# Experimental Study and Modelling of Surface Roughness of AISI D2 during Turning Process

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**Abstract:- Most of the manufacturing processes are defined by the two major characteristics named as productivity and quality. Surface roughness is important quality characteristics for the selection of cutting parameters and machine tools in process designing. In actual practice, factors such as tool variables, work piece variables and cutting conditions are significantly influence the surface roughness. This paper aims that presenting the results obtained by turning AISI D2 Steel. Taguchi Method is employed to design experiments L27 orthogonal array. Mean of roughness and S/N ratio (smaller the best) are calculated and rank of significant parameters obtained is in sequence: Cutting speed, Feed Rate, Depth of cut and Nose Radius. This result is validated and mathematical model is developed using MINITAB 18 software.**

***Keywords:-*** *Surface roughness, Cutting parameters, Turning process, Taguchi method, Orthogonal array.*

## I. INTRODUCTION

Recent developments in several methods of machining leads to increased industrial applications of turning. Turning has capability to produce complex geometric surfaces with acceptable tolerance and surface properties. Due to this feature of turning, it is the most essential operation and is commonly used in almost all manufacturing industries. During machining of a part, cutting parameters selected had impacts on surface roughness and reliability of components. Better surface finish is the most required properties of machined parts where customers never compromise. Surface roughness is the main characteristic to define surface quality. A part is said to have good surface properties only if it possess minimum surface roughness and waviness and no flaws remaining on the part. Both industries staff as well as in R&D team need to be focused, because this highly influences machining performances. Physical characteristics of material such as coefficient of friction, wear rate, corrosion resistance, fatigue strength, assembly tolerances and aesthetics depends on surface roughness while designing [1]. Including primary factors, researchers considered the effect of number input parameters such as built up edge formation, work material characteristics, tool nose radius, tool geometry, tool and workpiece setup, stability of material, vibration, application of cutting fluids, cutting forces, tool material, etc., for analyzing surface finish on their experiment. Numbers of experiments have been conducted by researchers for continuous improvement of performance of turning process by employing different optimization technique. There are several techniques used to improve productivity, model development, and optimization like Taguchi Method, Artificial Neural Network, Lean Manufacturing and Six Sigma, Genetic algorithm, Hill Climbing, Simulated annealing, Fuzzy logic, Ant colony and others. Experimentalists have used Taguchi method, genetic algorithms, expert systems or ANN (Artificial Neural Network), regression analysis for analyzing the process [2, 3].

Determining the optimal conditions of machining parameters based on surface roughness through experimental investigation with carbide tools in turning AISI D2 steel of Rockwell hardness 62 HRC and also develops a mathematical model to determine surface roughness ($R_a$) for different value of cutting parameters is the main aim of this this paper. In this work mean deviation of the profile or surface roughness ($R_a$) will be investigated. Due to its better mechanical properties such as red hardness, toughness and wear resistance properties AISI D2 is selected as tool steel among various work tool steel. AISI D2 steel gives better surface finish at high speed. AISI D2 steels are economical and reliable for tool and die manufacturing. The main application of this grade of steel is generally manufacturing deep drawing and forming dies, master tool sand gauges, slitting cutters, cold drawing punches, hobbing , blanking, burnishing rolls, thread rolling & wire dies, lamination and stamping dies, shear blades, extrusion dies etc.

## II. LITERATURE REVIEW

**Prasad et al. (2014) [4]** focused on the effects of turning process parameters on surface roughness when workpiece material, Inconel 718 was turned at dry condition with CBN tool. They considered cutting speed (50, 60 and 70 m/min), feed rate (0.103, 0.137 and 0.164 mm/rev) and depth of cut (0.50, 0.75 and 1.00 mm) as input and surface roughness as response parameter. They employed Taguchi design L9 orthogonal array and ANN approach for optimization of roughness parameter. It can be concluded that feed rate has greater impact followed by cutting speed and depth of cut on surface roughness.

**Asilturk et al. (2011) [5]** studied on turning of AISI 4140 hardened steel with $Al_2O_3$ TiC coated carbide tools using L9 array and results were analyzed using ANOVA. This experiment revealed that Ra and Rz were mainly affected by feed rate at confidence level of 95 %.

**Ali Riza Motorcu (2010) [6]** focused on optimization of surface roughness in turning process applying L16 orthogonal array. Process parameters such as cutting speed (V), feed rate (f), depth of cut (d) and tool nose radius (r) are considered for turning process though these parameters have significant effect on surface roughness. In this study ceramic tools were employed in turning AISI 8660 hardened alloy steel on CNC lathe. This study revealed that the feed rate has significant effect on surface roughness followed by depth of cut. Nature of surface roughness obtained increased with increasing depth of cut and feed rate and decreased with increasing tool's nose radius. Cutting speed (V) and interactions of Vf, Vd, Vr, fr and dr had no significant effect due to surface hardening.

**Yang et al. (2009) [7]** employed Taguchi method followed with grey relational analysis. Researchers measured mean roughness ($R_a$), maximum roughness ($R_t$) and surface roundness (ø) on turning SKD 11 using rigid CNC Lathe. The order at which controllable parameters affect $R_a$, $R_t$ and ø were in sequence: depth of cut, cutting speed, feed rate and the cutting fluid mixture ratio; and cutting speed, depth of cut, feed rate and cutting fluid mixture ratio; and cutting speed, depth of cut, feed rate and cutting fluid mixture ratio respectively.

**Fnides et al (2008) [8]** studied to analyze the effects of machining parameters like cutting speed, feed rate, depth of cut and flank wear on response parameters surface roughness and cutting forces after turning of X38CrMoV5-1 steel having hardness 50 HRC with a mixed ceramic tool (insert CC650). The authors revealed that depth of cut had more significant impact on tangential cutting force and feed rate was most influencing parameter on surface roughness also generation of cutting force components and the properties of surface roughness were greatly influenced by flank wear.

**Thamma (2008) [9]** determined the optimal condition of machining parameters and developed regression model in turning of Aluminium 6061 workparts. It can be concluded that cutting speed, nose radius and feed rate had main impact on surface roughness. Better surface finish i.e. minimum roughness could be achieved by setting smaller feed rate, higher cutting speed and smaller nose radius in turning operation.

**Ozel et al. (2007) [10]** conducted turning operation using ceramic wiper (multi-radii) design inserts on AISI D2 steels (60 HRC). In this study tool flank wear and surface roughness were considered as response parameters. Multiple linear regression models and neural network models were used in this study. They established model for prediction of response parameter surface roughness and tool flank wear. The results therefore proved that observed neural network models were comparatively efficient than regression model to determine surface roughness patterns and tool wear for a range of turning conditions. It can be concluded that lowest value of cutting speed and lowest value of feed rate give rise to best tool life for turning process.

**Kirby et al. (2004) [11]** established mathematical model to predict response surface in turning process. They considered surface roughness as response parameter and feed rate, cutting speed, depth of cut, vibration measured in three axes as input parameters. They employed multiple regression and ANOVA for analysis. They found that feed rate and vibration has linear relationship with response, surface roughness. The researchers highlighted that the developed regression model had no significant effect of spindle speed and depth of cut on effective surface roughness.

**Nalbant et al. (2007) [12]** performed an experiment to optimize cutting parameters of turning on AISI 1030 steel for surface roughness. TiN coated cutting tool was used as insert and Taguchi Method was applied for optimization. It can be concluded that higher insert radius (1.2 mm), minimum feed rate (0.15 mm/rev) and least depth of cut (0.5 mm) generated better surface finish for this experimental value.

**Bernados et al. (2003) [13]** studied and analyzed various researchers' experiment of surface roughness in machining process and conclude them as review. They predict the surface roughness in different machining processes by adopting different methodologies and strategies. Their study was categorized in four types. First category explained about machining theory to develop models and algorithms for representing machined surface. Next or second category was depending on approaches that examined the effects of various factors and analyze the results obtained after performing experiments. In third category, they discussed approaches that are used for design of experiments. The last and fourth category was based on artificial intelligence approach. Machining theory based approach considered process kinematics, cutting tool properties & tool geometry, and chip formation morphology. Model building which simulate the generation of machined surface profile and assessing surface roughness can be achieved by CAD methods and tools. In general, geometrical model development helps in formation of governing equations. This mathematical model is then employed by a computer algorithm to perform the intricate calculations. These models are generally not accurate because surface roughness formation is a complex process. So theoretical background used is considered as a necessary factors for machining process.

**Kopac et al. (2002) [14]** used Taguchi method to determine the optimal cutting parameters for a desired surface roughness during traditional turning operation. The factors selected for analysis were cutting speed, work-piece material, cutting material, cutting depth, and number of cuts. The effect of parameters on an output was determined by Taguchi technique. Analysis showed that the factors affecting significantly in the sequence of cutting speed, cutting tool material, cutting depth and consecutive cut. Interaction effects between the parameters were also analyzed. The experiment showed that the significant interactions occurs between cutting speed and consecutive cut, cutting speed and cutting depth and cutting tool material and consecutive cut.

**Feng (2001) [15]** performed experiment to study the surface roughness considering the effects of turning parameters. The parameters selected for surface roughness were feed, workpiece hardness, cutting tool point angle, spindle speed and depth of cut. The cutting tool used during the experiments was carbide inserts having a multi-phase coating with Ti, $Al_2O_3$ and TiN. The nose radius was fixed at 0.819 mm. Two levels of each factor were taken for experimental design. A fractional factorial design was employed to investigate significant effect. The experiments were carried out on a production type CNC lathe and the developed surface roughness was measured by Mitutoyo surface roughness tester SJ-301. The data obtained from experiments were analyzed with the MINITAB software. From the analysis of main effects, only tool point angle had a significant effect on roughness in addition to the other factors was observed.

**Liew et al. (2017) [16]** determined the optimal parameters using Taguchi method and response surface methodology by turning D2 steel in wet condition. Tool wear and surface roughness were selected as response parameter in their experiment. Initially ANOVA was employed to identify the significant parameters and determine the optimal level for each input parameters further RSM was implemented to build the relationship between input and response parameters. For both, tool wear ($V_b$) and surface roughness ($R_a$) rank of input parameters was listed: feed rate – rank 1, cutting speed – rank 2 and type of coolant – 3.

**Salunke et al. (2015) [17]** conducted an experimental study to optimize cutting parameters by turning AISI D2 steel using ceramic insert. Cutting speed, feed and depth of cut were selected as input parameters whereas surface roughness as response parameter. L9 orthogonal array was used for experimentation and ANOVA to study the quality characteristics. Mathematical model has been developed using regression analysis which helps to predict the surface roughness for various ranges of input parameters. From their study, it can be concluded that the cutting speed had most effect on surface roughness followed by feed rate. Surface roughness can be predicted effectively with this developed model.

**Davim et al. (2007) [18]** investigated the effect of machining parameters like cutting speed, feed rate and cutting time. AISI D2 hardened cold work steel was used as work piece and ceramic as tool insert. Flank wear, specific cutting pressure and surface roughness were considered as response on turning of work piece. After employing ANOVA it was observed that tool wear was highly influenced by cutting velocity whereas surface roughness and specific cutting pressure was affected by feed rate followed with cutting time.

**Bartarya et al. (2012) [19]** put forwarded **a** mathematical model for force prediction during turning of EN31 grade steel using uncoated CBN insert. To analyze combination of controllable parameters full factorial design of experiments were employed and developed force & surface roughness regressions models which can be used for further analysis. They concluded that model developed from analysis for surface roughness predictions was found insignificant.

**Davis et al. (2014) [20]** conducted turning operation on EN24 steel using carbide cutting tool in wet condition to obtain desired surface roughness by optimizing speed, feed and depth which are machining parameters. Taguchi method was used to develop DOE which helps in study of effect of machining parameters on surface roughness. It can be concluded that feed rate had main effect on surface roughness followed by depth of cut and then spindle speed and by ANOVA they found that none of the factors were significant.

**Singh et al. (2007) [21]** developed mathematical model for surface roughness using ceramic inserts on turning of AISI 52100. Using response surface methodology, it can be concluded that cutting velocity, feed, effective rake angle & nose radius had effect on surface nature where feed is significantly affected on surface roughness.

Literature review showed that turning is a complex machining process. It involves a number of process parameters that affect the product quality, tool life, metal removal rate, tool wear and others. Different researchers have used different techniques like "Taguchi Method and Grey Relational Analysis, ANOVA, Regression Analysis, ANN, Fuzzy logic, Genetic Algorithms (GA), Non Linear Modeling, Response Surface Methodology (RSM)" helps in developing mathematical model and optimize machining parameters. Reviewing research work it is observed that most experiments were conducted considering cutting speed, feed rate, depth of cut, nose radius, workpiece material, types of insert materials, working temperature, turning condition (dry and wet), number of cuts. Generally surface roughness, cutting force and tool vibration are the response parameters.

## III. EXPERIMENTATION

This study was based on mathematical modeling of turning process using AISI D2 as work material and considering cutting speed, depth of cut, feed rate and nose radius as controlling parameters. AISI D2 is a cold worked steel material, more commonly suitable for making tool and die which are used in mechanical system (manufacturing processes). Mean or Average surface roughness ($R_a$) was selected as response parameter as it is mostly used in industrial application. In order to find the ranking of the input process parameter, Taguchi design of experiment was used as it is common and versatile techniques of reducing the number of runs and experiment to be performed.

Regression analysis was used to develop a mathematical model and its validation.

*A. Materials and Methods:*

Composition of material used in experiments has significant effect on experimentation. After studying number of research works following materials are used for experimentation.

➢ *Cutting Tool*

A Sandvik made carbide inserts having six cutting edges designed with grade by manufacturer as TNMG 16 04 04-PM, TNMG 16 04 08-PM and TNMG 16 04 12-PM of nose radius 0.4 mm, 0.8 mm and 1.2 mm respectively. Each inserts were used for nine experiments as per Taguchi DOE (L27).

➢ *Work-piece Material*

Workpiece material used for this experiment is AISI D2 steel (Tool and Die steel) having hardness 62 HRC in the form of bar. Dimension of workpiece is 100 mm lengthwise and 20 mm diameter. **Table 1** shows the chemical composition of AISI D2 steel in percentage.

| Cr | C | Mo | W | Mn | Si | P | S |
|---|---|---|---|---|---|---|---|
| 11.8 | 1.55 | 0.7 | 0.6 | 0.4 | 0.4 | 0.03 | 0.03 |

Table 1:- Chemical composition of AISI D2 steel workpiece (wt %)

➢ *Methodology*

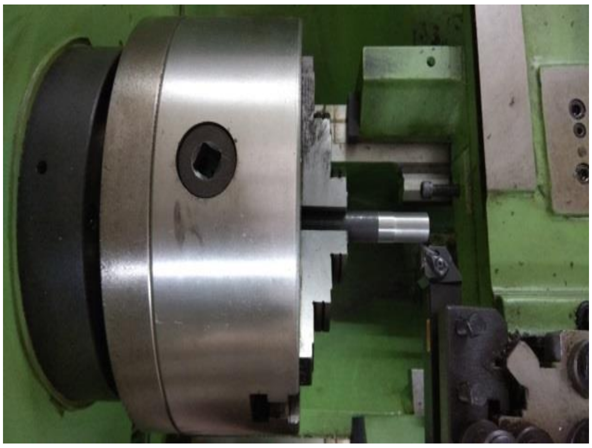

Fig 1:- Experimental Setup

In this experimental work, Taguchi robust design methodology is adopted to achieve the optimal settings of input process parameters for desired surface finish in turning of AISI D2 steel under dry condition. MINITAB 18, statistical software is applied to obtain results for Taguchi analysis, ANOVA and Regression analysis (RA). The experiments are performed on a NH-22 HMT lathe illustrated in **Figure 1,** at different specific range of selected input parameters feed rate, tool nose radius, cutting speed, depth of cut. As per tool manufacturer recommendation and literature review i.e. researcher's work the ranges of cutting parameters have selected. MITUTOYO SJ-201 surface roughness tester is employed for measuring surface roughness during different machining condition. Surface roughness ($R_a$) is measured at 3 different locations at 120° apart after each experimental runs and mean of it has been taken for analysis to minimize error.

*B. Surface Roughness Tester*

Surface roughness tester used to measure surface roughness ($R_a$) is stylus type MITUTOYO SJ-201. For roughness tester cutoff length was set at 0.8 mm for each roughness measurement in µm. **Figure 2** represents the schematic diagram of Mitutoyo SJ-201 surface roughness tester.

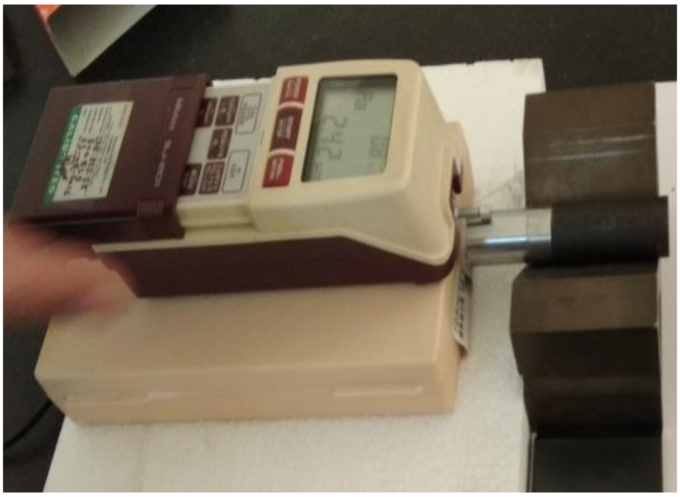

Fig 2:- Surface roughness tester (Mitutoyo SJ-201)

*C. Control Parameters and Levels*

Surface roughness is significantly influenced by cutting parameters thus this experiments focused on analysis of its influence on fine-turned workpieces. Control parameters or the process parameters selected are sufficiently far apart to cover wide range of setting value (input value). Three levels are chosen for each of four process parameters. Based on study of various literatures, machine operator experiences, machine tool's setting range the process parameter and their ranges were selected. For this experiment cutting speed, feed rate, depth of cut and tool nose radius were selected as controllable parameters. In this experiment the effects of controllable parameters as well as significance of their interactions on surface roughness of workparts are considered for analysis. Influences of following interaction of interest are considered:

➢ Cutting speed and feed rate (A × B)
➢ Cutting speed and depth of cut (A × C)
➢ Feed rate and depth of cut (B × C)

| Parameters/Levels | Cutting speed (mm/sec) | Feed rate (mm/rev) | Depth of cut (mm) | Nose radius (mm) |
|---|---|---|---|---|
| Low (-1) | 88 | 0.08 | 0.3 | 0.4 |
| Medium (0) | 148 | 0.12 | 0.4 | 0.8 |
| High (+1) | 192 | 0.16 | 0.5 | 1.2 |

Table 2:- Control Parameters and levels

Experimental plan had 3 levels and 4 factors as shown in **Table 2.** This experimental plan had 26 degrees of freedom including 3 levels and 4 factors as well as number of desired interactions between control factors. Thus a standard L27 Taguchi DOE was chosen.

*D. Analysis of s/n Ratio for Surface Roughness*

Taguchi method emphasizes three different quality characteristics based on signal to noise (S/N) ratio. Depending upon the variation due to uncontrollable parameter on response parameters, S/N ratio may be smaller is better, nominal is better and larger is better. As surface roughness was the response parameter for this experiment S/N ratio is calculated using smaller is better characteristics. Mathematically it can be written as

$$S/N_S = -10*\log\left(\frac{1}{n}\sum_{i=1}^{n} y_i^{2}\right)$$

Where,
n is the number of measurement (3 each at 120° apart) in a trial/row and $y_i$ is the measured value of surface roughness ($R_{a1}$, $R_{a2}$ & $R_{a3}$) after each experimental runs.

*E. Experimental results and discussions*

Signal-to-noise response table helps in analyzing the effect on surface roughness $R_a$ generated by each of the control factor (A, B, C and D). **Table 3** represents the response table of fine turning process. Surface roughness was measured at three locations and their mean were considered for analysis.

| Experiment No. | Cutting speed (A) | Feed rate (B) | Depth of cut (C) | Nose Radius (D) | $R_a1$ | $R_a2$ | $R_a3$ | SNRA1 | MEAN1 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | 3.78 | 4.03 | 4.08 | -11.966 | 3.96 |
| 2 | -1 | -1 | 0 | 0 | 3.93 | 4.02 | 4.14 | -12.108 | 4.03 |
| 3 | -1 | -1 | +1 | +1 | 4.24 | 4.2 | 4.1 | -12.424 | 4.18 |
| 4 | -1 | 0 | -1 | 0 | 4.37 | 4.25 | 4.55 | -12.853 | 4.39 |
| 5 | -1 | 0 | 0 | +1 | 4.1 | 4.19 | 4.4 | -12.531 | 4.23 |
| 6 | -1 | 0 | +1 | -1 | 5 | 4.86 | 4.99 | -13.893 | 4.95 |
| 7 | -1 | +1 | -1 | +1 | 4.74 | 4.73 | 4.93 | -13.626 | 4.8 |
| 8 | -1 | +1 | 0 | -1 | 5.3 | 5.01 | 4.96 | -14.138 | 5.09 |
| 9 | -1 | +1 | +1 | 0 | 5.48 | 5.26 | 5.52 | -14.682 | 5.42 |
| 10 | 0 | -1 | -1 | 0 | 3.43 | 3.72 | 3.77 | -11.229 | 3.64 |
| 11 | 0 | -1 | 0 | +1 | 3.6 | 3.24 | 3.54 | -10.791 | 3.46 |
| 12 | 0 | -1 | +1 | -1 | 3.91 | 3.75 | 3.99 | -11.787 | 3.88333 |
| 13 | 0 | 0 | -1 | +1 | 3.26 | 3.56 | 3.62 | -10.84 | 3.48 |
| 14 | 0 | 0 | 0 | -1 | 4.22 | 4.08 | 4.27 | -12.446 | 4.19 |
| 15 | 0 | 0 | +1 | 0 | 4.46 | 4.34 | 4.31 | -12.811 | 4.37 |
| 16 | 0 | +1 | -1 | -1 | 4.34 | 4.47 | 4.53 | -12.962 | 4.44667 |
| 17 | 0 | +1 | 0 | 0 | 4.28 | 4.59 | 4.63 | -13.069 | 4.5 |
| 18 | 0 | +1 | +1 | +1 | 4.5 | 4.43 | 4.75 | -13.183 | 4.56 |
| 19 | +1 | -1 | -1 | +1 | 2.64 | 2.42 | 2.37 | -7.8871 | 2.47667 |
| 20 | +1 | -1 | 0 | -1 | 3.28 | 3.2 | 3.36 | -10.319 | 3.28 |
| 21 | +1 | -1 | +1 | 0 | 3.17 | 3.23 | 3.02 | -9.942 | 3.14 |
| 22 | +1 | 0 | -1 | -1 | 2.98 | 3.13 | 3.1 | -9.7447 | 3.07 |
| 23 | +1 | 0 | 0 | 0 | 3.53 | 3.57 | 3.25 | -10.764 | 3.45 |
| 24 | +1 | 0 | +1 | +1 | 3.56 | 3.3 | 3.55 | -10.812 | 3.47 |
| 25 | +1 | +1 | -1 | 0 | 3.52 | 3.21 | 3.42 | -10.593 | 3.38333 |
| 26 | +1 | +1 | 0 | +1 | 3.38 | 3.57 | 3.55 | -10.884 | 3.5 |
| 27 | +1 | +1 | +1 | -1 | 3.88 | 3.91 | 4.07 | -11.941 | 3.95333 |

Table 3:- Response Table for turning process

S/N ratio and mean for smaller is better for surface roughness for each level of parameters are shown in **Table 4** and **Table 5** respectively.

| Factors | A | B | C | D |
|---|---|---|---|---|
| 1 | -13.131 | -10.921 | -11.290 | -12.128 |
| 2 | -12.115 | -11.847 | -11.886 | -11.997 |
| 3 | -10.312 | -12.78 | -12.381 | -11.432 |
| Range (R) | 2.8188 | 1.8592 | 1.0911 | 0.6965 |
| Rank | 1 | 2 | 3 | 4 |

Table 4:- Response table for S/N ratio for surface roughness ($R_a$)

**Table 4** predicts the rank of control parameters for surface roughness for S/N ratio (smaller is better): cutting speed is found most significant parameter, followed by feed rate then depth of cut and nose radius is seen as least significant as far as surface roughness is concerned.

| Factors | A | B | C | D |
|---|---|---|---|---|
| 1 | 4.565 | 3.5647 | 3.73867 | 4.09189 |
| 2 | 4.059 | 3.9556 | 3.97 | 4.03589 |
| 3 | 3.302 | 4.4059 | 4.2174 | 3.79833 |
| Range (R) | 1.263 | 0.8412 | 0.47873 | 0.29356 |
| Rank | 1 | 2 | 3 | 4 |

Table 5:- Response table for mean for surface roughness ($R_a$)

**Table 5** predicts the rank of control parameters for surface roughness for mean ($R_a$): cutting speed is found most significant parameter, followed by feed rate then depth of cut and nose radius is seen as least effect on surface roughness

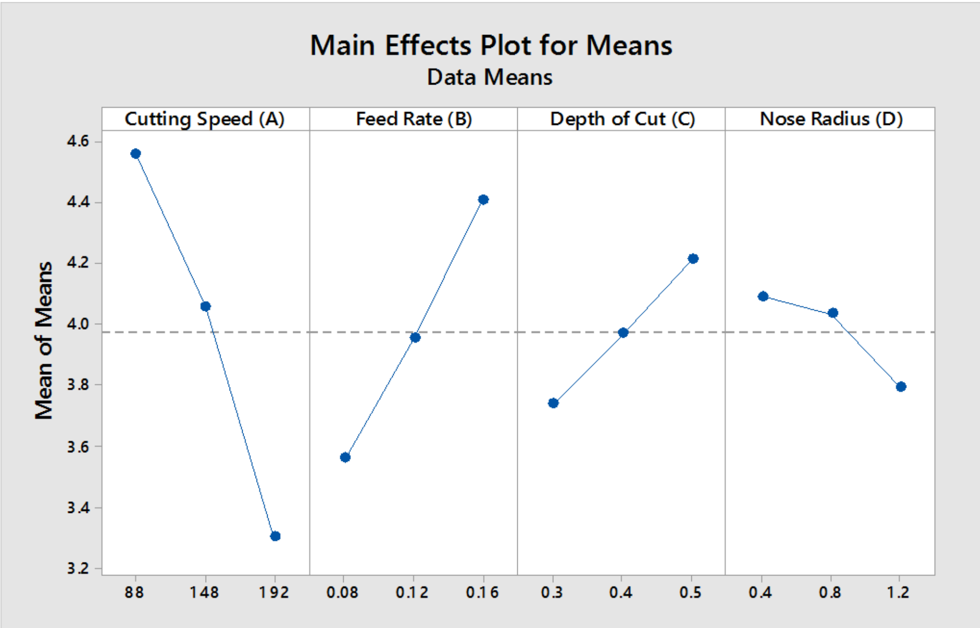


Fig 3:- Main effects plot for mean surface roughness

**Figure 3** and **Figure 4** illustrate the main effects plot for mean and S/N ratios of surface roughness respectively of various ranges of each parameter. In **Figure 3**, lowest mean value of roughness of level of corresponding parameters give rise to optimum value. And in **Figure 4**, maximum negative values of level of corresponding parameters give rise to optimum value. From both figures it was observed that with increase in cutting speed and nose radius the surface roughness decreases and with increase in feed rate and depth of cut the surface roughness decreases. Therefore the optimum level of cutting parameters is cutting speed (A) at 192 mm/sec, feed rate (B) at 0.08 mm/rev, depth of cut at 0.3 mm and nose radius at 1.2 mm as shown in **Table 6.**

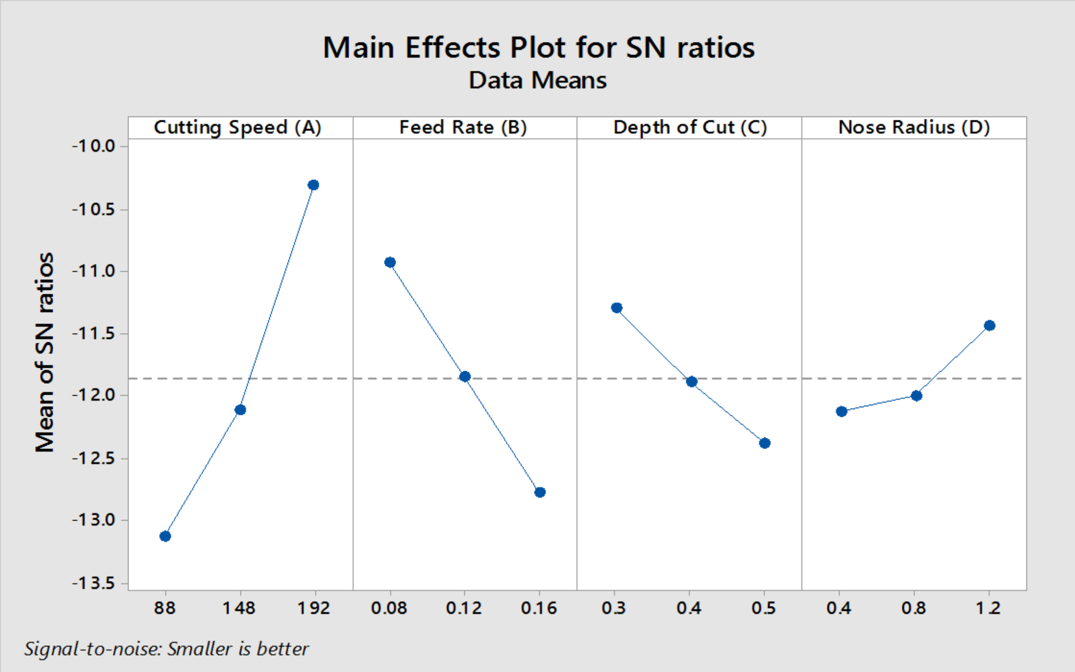


Fig 4:- Main effects plot for S/N ratio of surface roughness

| Cutting Speed (A) | Feed Rate (B) | Depth of Cut (C) | Nose Radius (D) |
|---|---|---|---|
| 192 | 0.08 | 0.3 | 1.2 |

Table 6:- Factor level for prediction

**Analysis of variance (ANOVA):-** After completion of all experimental runs, obtained data are subjected to ANOVA which helps to identify significant parameters at 95% confidence level. The results obtained from ANOVA for the response parameter are illustrated in **Table 7.**

| Source | DF | Adj SS | Adj MS | F | P | % cont. |
|---|---|---|---|---|---|---|
| Cutting Speed (A) | 2 | 7.22815 | 3.61408 | 431.75 | 0.000 | 59.9228 |
| Feed Rate (B) | 2 | 3.21364 | 1.60682 | 191.96 | 0.000 | 26.6422 |
| Depth of Cut (C) | 2 | 1.01636 | 0.50818 | 60.71 | 0.000 | 8.42598 |
| Nose Radius (D) | 2 | 0.44728 | 0.22364 | 26.72 | 0.001 | 3.70848 |
| Cutting Speed (A)*Feed Rate (B) | 4 | 0.13387 | 0.03347 | 4.00 | 0.065 | 0.55516 |
| Cutting Speed (A)*Depth of Cut (C) | 4 | 0.12061 | 0.03015 | 3.60 | 0.079 | 0.49965 |
| Feed Rate (B)*Depth of Cut (C) | 4 | 0.05932 | 0.01483 | 1.77 | 0.253 | 0.24566 |
| Residual Error | 6 | 0.05022 | 0.00837 | | | |
| Total | 26 | 12.2695 | | | | |

Table 7:- Analysis of Variance for surface roughness

- *Model summary:*

S = 0.177207, R-sq = 95.17%, R-sq (adj) = 93.38%, R-sq (pred) = 90.26 %

After analyzing the obtained data it can be concluded that all four factors are significant but cutting speed and feed rate are mainly contributed on $R_a$ with percentage contribution of 59.92 and 26.64 respectively. The interaction of parameters i.e. AB, AC & BC are found to be less significant since confidential level is less than 95%. However, the less significant factors are still important in case of surface roughness as they are considered for the turning process.

- *Regression model for surface roughness*

Regression analysis develops the relationship between the control factors cutting speed, feed rate, depth of cut, nose radius and the output performance surface roughness.

$R_a$ = 3.304 – 0.00750*Cutting speed (A) + 15.85*Feed rate (B) + 1.45*Depth of cut (C) – 0.371*Nose radius (D) – 0.0476*Cutting speed (A)*Feed rate (B) + 0.00333*Cutting speed (A)*Depth of cut (C) + 3.7*Feed rate (B)*Depth of cut (C)

95.17% of the total variations are defined by the regression model. Normality assumption is satisfied if the residuals plot approximately along straight line. After plotting a graph between normal probabilities vs. residuals of linear **(Figure)** shows that the residuals are nearly close to a straight line dictating that errors are distributed normally and giving support that the terms considered in model are significant. The graph of residuals vs. fitted values shows no unusual structure is apparent. A check on the normal probability plot vs. residuals of linear **(Figure 5)** shows that the residuals lie reasonably close to a straight line dictating that errors are distributed normally and giving support that the terms mentioned in the model are significant. The graph of residuals vs. fitted values shows no unusual structure is apparent. Residual plot generates the graph of residuals vs. order of data which dictates random nature of residuals without exhibiting any pattern with respect to experimental order run. It also reveals that there is no noticeable pattern or abnormal structure present in the data. It represents that the regression model obtained is adequate and does not violate independence or constant assumption.

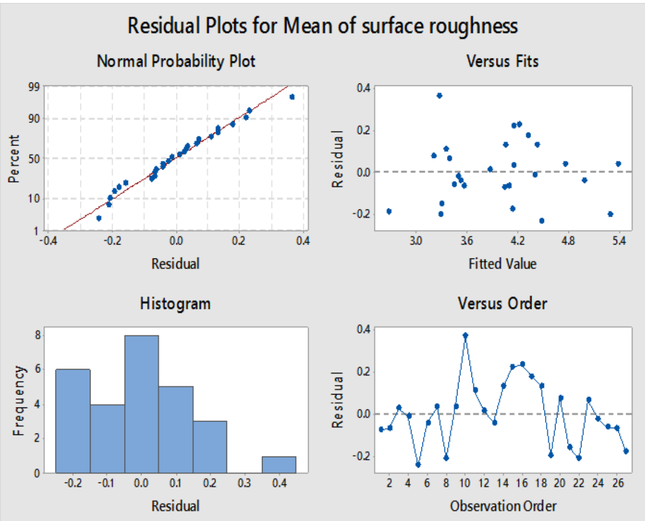


Fig 5:- Residual plot for mean of surface roughness

- *Validation Test:*

An experiment has been conducted at cutting speed 192 mm/sec, feed rate 0.08 mm/rev, depth of cut 0.3 mm and nose radius 1.2 mm and measured surface roughness ($R_a$) was found to be 2.5831 µm. Same range of cutting parameters were substituted in obtained regression model and surface roughness ($R_a$) value obtained was found to be 2.6713 µm. The error observed was 3.3 %.

## IV. CONCLUSION

On turning AISI D2 steel Taguchi design of experiment was implemented to obtain optimum level of cutting parameters. After completion of experimental runs, the data obtained were analyzed by ANOVA using MINITAB 18 software.

The results obtained are given below:

- The main advantage of employing Taguchi method is effective utilization of experimental investigation for design and analysis of surface quality.
- From the ANOVA, it is found that the cutting speed has most influence on surface roughness followed by feed rate than depth of cut and nose radius has least influence among input parameters. Interactions AB, AC and BC have least significance on surface roughness. These interactions cannot be neglected though they are considered for experiments.
- The validation experiment confirmed that the error occurred was 3.3% which is less than 5.0% between regression equation and actual value. The optimal level of cutting process parameters are in sequence: cutting speed 198 mm/sec, feed rate 0.08 mm/rev, depth of cut 0.03 mm and nose radius 1.2 mm at which minimum surface roughness value of 2.5831 µm is obtained i.e. better surface finish.
- In regression model, the value of R-sq obtained describes that 95.17% of the total are explained by the model. It concludes that, to predict the surface roughness on machining D2 steel, this developed model can be effectively used for 95% confidence level for different ranges of controllable input parameters.
- Developed regression model can be further used to calculate surface roughness for different value of controlling parameters.

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