# OPTIMIZING MACHINING PARAMETERS WHILE TURING STEEL (SS 316 L) UNDER MQL CONDITIONS

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**ABSTRACT**:- *Minimum quantity lubrication is a technique to have the advantages that cutting fluids bring yet keeping their use at minimum. Signify MQL and MQL with nanoparticles was selected in this study as the cutting fluid for turning of steel (SS 316L). The hard turning was at various cutting speeds (100, 150, and 200 m/min) and feeds (0.1, 0.15, and 0.2 mm/rev) and depth of cut (0.4, 0.6, 0.8) take place. The machining responses were surface roughness, and cutting forces . Design of experiments was applied to quantify the effects of cutting parameters to the machining responses.Empirical models surface roughness, and cutting forces were developed within the range of cutting parameters selected. Box-Behnken technique was used to decide no. of experiments. Analysis of variance (ANOVA) was performed to determine the significance parameters at a 95% confidence interval. All machining responses are significantly influenced by the cutting speed, feed, depth of cut and also MQL with nanoparticles.*

***Keywords: MQL(minimum quantity lubrication), SS316L , Machining***

## I. INTRODUCTION

Industries are seeking methods for reducing consumption of lubricants during metal cutting operation because of economical and ecological pressures. Those organizations which signed up international standard 14001 will need to quantify and prove reduction on the consumption / damage of the following five elements. First is reduction in harmful emission to air, second is reduction in release of harmful effluents into water, third is focus on waste management, fourth is reduction in contamination in land, and fifth is reduction in use of raw materials and natural resources (Gordana et al, 2013). Research has found that the costs related to cutting fluids are frequently higher than those related to cutting tools. Moreover, cooling lubricants have been found to cause health and safety problems for workers, related to lubricant use and correct disposal (Diniz and Micaroni, 2002)

Therefore, many researchers have focus on environment friendly machining technology. Environment friendly machining technologies can be classified into dry and semi-dry machining technologies according to consumption of cutting fluids. It is important to consider environmental factors and economic factors(Lee and Lee, 2001). MQL (minimum quantity lubrication) machining in particular, has been accepted as a successful semi - dry application because of its environment friendly characteristics. However, in the case of MQL machining, not many studies have been done on the effects of cutting parameters on the machinability (cutting force, surface roughness, toollife, etc.) and selection of optimal cutting conditions.

The goal of any machining operation is to lower the machining costs by improving quality and productivity. This is possible if machining is carried out at top/maximum cutting parameters and simultaneously, be able to achieve long Tool Life, have minimum part rejections and minimum downtime.

**Cutting Fluids**

Cutting fluids are employed in machining operation to improve the tribology process, which occur when the two surfaces, the turning tool and the workpiece make contact during the operation. On the other hand, the cutting fluids have many detrimental effects. Many of the fluids, which are used to lubricate metal forming and machining, contain harmful chemical constituents. These fluids are difficult to dispose and very expensive to recycle and can cause skin and lung diseases to the operators and apart from this they also cause air pollution (Kardekar, 2005). On the other hand MQL systems have seen some success in reducing cutting fluids consumption with minimum reduction in work piece property. They have not yet been widely used in turning operation industry. Much of the work done on the effectiveness of MQL systems based on comparative cutting trails with and without the use of cutting fluids.

**Minimum Quantity Lubrication (MQL)**

Reducing the use of cutting fluid in machining process is a critical need with the aim of eliminating environment pollution and economic cost. Machining with minimum quantity lubrication (MQL) has been considered as an alternative, in which a small quantity of lubricating oil mixed with compressed air flow is delivered in the tool-workpiece interface.

MQL sprays only a small quantity of lubricant for reducing friction at the tool-workpiece interface. Most of literatures had made great effort to compare environment effects including dry, metal working fluid and MQL (Liu et al, 2013).The main component of this MQL system is an air blast atomizer injector shown in Fig. 1.1, with an oil nozzle (nozzle diameter may vary as per requirement), and the injector operates with pressurized air, the pressurized air arrives at the system and passes through a filter equipped with a dryer. The air then goes through a pressure regulator and reaches the external channel of the atomizer. Oil is transported to the internal channel of the atomizer through a micro-volumetric piston pump and various regulators (Kouam et al, 2015).

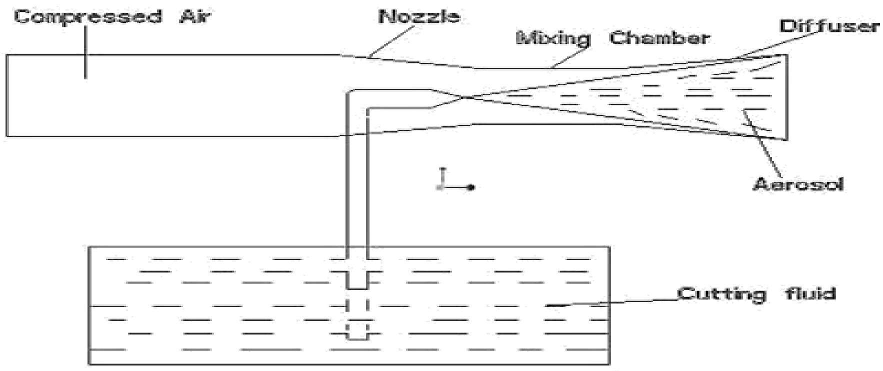


Figure 1.1 Schematic of an Atomizer

The advantages of MQL are shown below:

- Increased cutting rates reduce the machining times and, therefore, manufacturing cost.
- Longer tool life through more consistent cooling without sudden thermal shock reduces the number of tool changes and tooling requirement.
- The workpieces remain dry, so that you can save on the de-greasing.
- Dryer chips can be disposed of easier and more cost-efficient.
- The surface quality of the workpieces to be machined is improved by the pure lubricant.

## II. PROBLEM FORMULATION

After doing literature review, we observed that most of the researchers did their studies in machining behavior of different materials with different tools and different cutting parameters. They studied the effect of speed, feed, depth of cut on machinability characteristics such as tool wear, tool stresses, cutting forces, chip thickness ratio, tool tip temperature, surface roughness and tool life under dry cooling and MQL condition. But MQL with nanoparticles has not been performed in previous research work, and machining of SS316L under MQL condition has not been studied. So, in this research work SS316L was taken as work material under MQL with nanoparticles cooling condition to study the machinability characteristics such as cutting forces and surface roughness.

## III. RESEARCH GAP

Most of the research work of machining is done on different type of steel alloy such as carbon steel alloy, 100CR6 steel alloy, AISI1040 steel alloy, EN31 steel alloy, CK45E steel alloy etc. Thus, for the following research the SS316L steel was brought into use as the literature reveals that scanty work has been done on this material in contribution with the nano particle lubrication.

## IV. OBJECTIVE OF RESEARCH

- To experimentally investigate the role of minimum quantity lubrication (MQL) on the surface roughness and cutting forces in turning operation of steel 316 L (SS316L).
- To optimize the cutting parameters on the basis of surface roughness and cutting forces during turning operation.

## V. EQUIPMENTS AND EXPERIMENTAL WORK

To complete this experimental work many of the equipment were used. For this metal cutting operation a CNC turning center used and for measuring cutting forces a dynamometer is also used. A Mitutoyo portable surface roughness measurement instrument was used for measuring surface roughness. For cutting tool coated carbide inserts were used. A detail description of all equipment used in this research work is discussed in this chapter.

**Turning Machine**

The turning operation is performed at the turning machine is used shown in figure 5.1. For the turning process, a Sprint TC 16 CNC Turning Centre was used . And it also has independent coolant tank and chip tray for ease in cleaning and maintenance. And Specification of Turning machine listed in below table 5.1 , specification of Sprint 16 TC

| | |
|---|---|
| Swing over bed | 400 mm |
| Turning diameter | 225 mm |
| Turning length | 300 mm |
| Power chuck | 165 mm |

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| | |
|---|---|
| Spindle speed | 30-5000 rpm |
| Spindle motor | 5.5/7.5 kw |
| z-axis stroke | 325 mm |
| x-axis stroke | 125 mm |
| Maximum no. of tools in turret | 8 |
| Rapid traverse | 20 m/min |
| Tail stock | Hydraulic |


Figure 5.1 Turning Machine

**Workpiece Material**

Steel alloy SS 316 L is used as a workpiece material for this research work. SS316L is an austenitic Chromium-Nickel stainless steel with superior corrosion resistance. The low carbon content reduces susceptibility to carbide precipitation during welding. This permits usage in severe corrosive environments such as isolator diaphragms. SS316L steel alloy has a wide range of application such as pipes, tubes, sheets, coils, plates, ball valves, rods, bars, angles and also used in designer or architectural work. Chemical composition of SS316L is shown below

Table 5.2 Chemical Composition of SS316L

| Sr. No. | Chemical Composition | Wt % |
|---|---|---|
| 1 | Chromium | 17.2 % |
| 2 | Nickel | 10.9 % |
| 3 | Molybdenum | 2.1 % |
| 4 | Manganese | 1.6 % |
| 5 | Carbon | 0.02 % |
| 6 | Iron | 68.18 % |

Mechanical properties such as ultimate tensile strength, yield strength, elongation, modulus of elasticity, poisson's ratio are below

| Sr. No. | Mechanical properties | Annealed | Cold rolled |
|---|---|---|---|
| 1 | Ultimate tensile strength | 620.528 Mpa | 1241.05 Mpa |
| 2 | Yield strength | 289.57 Mpa | 1103.16 Mpa |
| 3 | Elongation | 40 % | 2 % |
| 4 | Modulus of elasticity | 19.3 x Mpa | 19.3 x Mpa |

**Experimental Work**

Turning operation was carried out using three levels of cutting speeds 100 m/min., 150 m/min. and 200 m/min. Three levels of feed rate 0.1 mm/rev, 0.15 mm/rev, 0.20 mm/rev and also with three levels of depth of cut 0.4 mm, 0.6 mm, 0.8 mm were used for this research work. Three types of MQL conditions as signifies MQL, signifies MQL + Nano graphite, signifies MQL + Nano molybdenum disulphide were also used. In this research work commercially available vegetable oil was used as cutting oil with 1% mixing. Total 29 experiments were performed with different sets of cutting speed, feed, depth of cut and MQL conditions. For every sets of experiment cutting forces was measured by piezoelectric type dynamometer and surface roughness was measured by Mitutoyo portable surface roughness measurement instrument

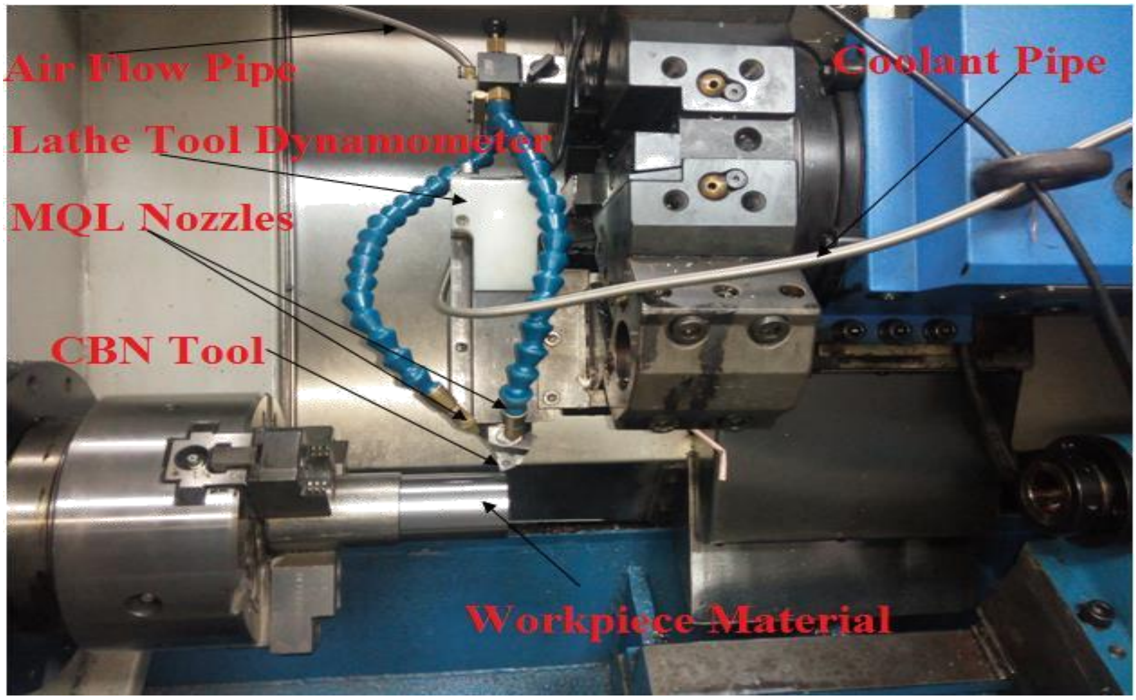


Fig. 5.2 Experimental setup

For analyse and optimize experimental data, Design of Experts software was used. The experiments were designed by Box-Behnken in response surface of Design experts. Response surface technique helps in reducing the no. of experiments. The experiments were conducted according to three levels and four factors. Three factors were used i.e. cutting speed, feed rate and depth of cut were numerical factors and one factor was categorical factor. The surface roughness and cutting forces were taken as the response parameters.

Table 5.4 Experimental Data

| RUN | CUTTING SPEED (vc, m/min) | FEED RATE (fn, mm/rev) | DEPTH OF CUT (ae, mm) | CUTTING FLUIDS (ml/hrs.) | SURFACE ROUGHNESS ($R_a$, μm) | CUTTING FORCE (CF, N) |
|---|---|---|---|---|---|---|
| 1 | 200 | 0.15 | 0.6 | 3 | 0.71 | 153 |
| 2 | 150 | 0.15 | 0.6 | 2 | 0.76 | 132 |
| 3 | 150 | 0.15 | 0.6 | 2 | 0.72 | 129 |
| 4 | 150 | 0.1 | 0.8 | 2 | 0.67 | 92 |
| 5 | 150 | 0.1 | 0.6 | 3 | 0.61 | 96 |
| 6 | 150 | 0.2 | 0.4 | 2 | 0.83 | 168 |
| 7 | 150 | 0.15 | 0.6 | 2 | 0.75 | 122 |
| 8 | 150 | 0.15 | 0.8 | 1 | 0.71 | 141 |
| 9 | 200 | 0.15 | 0.8 | 2 | 0.81 | 172 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 10 | 100 | 0.15 | 0.8 | 2 | 0.55 | 103 |
| 11 | 150 | 0.15 | 0.8 | 3 | 0.63 | 119 |
| 12 | 150 | 0.2 | 0.6 | 1 | 0.95 | 160 |
| 13 | 150 | 0.15 | 0.6 | 2 | 0.75 | 129 |
| 14 | 100 | 0.15 | 0.6 | 1 | 0.62 | 118 |
| 15 | 150 | 0.2 | 0.8 | 2 | 0.87 | 159 |
| 16 | 200 | 0.15 | 0.6 | 1 | 0.91 | 172 |
| 17 | 200 | 0.2 | 0.6 | 2 | 0.85 | 179 |
| 18 | 100 | 0.15 | 0.6 | 3 | 0.64 | 86 |
| 19 | 150 | 0.15 | 0.4 | 1 | 0.87 | 123 |
| 20 | 150 | 0.15 | 0.6 | 2 | 0.74 | 128 |
| 21 | 200 | 0.15 | 0.4 | 2 | 0.79 | 152 |
| 22 | 150 | 0.2 | 0.6 | 3 | 0.93 | 145 |
| 23 | 100 | 0.15 | 0.4 | 2 | 0.6 | 82 |
| 24 | 150 | 0.1 | 0.4 | 2 | 0.65 | 97 |
| 25 | 200 | 0.1 | 0.6 | 2 | 0.53 | 122 |
| 26 | 100 | 0.2 | 0.6 | 2 | 0.61 | 98 |
| 27 | 100 | 0.1 | 0.6 | 2 | 0.49 | 76 |
| 28 | 150 | 0.1 | 0.6 | 1 | 0.61 | 113 |
| 29 | 150 | 0.15 | 0.4 | 3 | 0.85 | 100 |

# VI. RESULTS AND DISCUSSION

**Analysis of Surface roughness**

As the feed rate increases the surface roughness increases and As the cutting speed increase, surface roughness increase. P value in the ANOVA(Analysis of variance) analysis shows that model is significant. ANOVA results show that feed rate has significant effect on the surface roughness. When F value increase the significance of that parameter also increases. The Model F-value of 5.91 implies the model is significant. There is only a 0.10% chance that a Model f-value|| is large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant Fig 4.1 shows the perturbation graph for surface roughness for cutting fluid 1. In this graph cutting speed, feed rate, depth of cut are the process parameters. And this graph is for cooling condition signifies MQL. The line which has more slope is most significant parameter for the response. In this graph feed rate (B) has the maximum slope. So this affects most to the response i.e. surface roughness

Table 6.1 ANOVA Analysis of surface roughness

| Source | Df | Mean square | F-value | p-value(p>f) |
|---|---|---|---|---|
| Model | 14 | 0.027 | 5.91 | 0.0010 (significant) |
| A-cutting speed | 1 | 0.099 | 21.73 | 0.0004 |
| B-feed rate | 1 | 0.18 | 40.07 | < 0.0001 |
| C-depth of cut | 1 | 0.18 | 40.07 | < 0.0001 |
| D-cutting fluid | 2 | 0.012 | 2.69 | 0.1024 |
| AB | 1 | 1.000E-002 | 2.20 | 0.1606 |
| AC | 1 | 1.225E-003 | 0.27 | 0.6122 |
| AD | 2 | 6.052E-003 | 1.33 | 0.2963 |
| BC | 1 | 1.000E-004 | 0.022 | 0.8843 |
| BD | 2 | 5.258E-003 | 1.15 | 0.3436 |
| CD | 2 | 0.013 | 2.95 | 0.0851 |
| Residual | 14 | 4.556E-003 | 0.27 | 0.6122 |

1. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL

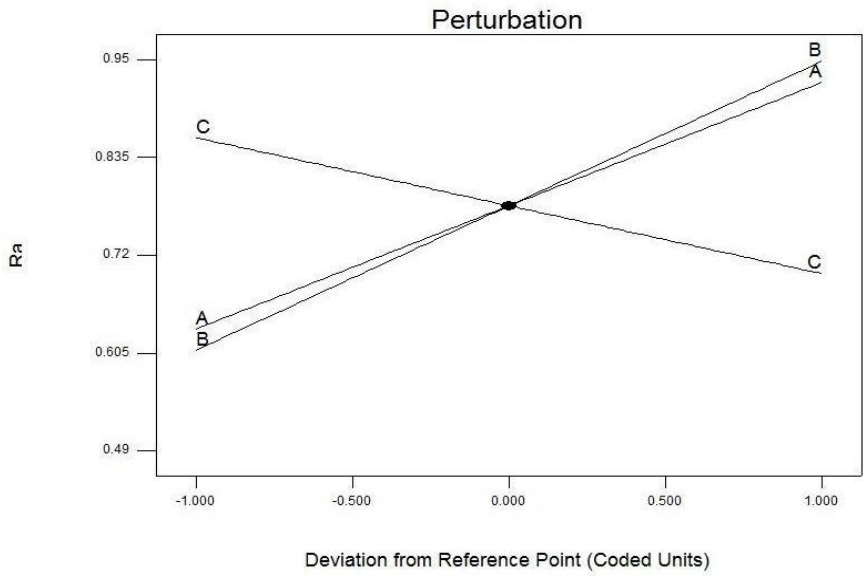


Fig 6.1 Surface Roughness Perturbation Graph for cutting fluid 1

**Final Equation of Surface Roughness from ANOVA in Terms of Actual Factors under Cutting Fluid 1:** $R_a$ = 0.72583 - 1.15000E – 003 * vc + 0.10000 * fn - 0.73750 * ap + 0.020000 * vc * fn + 1.75000E – 003 * vc * ap + 0.50000 * fn * ap …(1)

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(vc=Cutting Speed, fn=Feed Rate, ap=Depth of Cut)

2. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL + Nano Graphite

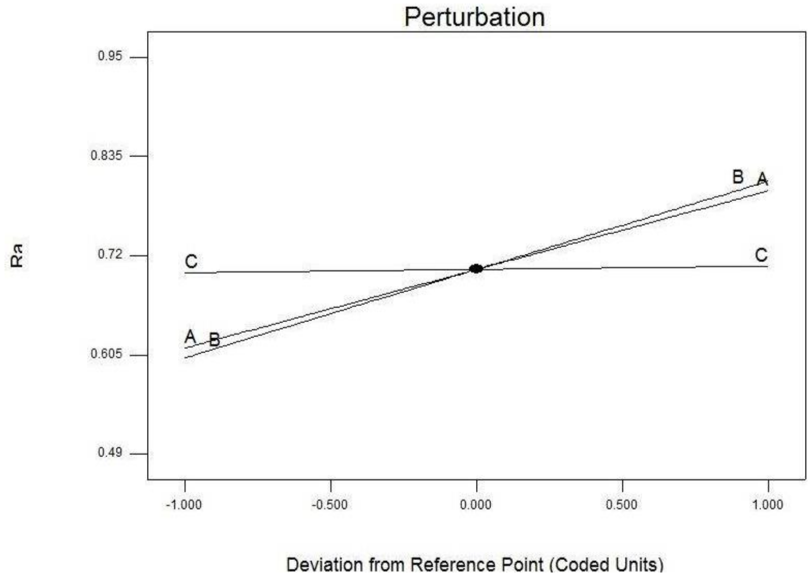


Fig 6.2 Surface Roughness Perturbation Graph for cutting fluid 2

**Final Equation of Surface Roughness from ANOVA in Terms of Actual Factors under Cutting Fluid 2:** $R_a$ = 0.76412 – 2.22500E – 003 * vc – 1.25000 * fn – 0.31875 * ap + 0.020000 * vc * fn+ 1.75000E – 003 * vc * ap + 0.50000 * fn * ap ……(2)

3. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL + Nano Molybdenum Disulphide

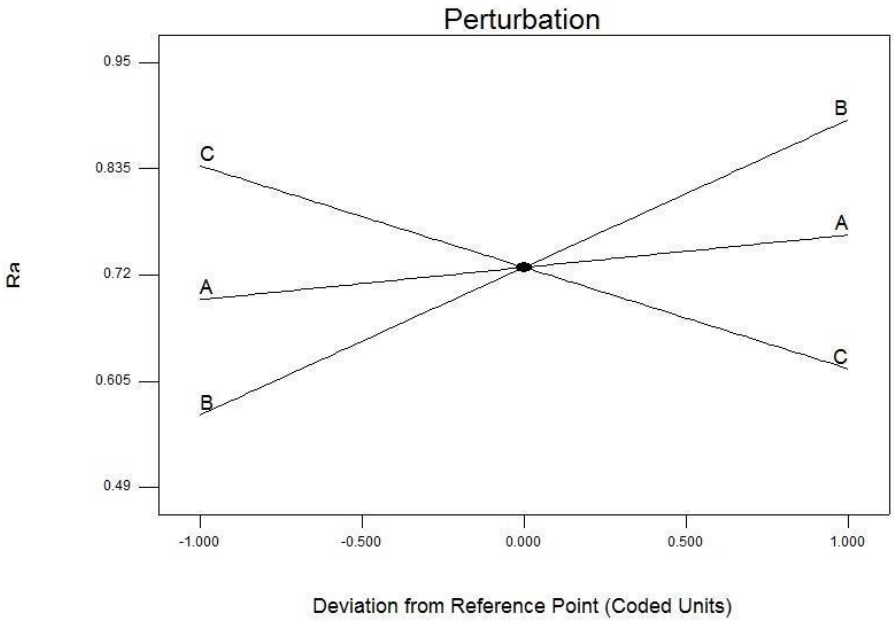


Fig 6.3 Surface Roughness perturbation Graph for cutting fluid 3

**Final Equation of Surface Roughness from ANOVA in Terms of Actual Factors under Cutting Fluid 3:** $R_a$ = 1.12583 - 3.35000E – 003 * vc - 0.100000 * fn - 0.88750 * ap + 0.020000 * vc * fn+ 1.75000E – 003 * vc * ap + 0.50000 * fn * ap …(3)

(vc=Cutting Speed, fn=Feed Rate, ap=Depth of Cut)

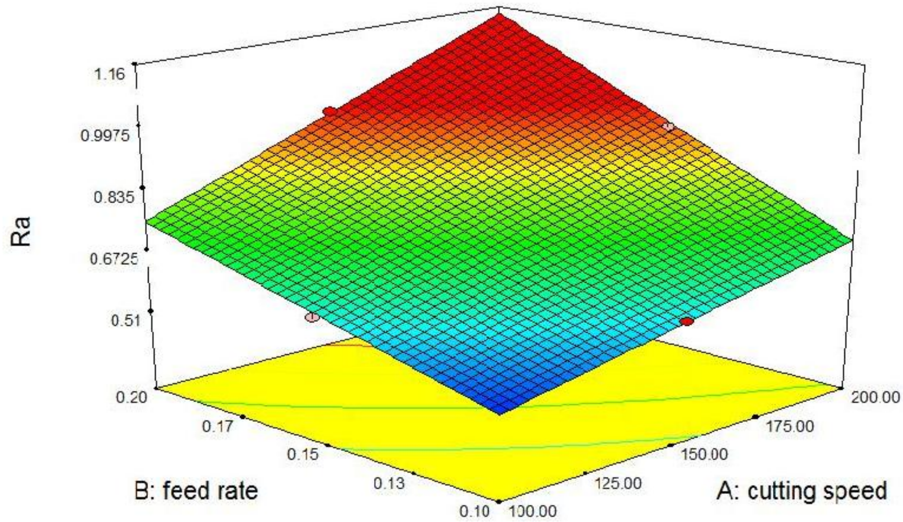


Fig. 6.4 3D surface of surface roughness

Above fig. shows 3D surface for surface roughness. By this figure, it is concluded that surface roughness is proportional to cutting speed and feed rate i.e. surface roughness increases with increasing of cutting speed and feed rate or vice versa.

When in this research work cooling fluid type 3 i.e. signifies MQL + Nano Molybdenum Disulphide was used then surface roughness value comes in between the value of surface roughness when used cooling fluid type 1 and cooling fluid type 2. Hence to minimize surface roughness cooling fluid type 2 i.e. signifies MQL + Nano Graphite is best.

**Analysis of Cutting Forces**

For cutting forces analysis of variance is based on the criteria lower is better. The main purpose of ANOVA is to find which of the process parameters significantly affect the performance characteristics

In below table the Model F-value of 15.45 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. Values greater than 0.1000 indicate the model terms are not significant

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| Source | Df | Mean square | F-value | p-value(p>f) |
|---|---|---|---|---|
| Model | 14 | 1632.80 | 15.45 | < 0.0001 |
| A-cutting speed | 1 | 12480.75 | 118.07 | < 0.0001 |
| B-feed rate | 1 | 8164.08 | 77.24 | < 0.0001 |
| C-depth of cut | 1 | 341.33 | 3.23 | 0.0939 |
| D-cutting fluid | 2 | 688.47 | 6.51 | 0.0100 |
| AB | 1 | 306.25 | 2.90 | 0.1108 |
| AC | 1 | 0.25 | 2.365E-003 | 0.9619 |
| AD | 2 | 33.13 | 0.31 | 0.7360 |
| BC | 1 | 4.00 | 0.038 | 0.8486 |
| BD | 2 | 13.52 | 0.13 | 0.8809 |
| CD | 2 | 46.15 | 0.44 | 0.6548 |
| Residual | 14 | 105.70 | Residual | 14 |

Perturbation graphs of cutting forces show the dependency of cutting forces of feed rate, cutting speed, depth of cut and type of cutting fluid. The parameter which has more slopes on graph affects most to the cutting forces. In these graph speed has more slope so it affects cutting forces most. Curve B which shows feed rate line is second most slope in the graph so it affects the cutting forces most after cutting speed. Depth of cut has less effect on the cutting forces

I. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL

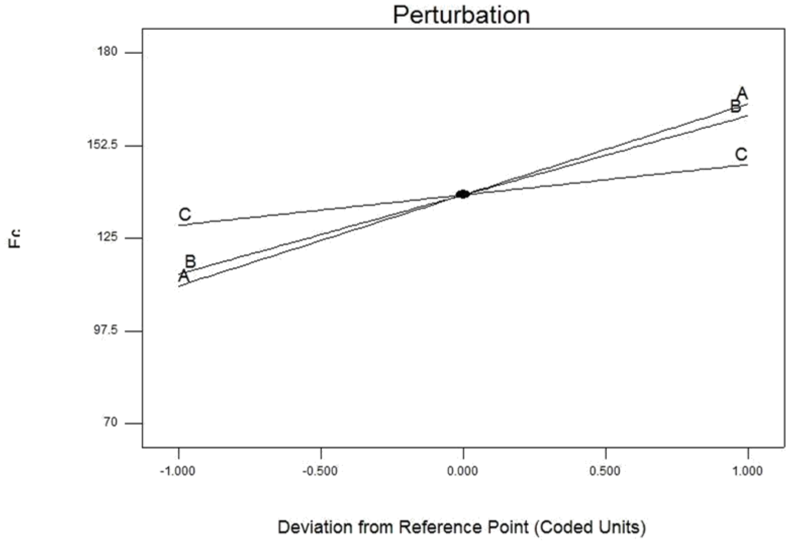


Fig 6.5 Cutting Forces Perturbation Graph for cutting fluid 1

**Final Equation of Cutting Forces from ANOVA in Terms of Actual Factors under Cutting Fluid 1:** CF = 26.83333 + 0.030000E * vc + 5.00000 * fn + 63.75000 * ap + 3.50000 * vc * fn- 0.025000 * vc * ap – 100.00000 * fn * ap ………………….(4)

II. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL + Nano Graphite

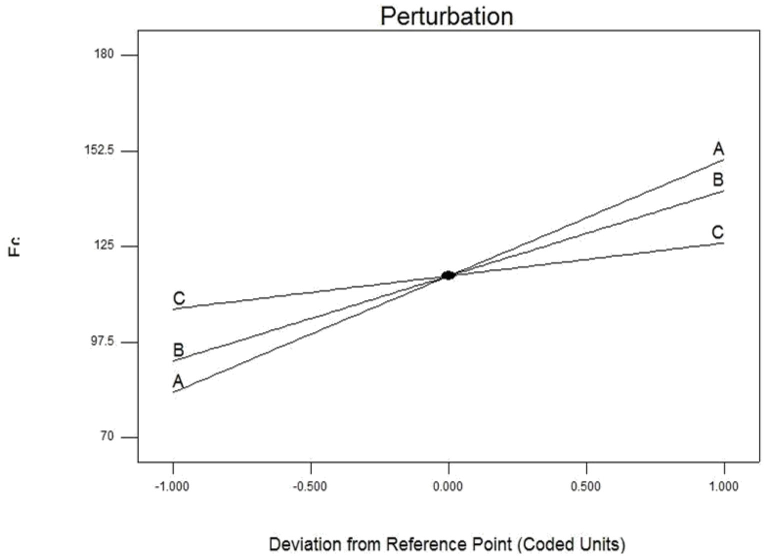


Fig 6.6 Cutting Forces Perturbation Graph for cutting fluid 2

**Final Equation of Cutting Forces from ANOVA in Terms of Actual Factors under Cutting Fluid 2:**CF = 2.13235 + 0.15500 * vc + 77.50000 * fn + 35.62500 * ap + 3.50000 * vc * fn- 0.025000 * vc * ap – 100.00000 * fn * ap ………..(5)

III. Actual factors: A (cutting speed) = 150, B (feed rate) = 0.15, C (depth of cut) = 0.60, cutting fluid = signifies MQL + Nano Molybdenum Disulphide

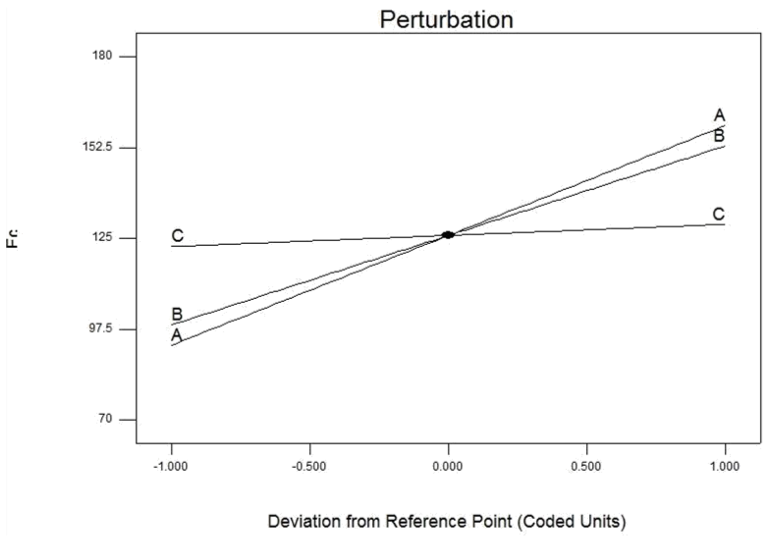


Fig 6.7 Cutting Forces Perturbation Graph for cutting fluid 3

**Final Equation of Cutting Forces from ANOVA in Terms of Actual Factors under Cutting Fluid 3:** CF = - 18.50000 + 0.16000 * vc + 25.00000 * fn + 66.25000 * ap + 3.50000 * vc * fn- 0.025000 * vc * ap – 100.00000 * fn * ap ………...(6)

As fig. 4.5, 4.6, and 4.7 show cutting forces under different cooling fluid conditions. Here maximum value of cutting forces come under the cooling fluid type 1 is used i.e. signifies MQL. And minimum value of surface roughness comes under the cooling fluid type 3 is used i.e. signifies MQL + Nano Molybdenum Disulphide.

3D surface for cutting forces. By this figure, it is concluded that cutting forces is proportional to cutting speed and feed rate i.e. cutting forces increases with increasing of cutting speed and feed rate or vice versa.

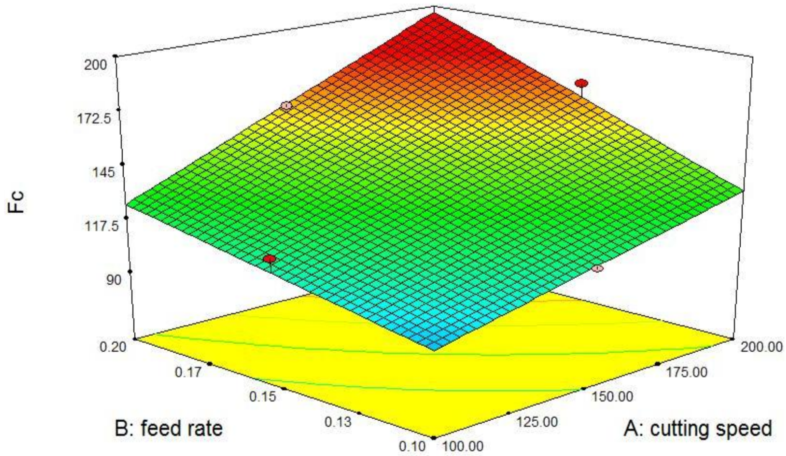


Fig.6.8 3D surface of cutting forces

When in this research work cooling fluid type 2 i.e. signifies MQL + Nano Graphite was used then cutting forces value comes in between the value of cutting forces when used cooling fluid type 1 and cooling fluid type 2. Hence to minimize cutting forces cooling fluid type 3 i.e. signifies MQL + Nano Molybdenum Disulphide is best.

**Optimization of Cutting Parameters:**

Constraints are shown in table 4.3. Optimized parameters are based on the desirability of parameters like feed rate in range, cutting speed in range, depth of cut in range, cooling fluids all type, surface roughness minimum and cutting forces also minimum. Many combination of cutting parameters were tested by software and the combination of cutting parameters which shows maximum desirability are optimum cutting parameters. In the table 4.4 row one satisfies all the parameters so these are optimum values.

| Name | Goal | Lower Limit | Upper Limit |
|---|---|---|---|
| cutting speed | is in range | 100 | 200 |
| feed rate | is in range | 0.1 | 0.2 |
| depth of cut | is in range | 0.4 | 0.8 |
| cutting fluid | is in range | 1 | 3 |
| Ra | minimize | 0.49 | 0.95 |
| Fc | minimize | 76 | 179 |

Table 6.3 Constraints for Optimizing Cutting Parameters

| Cutting speed (vc) | feed rate (fn) | depth of(ae) | cutting fluid | Ra | CF | Desirability |
|---|---|---|---|---|---|---|
| 100.12 | 0.10 | 0.75 | 3 | 0.489776 | 75.6957 | 1.000 (selected) |
| 102.02 | 0.10 | 0.74 | 3 | 0.489876 | 75.8471 | 1.000 |
| 100.44 | 0.10 | 0.74 | 3 | 0.488254 | 75.3095 | 1.000 |
| 100.00 | 0.10 | 0.78 | 2 | 0.543639 | 78.3843 | 0.929 |
| 103.12 | 0.10 | 0.80 | 1 | 0.417913 | 107.463 | 0.833 |
| 118.92 | 0.10 | 0.80 | 2 | 0.563843 | 88.0563 | 0.861 |
| 100.00 | 0.13 | 0.80 | 1 | 0.485243 | 114.518 | 0.791 |

**Experimental Validation**

For validation of this research work three different experiments were performed at optimized cutting speed (vc), feed rate (fn), depth of cut (ae) and also obtained best cutting fluid then following results were found shown in table 4.5.

| | Cutting speed (vc) | Feed rate (fn) | Depth of cut (ae) | Cutting fluid | Ra | % error | CF | % error |
|---|---|---|---|---|---|---|---|---|
| **Exp.1** | 100.12 | 0.10 | 0.75 | 3 | 0.514264 | 5% | 80.3888 | 6.2% |
| **Exp.2** | 100.12 | 0.10 | 0.75 | 3 | 0.517693 | 5.7% | 80.8430 | 6.8% |
| **Exp.3** | 100.12 | 0.10 | 0.75 | 3 | 0.521611 | 6.5% | 80.9943 | 7% |

## VII. CONCLUSIONS

- As the cutting speed, feed rate and depth of cut increase then cutting forces also increase. Cutting speed is main parameter that effect cutting forces as compare to other parameters

- Signify MQL gives more cutting forces but signify MQL + Nano Molybdenum Disulphide use of cutting fluid gives best results i.e. this cutting fluid gives minimum cutting forces
- Cutting speed, feed rate and depth of cut effect surface roughness. Depth of cut has minimum effect on surface roughness but feed rate has maximum effect on surface roughness. As feed rate increase then surface roughness also increase
- Signify MQL also gives more surface roughness but signify MQL + Nano Nano Graphite use of cutting fluid gives best results i.e. this cutting fluid gives minimum surface roughness.
- Minimum cutting forces are obtained at cutting speed = 100.75 m/min., feed rate = 0.10 mm/rev., depth of cut = 0.61 mm and under signify MQL + Nano Molybdenum Disulphide cooling fluid condition.
- Minimum surface roughness are obtained at cutting speed = 100 m/min., feed rate = 0.10 mm/rev., depth of cut = 0.79 mm and under signify MQL cooling fluid condition.
- Optimum cutting parameters to satisfy all the constraints are cutting speed = 100.12 m/min., feed rate = 0.10 mm/rev., depth of cut = 0.75 and under signify MQL + Nano Molybdenum Disulphide cooling fluid condition

## VIII. Future Scope

In the present research work it has been observed that the input parameters affect the responses in one way or the other. This creates a lot of scope for the future work that can be taken up for the further study of turning process.

- Measuring the surface roughness and cutting forces with the different type cooling fluids and with different Nano fluid particles. That they may be more eco-friendly.
- By changing the work piece steel SS 316 L then seeing the effect on the cutting forces and surface roughness.

Varying the cutting parameters and observe the effect on the cutting forces and surface roughness

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