# Taguchi Optimization of Minimum Quantity Lubrication on turning of AISI-1040 Steel using Ferrite Nanolubricants

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**ABSTRACT**

The present research study explores the effect of Minimum Quantity Lubrication (MQL) parameters on the material removal rate and surface roughness of AISI-1040 Steel in turning operation by using Zinc Ferrite and Copper Ferrite with SAE 40 , SAE 50 base oils as lubricants. The main objective of the study is to optimize the process parameters of MQL turning by using Taguchi method. Several tests were conducted by varying process parameters (cutting speed, depth of cut) with the nanolubricants used for the study with a view to observe the resultant variations in the temperature and surface roughness. The study was conducted using Taguchi $L_{16}$ orthogonal array. According to the analysis, the feed rate is the most influencing parameter for temperature, the depth of cut is the most influencing parameter for surface roughness. It is observed that the lowest temperature and better surface finish is observed for 0.4 weight percentage of Copper Ferrite with SAE 50 oil as compared to other nanolubricants considered for the study

**Key words:** Optimization , MQL , nanolubricant, Taguchi method.

## Introduction

Machining is one of the essential and challenging tasks in the manufacturing industries today. It involves a controlled removal of material from the substance using acutting tool. As machining involves plastic deformation of work-piece material and also friction between tool-chip and tool work-piece interface, it needs high amount of energy which further gets converted into heat. In the process of machining, less amount of heat generation takes place in respect of low strength alloys.On the other hand, machining of ferrous and other high strength alloys are associated with larger amounts of heat generation. The dissipation of this generated heat is one of the important factors to be considered as a part of good machining process.

Machining is a manufacturing process that involves removal of unwanted material from some work-piece using cutting tools for converting it into the shape we desire. Machining processes have been classified into different categories, viz., Drilling, Turning, Milling, Grinding etc.

In traditional flood cooling, there are some negative impacts such as disposal of cutting fluid, cost of cutting fluid, spreading of cutting fluid around the machine, harmful residuals, disposal of wet chips and less visibility. MQL technique has been proved an alternative to overcome these deficiencies.

**Literature Review**

**Mao et al.** [1] has carried out an experiment in order to investigate the suspension stability of $Al_2O_3$ nanoparticles with MQL technique in grinding. The obtained results indicate that $Al_2O_3$ nanoparticles have got poor suspension stability in short-time ultrasonic vibration. It has claimed that suspension stability of $Al_2O_3$ nanoparticles can be improved by using 0.5% concentration and running the ultrasonic vibrator at least for one hour. **Yildirim C.V. et al.** [2] conducted a study on the development of nano-MQL by adding hBN nanoparticles compared to pure MQL and dry machining in turning of Inconel 625. Tool life, surface roughness and tool-chip interface temperature were analyzed. Wear mechanisms were evaluated using SEM photographs. The results showed that 0.5 vol.% hBN nanofluids have produced promising results for low tool wear and roughness. The results also showed high tool life with nanoparticulate MQL as compared to pure MQL and dry machining in turning of Inconel 625.

In a study conducted by Darshan, C et al. [3], it is reported that Nickel (Ni)-based alloys have become widely accepted materials for the manufacture of critical parts owing to their exceptional characteristics such as high creep, good rupture strength, and resistance to corrosion and oxidation. Due to excellent fatigue strength and possession of yield strength at high temperature and pressure (600 ◦C, 1000 MPa), Ni alloys are used in the manufacturing of aero-engines, turbine blades, nuclear reactors and in chemical industries, where there is a requirement for use of cyclic loads and high temperatures. Thakur and Gangopadhyay [4] have examined an aero-engine consisting of 50% Ni alloy in weight, due to its high thermal stability in severe environments. In the experiment conducted by Behera, B.C. et al.[5], it is reported that Ni alloys are ductile materials under cryogenic temperature because of their face-cantered cubic (FCC) structure; and hence they used Ni alloys in cryogenic tanks as superconducting materials, and in rocket motor casings. Ni-based alloys have several grades such as Inconel-718, FGH-95, ME-16, IN-100, Inconel-800, and Inconel-825. The experiments conducted by Gurraj et al. [6] revealed that Inconel-800 is a Fe–Ni–Cr alloy that offers adequate resistance to oxidation, and carburization even at elevated temperatures with moderate strength. M'Saoubi, R. et al.[7] reported that it is highly desirable for the manufacturing of high temperature equipment which is resistant to chloride stress corrosion cracking and shows high creep and stress rupture characteristics in the temperature range of 594–983 ◦C.

## Experimental Results

In the present investigation, the influence of different weight percentages of zinc ferrite and copper ferrite nanoparticles along with SAE 40 and SAE 50 base oils when used as a lubricant in turning of AISI 1040 steel, was studied. The variation of temperatures and surface roughness were studied during the experimentation.

**Fig.** Experimental set up of MQL on the lathe

The results of temperature and surface roughness were observed as below.

**Temperature v/s Sample, Feed rate, Depth of cut**

| Sample | Feed rate | Depth of cut | Temperature |
|---|---|---|---|
| S1 | 0.14 | 0.25 | 109 |
| S1 | 0.15 | 0.5 | 120 |
| S1 | 0.16 | 0.75 | 145 |
| S1 | 0.17 | 1 | 155 |
| S2 | 0.14 | 0.5 | 109 |
| S2 | 0.15 | 0.25 | 110 |
| S2 | 0.16 | 1 | 135 |
| S2 | 0.17 | 0.75 | 132 |
| S3 | 0.14 | 0.75 | 110 |
| S3 | 0.15 | 1 | 128 |
| S3 | 0.16 | 0.25 | 116 |
| S3 | 0.17 | 0.5 | 119 |
| S4 | 0.14 | 1 | 110 |
| S4 | 0.15 | 0.75 | 115 |
| S4 | 0.16 | 0.5 | 116 |
| S4 | 0.17 | 0.25 | 117 |

**Surface roughness v/s Sample, Depth of cut**

| Sample | Depth of cut | Surface roughness |
|---|---|---|
| S1 | 0.25 | 4.18 |
| S1 | 0.5 | 5 |
| S1 | 0.75 | 6.12 |
| S1 | 1 | 7.45 |
| S2 | 0.25 | 3.8 |
| S2 | 0.5 | 4.5 |
| S2 | 0.75 | 5.61 |
| S2 | 1 | 6.31 |
| S3 | 0.25 | 3.5 |
| S3 | 0.5 | 4 |
| S3 | 0.75 | 5 |
| S3 | 1 | 5.3 |
| S4 | 0.25 | 3 |
| S4 | 0.5 | 3.9 |
| S4 | 0.75 | 4.5 |
| S4 | 1 | 5 |

**Optimization of MQL parameters by using Taguchi method**

**Barman, P.** [8] opined that Taguchi methods are the statistical methods that are developed recently; and applied to engineering, biotechnology, marketing and advertising. The work of Taguchi includes three principal contributions to statistics - a specific loss function, i.e. Taguchi loss function, the philosophy of off-line quality control; and innovations in the design of experiments. Taguchi philosophies are mostly used in engineering optimization processes. It should be carried in three step approach i.e. system design, parameter design and tolerance design. The system design involves scientific and engineering principles and used to know how they are used to create a prototype of the product that will meet functional requirements. In case of Parameter design, the settings of process parameter values for improving performance characteristics are to be optimized. Roshan R. Nikule [9] stated that Taguchi design also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by selecting parameter levels properly.

Nominal is the best:

$$S/NT = 10 \log (\hat{y}/s2)$$

Larger is the better (maximize):

$$S/NL= -10\log 1/\frac{1}{y}\Sigma_i^n \frac{1}{yi^2}$$

Smaller is better (minimize):

$$S/NS= -10\log 1/y \frac{1}{y}\Sigma_i^n 1yi^2$$

where ŷ the average of observed data is, ŷ /s2 is the variance of y, n the no. of observations and y is the observed data.

**Temperature versus sample, Feed rate, Depth of cut**

The following figures indicate the validation of experimental results obtained in respect of Temperature.

**Taguchi Orthogonal Array Design for Temperature**

Taguchi Orthogonal Array Design

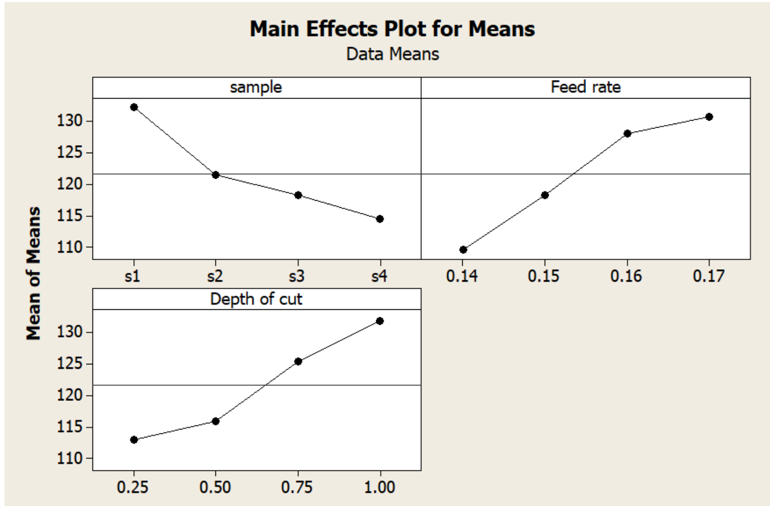
L16(4**3)

Factors: 3
Runs: 16

Columns of L16(4**5) Array
1 2 3

(a) Response Table for Means

| Level | sample | Feed rate | Depth of cut |
|---|---|---|---|
| 1 | 132.3 | 109.5 | 113.0 |
| 2 | 121.5 | 118.3 | 116.0 |
| 3 | 118.3 | 128.0 | 125.5 |
| 4 | 114.5 | 130.8 | 132.0 |
| Delta | 17.8 | 21.3 | 19.0 |
| Rank | 3 | 1 | 2 |

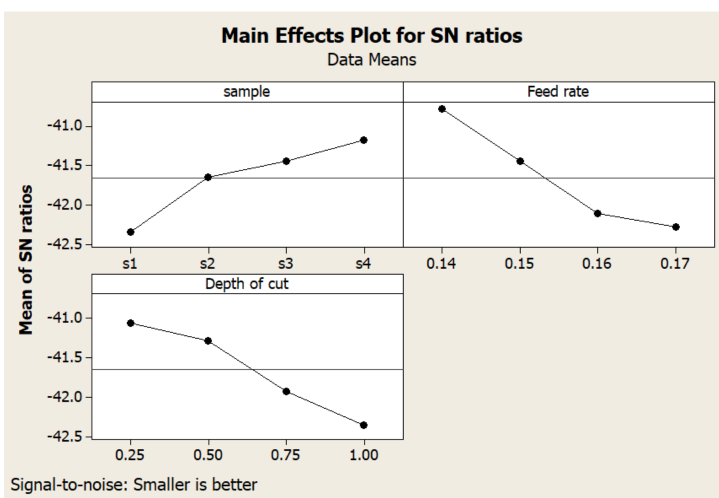



Main Effects Plot for Means

(b) Response Table for Signal to Noise Ratios

Smaller is better

| Level | sample | Feed rate | Depth of cut |
|---|---|---|---|
| 1 | -42.34 | -40.79 | -41.06 |
| 2 | -41.65 | -41.44 | -41.28 |
| 3 | -41.44 | -42.10 | -41.92 |
| 4 | -41.17 | -42.27 | -42.35 |
| Delta | 1.17 | 1.49 | 1.29 |
| Rank | 3 | 1 | 2 |




Main Effects Plot for S/N ratios

**(v) Surface roughness versus Sample, Depth of cut**

The following figures 6.5(a) & 6.5(b) indicate the validation of experimental results obtained in respect of Surface Roughness (See table-110 in the Annexure)

**Taguchi Orthogonal Array Design for Surface Roughness**

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Taguchi Orthogonal Array Design

L16(4**2)
Factors:  2
Runs:    16

Columns of L16(4**5) Array
1 2
(a) Response Table for Means
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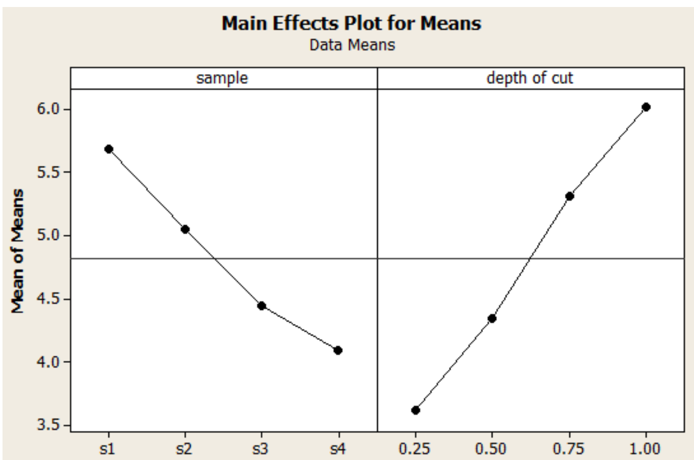
| Level | sample | depth of cut |
|---|---|---|
| 1 | 5.688 | 3.620 |
| 2 | 5.055 | 4.350 |
| 3 | 4.450 | 5.308 |
| 4 | 4.100 | 6.015 |
| Delta | 1.587 | 2.395 |
| Rank | 2 | 1 |

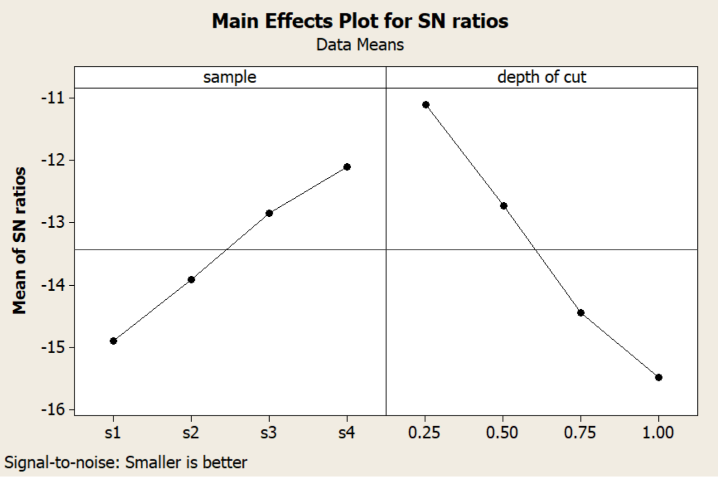



Main Effects Plot for Means

(b) Response Table for Signal to Noise Ratios

Smaller is better

| Level | sample | depth of cut |
|---|---|---|
| 1 | -14.90 | -11.11 |
| 2 | -13.91 | -12.73 |
| 3 | -12.85 | -14.44 |
| 4 | -12.10 | -15.48 |
| Delta | 2.79 | 4.37 |
| Rank | 2 | 1 |




Main Effects Plot for S/N ratio

**Temperature versus sample, Feed rate, Depth of cut**

The variations in the Temperature have been analysed with the help of Main Effects Plots for Means and Signal-to-Noise (S/N) ratio [See above figures]. The Main Effects Plot for Means reveal that the temperature is minimum for Sample 4 (Nanoparticulate lubricant $CuFe_2O_4$ + SAE 50 base oil) as compared to the other three samples and hence is considered the best nanoparticulate lubricant considered for the present investigation. These results are in tune with the experimentally obtained results. Further, the results also indicate that the Feed rate, with its highest delta value and Rank 1, is the most influential factor on temperature. The Depth of cut, with its next higher delta value and Rank 2, is the second influential factor. The S/N ratios also support the results.

### Surface roughness versus Sample, Depth of cut

The variations in the Surface roughness have been analysed with the help of Main Effects Plots for Means and Signal-to-Noise (S/N) ratio [See above]. The Main Effects Plot for Means reveal that the Surface roughness is minimum for Sample 4 (Nanoparticulate lubricant $CuFe_2O_4$ + SAE 50 base oil) as compared to the other three samples and hence is the best nanoparticulate lubricant among all those considered for the present investigation. These results are in tune with the experimentally obtained results. Further, the results also indicate that the Depth of cut, with its highest delta value and Rank 1, is the most influential factor on surface roughness. There is increase in the surface roughness with increase in the depth of cut of the work material. The Signal-to-Noise ratios also support the results.

## Results

(i) There is increase in the cutting tool temperature with the increase in any one or all the process parameters (Cutting speed, Feed and Depth of cut) with the nanoparticulate lubricants used in the present investigation.

(ii) There is improvement in the surface finish of the work material with increase in cutting velocity with all the nanoparticulate lubricants considered for the present investigation.

(iii) With the increase in the Depth of cut, there is decrease in surface finish with all the nanoparticulate lubricants considered for the study.

(iv) From the experimental results, it is concluded that 0.4 wt% of Copper Ferrite nanoparticulate lubricant in SAE 50 oil has shown better performance as compared to all other lubricants considered for the present investigation.

(v) The experimental results have been validated with $L_{16}$ Orthogonal Array of Taguchi design. The results obtained in Taguchi technique are in tune with the obtained experimental results.

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