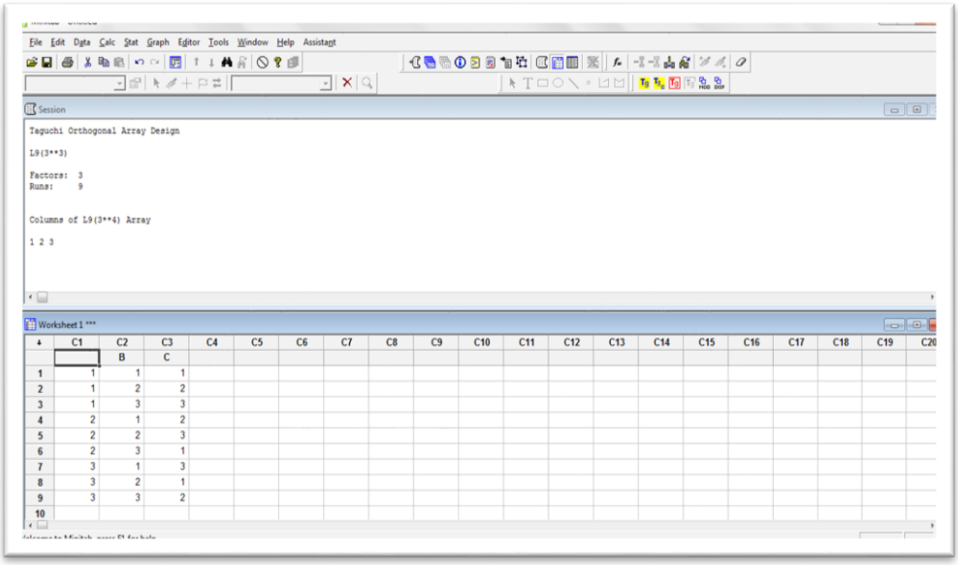


**Fig.(1) MINITAB 16 program**

**Table (4) Experimental layout of an L9 orthogonal array**

| No. | Control factor | | |
|---|---|---|---|
| | 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 |

## 5.Conducting the Experiments:

In this step, practical experiments are performed on all samples according to the data provided the MINITAB 16 software as showing in table (5).

**Table (5) Experimental layout of an $L_9$ orthogonal array**

| No. | Control factor | | |
|---|---|---|---|
| | Feed rate A | Cutting speed B | Depth of cut C |
| 1 | 50 | 500 | 0.2 |
| 2 | 50 | 750 | 0.4 |
| 3 | 50 | 1000 | 0.6 |
| 4 | 100 | 500 | 0.4 |
| 5 | 100 | 750 | 0.6 |
| 6 | 100 | 1000 | 0.2 |
| 7 | 150 | 500 | 0.6 |
| 8 | 150 | 750 | 0.2 |
| 9 | 150 | 1000 | 0.4 |

**Table (6) experimental result of the (Ra).**

| EXP.NO | Feed rate mm/min | Cutting speed RPM | Depth of cut mm | Ra1 µm | Ra2 µm | Ra3 µm |
|---|---|---|---|---|---|---|
| 1 | 50 | 500 | 0.2 | 3.103 | 3.279 | 4.327 |
| 2 | 50 | 750 | 0.4 | 3.199 | 2.896 | 2.827 |
| 3 | 50 | 1000 | 0.6 | 0.153 | 0.320 | 0.185 |
| 4 | 100 | 500 | 0.4 | 2.649 | 2.840 | 2.485 |
| 5 | 100 | 750 | 0.6 | 2.422 | 2.927 | 2.909 |
| 6 | 100 | 1000 | 0.2 | 0.157 | 0.600 | 0.515 |
| 7 | 150 | 500 | 0.6 | 0.705 | 0.790 | 0.703 |
| 8 | 150 | 750 | 0.2 | 3.659 | 2.983 | 2.810 |
| 9 | 150 | 1000 | 0.4 | 1.402 | 1.801 | 0.279 |

## 5. Signal-to-noise ratio

The optimization product and processes performance to get the goals of the results analysis, the Taguchi design were needed. Also for the optimal noise ratio in this study, the maximize the mean performance were needed[17, 18]. To find deviation between the required and experimental values for loss function by Taguchi. In signal to noise ratio, to obtain the performance character analysis, we have different ways such as lower and higher the nominal the better. To calculate performance machining in the optimal, the formation below are need to get values[19].

$$\boldsymbol{S/N = -10Log\ MSD} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (\mathbf{2})$$

MSD : Mean square deviation

$$MSD = \left| \frac{y_1^{\,2} + \ldots\ldots\ldots\ldots\ldots + Y_n^{\,2}}{n} \right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$S/N = -10\ LOg \left| \frac{y_1^{\,2} + \ldots\ldots\ldots\ldots\ldots + Y_n^{\,2}}{n} \right| \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

n= Number of measurement

**Table 8: Single ratio and averages S/N**

| No. Of Exp. | Response value | | | Average Ra µm | Sum of squares | MSD | S/N Signal-to-noise Ratio |
|---|---|---|---|---|---|---|---|
| | Ra1 µm | Ra2 µm | Ra3 µm | | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 3.103 | 3.279 | 4.327 | 3.596 | 39.1034 | 13.03446 | -11.1509 |
| 2 | 3.199 | 2.896 | 2.827 | 2.974 | 26.6123 | 8.87077 | -9.4796 |
| 3 | 0.153 | 0.320 | 0.185 | 0.219 | 0.1600 | 0.05333 | 12.7302 |
| 4 | 2.649 | 2.840 | 2.485 | 2.658 | 21.2580 | 7.086 | -8.5040 |
| 5 | 2.422 | 2.927 | 2.909 | 2.752 | 22.8957 | 7.6319 | -8.8263 |
| 6 | 0.157 | 0.600 | 0.515 | 0.423 | 0.6499 | 0.21667 | 6.6420 |
| 7 | 0.705 | 0.790 | 0.703 | 0.732 | 1.6153 | 0.53843 | 2.6887 |
| 8 | 3.659 | 2.983 | 2.810 | 3.150 | 30.1827 | 10.0609 | -10.0263 |
| 9 | 1.402 | 1.801 | 0.279 | 1.160 | 5.2870 | 1.76233 | -2.4608 |
| Averages | | | | 1.96 | | | -3.1541 |

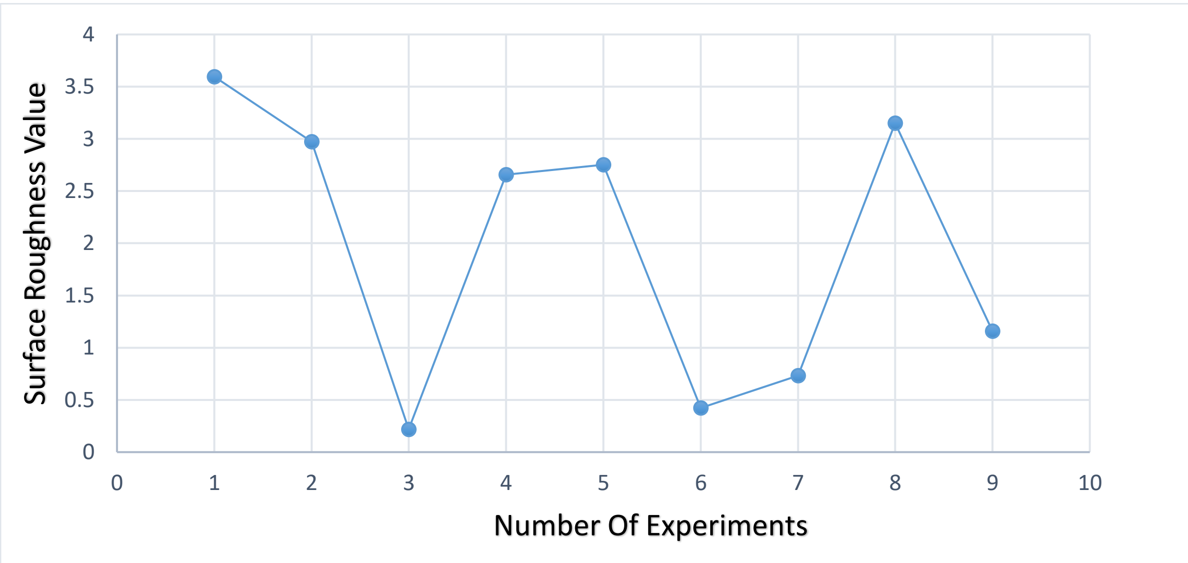


Fig (2) average surface roughness values

From fig. (2) The minimum surface roughness value was 0.219µm at Experiment No. three is the best, the cutting variable was 50mm the feed rat, 1000rpm cutting speed and 0.6mm depth of cut.

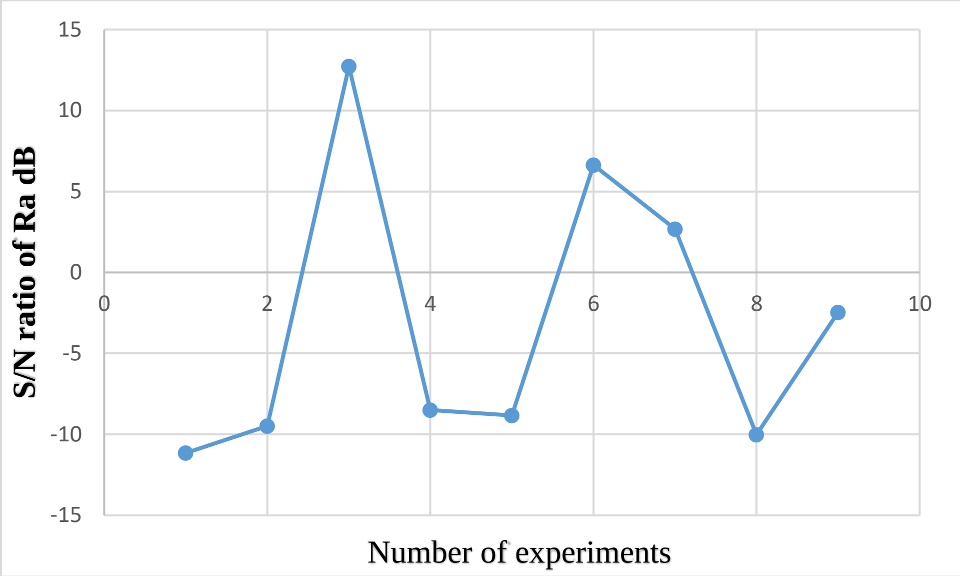


Fig. (3) S/N ration graph for (Ra)

Fig. (3) presented the optimal signal ratio results and the specimen 3 have (12.7302 ) dB, the cutting variable was 50mm the feed rat, 1000rpm cutting speed and 0.6mm depth of cut.

**Table 9 : Mean values of surface roughness (Ra).**

| Level | Feed rat (mm/min) | Cutting speed(rpm) | Depth of cut (mm) |
|---|---|---|---|
| 1 | 6.789 | 6.986 | 7.169 |
| 2 | 5.833 | 8.876 | 6.792 |
| 3 | 5.042 | 1.802 | 3.3703 |
| Large- Small | 1.747 | 7.074 | 3.7987 |
| Rank. | 3 | 1 | 2 |

**Table 10 : Mean values of signal –to- noise ratio (S/N).**

| Level | Feed rat (mm/min) | Cutting speed(rpm) | Depth of cut (mm) |
|---|---|---|---|
| 1 | -2.464* | 6.458* | -4.536 |
| 2 | -3.270 | -5.633 | -6.416 |
| 3 | -2.849 | -9.409 | 2.369* |
| Large- Small | 0.806 | 15.861 | 8.785 |
| Rank. | 3 | 1 | 2 |

* Best level of parameter

**Mean values of surface roughness (Ra).**

**Table 10 : Mean values of signal –to- noise ratio (S/N).**

| Level | Feed rat (mm/min) | Cutting speed(rpm) | Depth of cut (mm) |
|---|---|---|---|
| **1** | 6.789 | 6.986 | 7.169 |
| **2** | 5.833 | 8.876 | 6.792 |
| **3** | 5.042 | 1.802 | 3.3703 |
| **Large- Small** | 1.747 | 7.074 | 3.7987 |
| **Rank.** | 3 | 1 | 2 |

*** Best level of parameter**

## 6. Results and discussion:

The results shown three values were used from table 10 and from use MINITAB 16program we noted from the table that the values of S/N ratio the large values for each level are the best for each of the factors from three levels. Therefore, the first level of feed rate is the best (50mm/min), the first level of cutting speed is the best and its value is (100 rpm), and the Thirt level of depth of cut was the best and its value is (0.6mm) as showing in fig.(4) .The three values of the factors were the best to obtain the best surface roughness with respect to the values given in the experimental design table.

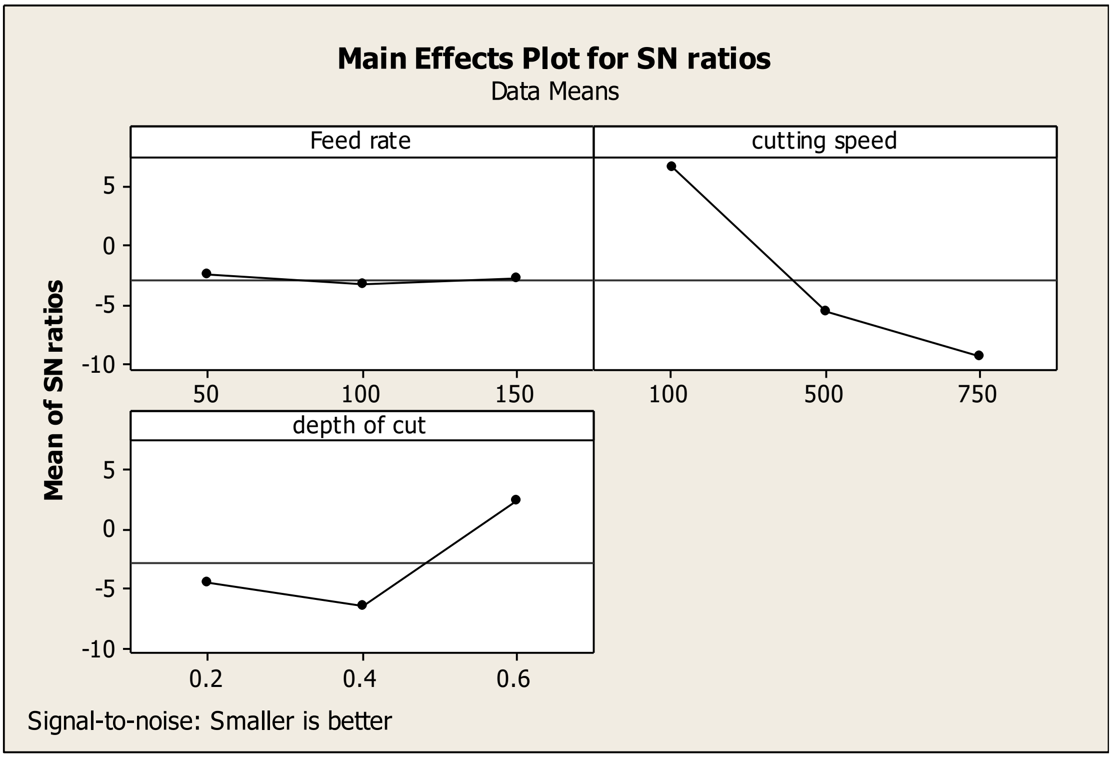


Fig.(4) showing effect of cutting parameters on S/N Ratio

## 8.Regression Analysis :

| Predictor | Coef. | T | P | VIF | S | R-Sq | R-Sq(adj) |
|---|---|---|---|---|---|---|---|
| constant | 6.292 | 3.15 | 0.025 | - | 1.16506 | 21.2% | 50.7% |
| Feed rate | -0.005823 | -0.61 | 0.567 | 1.000 | | | |
| Cutting speed | -0.003456 | -1.82 | 0.129 | 1.000 | | | |
| Depth of cut | -2.888 | -1.21 | 0.279 | 1.000 | | | |

## 9-Analysis of variance:

| source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 3 | 6.990 | 2.330 | 1.72 | 0.278 |
| Error | 5 | 6.787 | 1.357 | | |
| Total | 8 | 13.777 | | | |

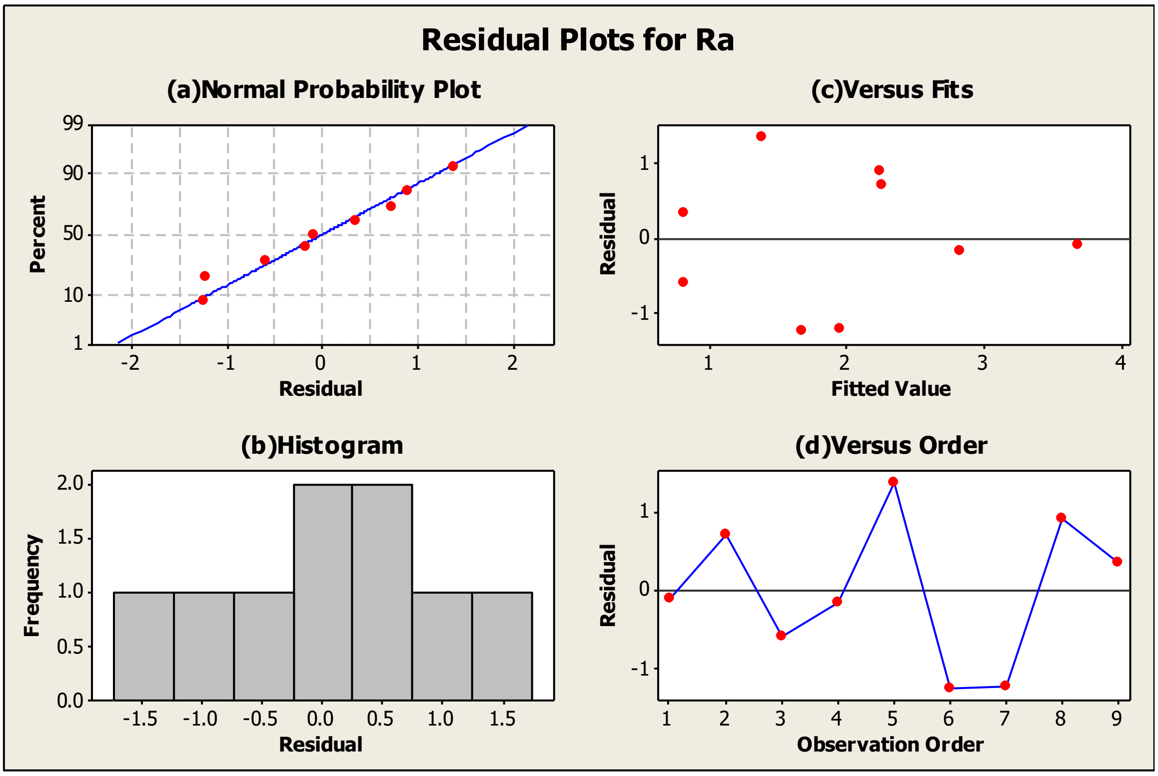


Fig.(5) testing the conditions upon which multiple linear regression analysis based

The regression equation is Ra = 6.29 - 0.00582 feed rate - 0.00346 cutting speed - 2.89 depth of cut.

Table (14) average and predictive (Ra) for multiple linear regression module.

| No. | Average Ra | Predicted Ra | Absolute Error | Error % |
|---|---|---|---|---|
| 1 | 3.596 | 3.696 | 0.100 | 2.78% |
| 2 | 2.974 | 2.254 | 0.720 | 24.21% |
| 3 | 0.219 | 0.812 | 0.593 | 270.32% |
| 4 | 2.658 | 2.827 | 0.169 | 6.36% |
| 5 | 2.752 | 1.385 | 1.367 | 49.68% |
| 6 | 0.423 | 1.676 | 1.253 | 296.22% |
| 7 | 0.732 | 1.676 | 0.944 | 128.96% |
| 8 | 3.150 | 2.249 | 0.901 | 28.60% |
| 9 | 1.160 | 0.808 | 0.352 | 30.34% |

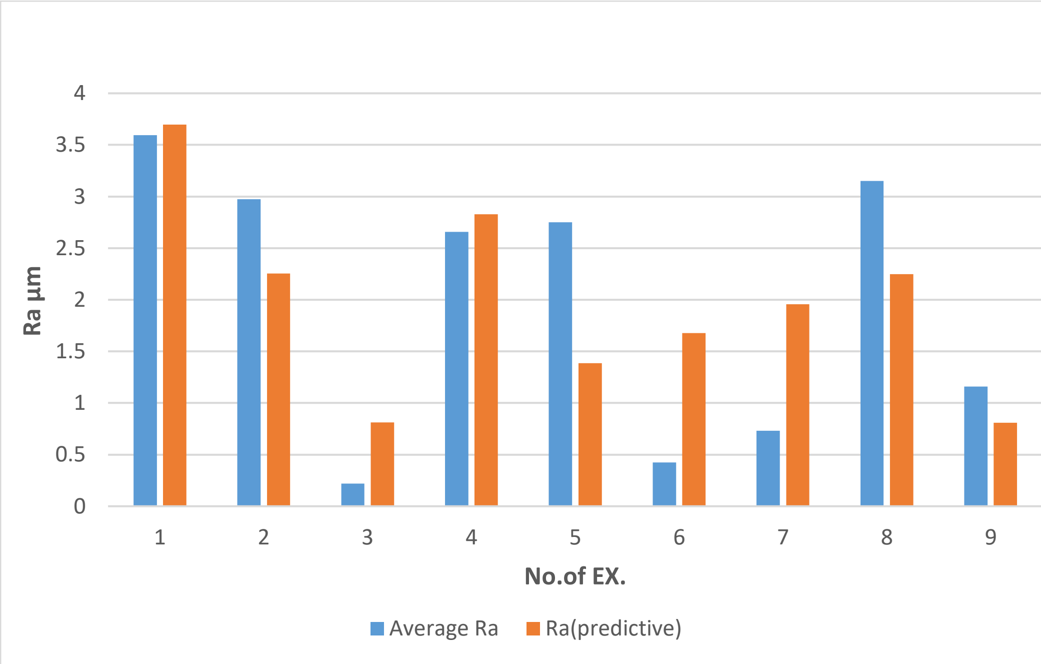


Fig.(6) comparison between the average Ra and predictive (Ra) of multiple regression model

Best Prediction (Lowest Error): Experiment 1 with only 2.78% error. The regression model is fairly accurate here. Worst Prediction (Highest Error): Experiment 6 with 296.22% error. This indicates a significant mismatch between the actual and predicted values — possibly due to model overfitting, underfitting, or insufficient training data for certain ranges. General Trend: Low Ra values (e.g., 0.2–0.7) tend to have higher percentage errors. Model predictions for higher Ra values (e.g., above 2.5) are generally more reliable.

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