# Analysis of Surface Roughness and Material Removal Rate in Dry and Cryogenic Machining of En31 Steel

Palwinder Singh
Student, M.Tech.
Mechanical Engg.
BGIET Sangrur

Ashish Singla
Assistant Professor
Mechanical Engg.
BGIET Sangrur

Gaurav Kumar
Assistant Professor
Mechanical Engg.
BGIET Sangrur

## ABSTRACT
Production rates play important role in the turnover of any industry. In order to increase the production rates, industrial processes are need to be speedup by speeding input parameters such as cutting speeds, feed rates etc. But with the higher speeds and feeds the heat generation also increases between tool-chip, tool and work piece interfaces, which reduce the tool life, product quality and machining properties. The function of a MWF comes here to optimize the machining parameters. But the use of coolant fluids has become a problem in terms of human health, environmental pollution and also adds up the cost factors such as disposal of toxic lubricants. The various techniques used to cool down and to lubricate the machining processes are reckoned to be inefficient. To eliminate the problem of such inefficient usage of cutting fluids, some new approaches are introduced i.e.: near dry machining (NDM) and cryogenic machining. In present research, machining properties of different operations was analyzed under cryogenic machining techniques. The machining is done on EN31 STEEL. This cryogenic technique is applied to investigate the effects of parameters on the machining properties. It can thus be concluded that the surface finish improves due to reduction of cutting zone temperature with the cryogenic machining. The material removal rate is increased with cryogenic machining because of maintained tool tip.

## Keywords
Cryogenic Machining, EN31 Steel, Metal Working Fluids (MWFs) and Machining Properties

## 1. INTRODUCTION
Machining of steel inherently generates high cutting temperature. This heat is dissipated into the tool, chip, workpiece and environment. The transferred heat causes damages to the tool mainly in two ways: reeducation in the mechanical resistance and the wear resistance of the tool. As the wear increases some unlikely problems appear like inaccuracy of final piece dimensions and poor quality of the machined surface. One of the main obstacles towards the fast commercialization of these advanced ceramics and other heat resistant alloys are the difficulty in machining them to required shapes and the related high machining costs. There are mainly two methods commonly used to diminish the heat generated during the metal cutting processes: adequate cutting parameters to the work piece-tool pair, exploring the range with less heat generation, or the use of cutting fluids for cooling and lubrication of the cutting zone between tool and chip. The first method used alone, limits machining productivity which becomes dependent on the parameters chosen. The second method involves an entire area of knowledge related to heat transfer and tribology, and when well makes it possible to control the heat transferred to the cutting tool, increasing its life and improving the piece's surface finish.

### 1.1 Metal Working Fluid (MWF)
Metal working fluid is widely being used in industries due to its ease of application. The most common way to apply metal cutting fluids is the conventional one. These fluids increase productivity and the quality of manufacturing operations by cooling and lubricating during metal forming and cutting processes. Due to their advantages, the consumption of MWFs is increasing in machining industry. There are several types of metalworking fluids (MWFs), which may be used to carry out such tasks. Most of the MWFs are mineral oil based fluids. During the last two decades metalworking fluids have been under investigations. In 1999, MWFSAC recommended that the permissible exposure limit of metal working fluid be 0.5 mg/m$^3$ [1].

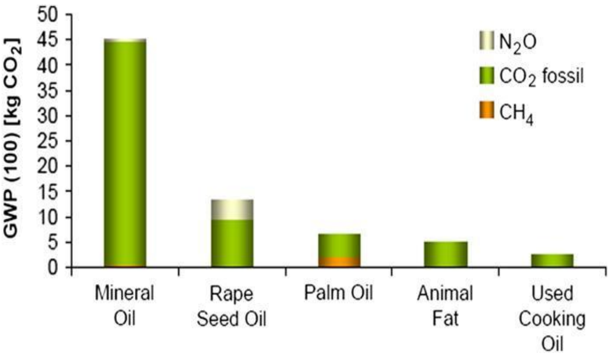


**Fig 1: Global warming potential [2]**

Figure 1 shows the potential impact on environment by different MWFs. Vegetable-oil-based fluids are becoming more attractive alternatives of mineral and petroleum oils, as the cost of crude oil is rising [3]. Successful applications of soybean oil and some other vegetable oils are found in the areas of metal cutting, rolling and casting [4]. In order to alleviate the economic and environmental impacts, some unconventional lubrication techniques were found to be an alternative to the conventional flood machining [5].

#### *1.1.1 Drawbacks of metal working fluids*
Due to their advantages, the consumption of MWFs is increasing in machining industry. Reports indicate that nearly 38 million metric tons of lubricants were used globally in 2005, with a projected increase of 1.2% over the next decade [6]. The United Auto Workers petitioned the Occupational Safety and Health Administration (OSHA) to lower the permissible exposure limit for metal-working fluids from 5.0 mg/m$^3$ to 0.5 mg/m$^3$. In response, OSHA established the Metalworking Fluid Standards Advisory Committee (MWFSAC) in 1997 to develop standards or guidelines related to metalworking fluids. In its final report in 1999, MWFSAC recommended that the exposure limit be

0.5 mg/m$^3$ and that medical surveillance, exposure monitoring, system management, workplace monitoring and employee training are necessary to monitor worker exposure to metalworking fluids [3]. Approximately 85% of lubricants being used around the world are petroleum-based oils. Enormous use of petroleum based oils, created many negative effects on environment. The major negative effect is particularly linked to their inappropriate disposal, which results in surface water and groundwater contamination, air pollution, soil contamination, and consequently, agricultural product and food contamination. As cutting fluids are complex in their composition, they may be irritant or allergic. Even microbial toxins are generated by bacteria and fungi present, particularly in water-soluble cutting fluids, which are more harmful to the operators. Many investigations are in progress to develop several new techniques to eliminate the use of metal working fluids. Some techniques like: Dry machining, and Cryogenic machining.

## 1.2 Cryogenic Machining Process

The cryogenic machining process consists, introducing small quantity of liquid nitrogen (LIN) onto the rake face of the cutting tool, during the cutting process. Liquid nitrogen is either transported from a bulk tank outside the building or from a pressurized cylinder close to the machine through vacuum jacket lines. The Liquid Nitrogen flow on demand, through flexible lines, to specifically designed nozzles either integrated into the clamp or mounted close to the tool. The nozzle discharges a stable, precise Liquid Nitrogen jet towards the chip/tool interface. Care is taken not to impinge the cryogenic jet directly onto the workpiece to prevent workpiece freezing. The temperature range of the Cryo-temper is -300 to 500 °F (approximately -185 to 260 °C) [7]. Liquefied nitrogen readily boils on contact with warmer surfaces (normal boiling point=-196$^o$C) to form a non-toxic, inert gas. Although successfully shown in academic laboratories as an effective, safe and cost-saving coolant, Liquid Nitrogen requires industrial delivery and jetting system capable of accommodating diverse tool geometries and integration with lathe machine.

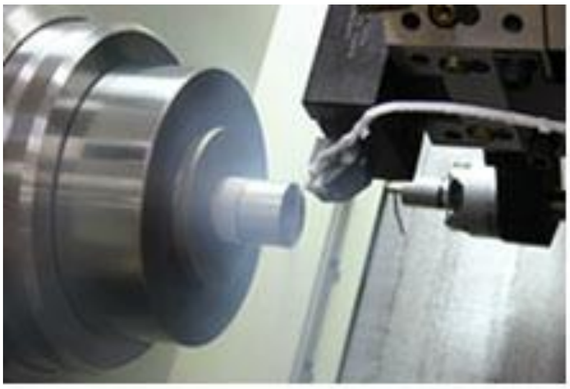

**Fig 1: Cryogenic Machining [8]**

### *1.2.1 Advantages of Cryogenic Machining*

Metal machining produces extreme temperatures that are the primary cause of tool failure. Traditional coolants are used to dissipate this heat and combat tooling wear.

## 2. EXPERIMENTATION

For the present experimental studies, EN 31 steel were plain turned in a rigid and powerful HMT lathe by carbide inserts CNMG 12408 at industrial speed–feed combinations under both dry and cryogenic cooling conditions. The experimental conditions are given in Table 1.

**Table 1. Experimental Conditions**

| | | |
|---|---|---|
| 1 | Tool | CNMG 12408 |
| 2 | Material | EN 31 steel |
| 3 | Input parameters | Speed, 101 m/min., 145 m/min., 182 m/min. feed, 0.05 mm/rev, 0.10 mm/rev., 0.15 mm/rev. depth of cut, 0.5 mm, 0.8 mm , 1.00 mm |
| 4 | Output parameters | MRR, Surface roughness |
| 5 | Machining operation | Fine turning |
| 6 | Machining environment | Dry machining, Cryogenic machining |

The ranges of the cutting velocity, depth of cut and feed rate were selected based on the tool manufacturer's recommendation and industrial practices.

The liquid nitrogen delivery system is schematically shown in Figure 2. For cryogenic cooling, liquid nitrogen in the form of thin but high speed jets were impinged from a specially designed nozzle towards the cutting zone along two directions almost parallel to the cutting edges.

## 2.1 Experimentation Setup

The aim of experiment is investigate the effects of cryogenic machining at different input parameters. The cryogenic machining is directly performed on lathe machine with the help external supply of nitrogen. To perform the experiment effectively the setup consists of following parts.

### *2.1.1 Cryogenic Unit*

Cryogenic unit consists of following parts

- $LN_2$ container
- Flow control valve
- Piping

A thermally insulated $LN_2$ cylinder has been installed along with a flow control valve. The insulated cylinder helps maintaining the temperature of the $LN_2$. Storage capacity of the container is 5 liter. A flow control valve is attached to the cylinder in order to control the flow of liquefied gas, so that suitable amounts of $LN_2$ can be introduced at cutting tool, dispersing the heat generated. A pipe is installed to accommodate the flexibility of operation. Cryogenic machining system provides many benefits over conventional coolants.

- Decreased tool wear
- Surface integrity and part quality
- Lower overhead
- Environmentally-friendly green manufacturing
- No more hazardous coolants

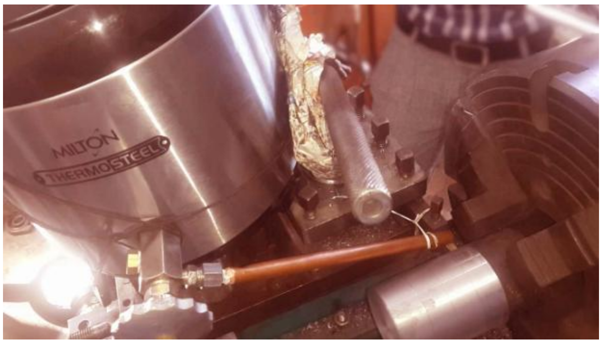


**Fig 3: Cryogenic set-up**

## 2.2 Design of Experiment

A total of 18 experiments based on Taguchi's L9 orthogonal array were carried out with different combinations of the levels of the input parameters, as shown in Table 2. In this experimental work, the assignment of factors was carried out using L9 orthogonal array were conducted on Lathe machine for turning operations through cryogenic technique and dry machining technique, By using this method number of experiments reduced to 18 instead of 54 with almost same accuracy. The levels for each factor have been kept according to the commercial avialability, experimental limitation and the machine tool capacity. These factors were selected for output parameters like surface roughness and material removal rate as provided in the literature.

**Table 2. Design of Experiment**

| Experiment No. | Machining environment | Depth of cut (mm) | Cutting velocity (m/min) | Feed Rate (mm/rev) |
|---|---|---|---|---|
| 1 | Cryogenic machining | 0.5 | 101 | 0.05 |
| 2 | | 0.5 | 145 | 0.10 |
| 3 | | 0.5 | 182 | 0.15 |
| 4 | | 0.8 | 101 | 0.10 |
| 5 | | 0.8 | 145 | 0.15 |
| 6 | | 0.8 | 182 | 0.05 |
| 7 | | 1.0 | 101 | 0.15 |
| 8 | | 1.0 | 145 | 0.05 |
| 9 | | 1.0 | 182 | 0.10 |
| 10 | Dry machining | 0.5 | 101 | 0.05 |
| 11 | | 0.5 | 145 | 0.10 |
| 12 | | 0.5 | 182 | 0.15 |
| 13 | | 0.8 | 101 | 0.10 |
| 14 | | 0.8 | 145 | 0.15 |
| 15 | | 0.8 | 182 | 0.05 |
| 16 | | 1.0 | 101 | 0.15 |
| 17 | | 1.0 | 145 | 0.05 |
| 18 | | 1.0 | 182 | 0.10 |

In the present investigation, three response variables has been selected- surface roughness, and material removal rate. The detail of these response variables are given in the table 3.

**Table 3. Response Variables**

| Sr. No. | Name | Units |
|---|---|---|
| 1 | Material Removal Rate | g/sec |
| 2 | Surface Roughness | µm |

## 2.3 Measurement of Surface Roughness

Surface roughness is measured with the 'Mitutoyo roughness tester SJ-201" shown in Figure 4. The surface roughness measured by this instrument in units of micro meter (µm) & inch meter (µinch). The roughness was measured after completion of the experiments using a diamond stylus having tip radius 5µm and cut off length =0.025. Mean out of three readings has been taken for best results.

The measuring range of roughness tester is of 350 µm (-200 µm to +150 µm). A stylus attached to the detector unit of roughness tester will trace the minute irregularities of work-piece surface. The vertical sylus displacement during the trace is processed and digitally displayed on the liquid crystal display of instrument.

**Fig 4: Surface roughness Tester**

## 2.4 Measurement Material Removal Rate (MRR)

The material removal rate, MRR, can be defined as the volume of material removed divided by the machining time. Since the depth of cut is changing the material removal rate changes continuously during the process an electronic weighing balance of range up to three decimal points is used for accurate results of weight loss. In order to calculate the material removal rate, machining time was noted for every experiment using stop watches. Workpieces were weighted before and after experiment. In order to calculate the material removal rate following formula was used-

Material removal rate = (W1-W2) / T
Where ,
W1= initial weight
W2= final weight
T= machining time.

## 3. RESULTS AND DISCUSSION

After conducting the experiments with different settings of the input factors i.e. machining environment, cutting speed, feed rate. The value of output variables (surface roughness and material removal rate) were recorded. The aim of present investigation was to find the effect of cryogenic machining on turning EN31 steel. According to the design of experiment, different values of output parameters were measured by precisely relevant instruments.

### 3.1 Influence of various input parameters on material removal rate

The material removal rate was calculating after machining and the results are recorded at various combinations of input parameters and machining environments (dry machining and cryogenic machining).

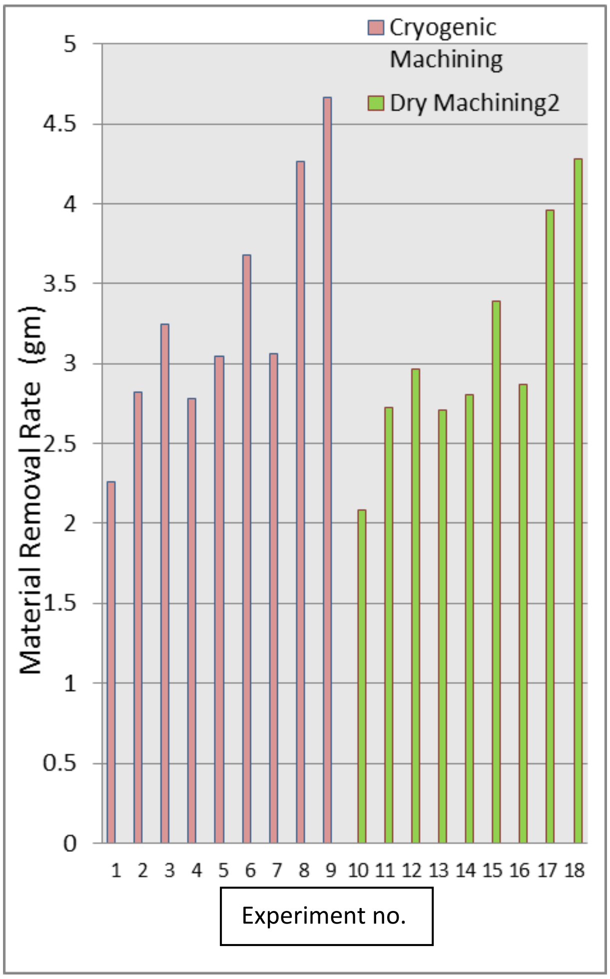


**Fig 5: Material removal rate at different machining parameters**

Figure 5 shows the graph for material removal rate at various machining parameters. Results have been plotted on graph. The graph clearly reveals the significance of cryogenic machining, as the results shown are far better than the results obtained from dry machining. Material removal rate has been found best at moderate feed rate, moderate speed rate and lowest depth of cut during cryogenic machining. Cryogenic technique can be considered as good technique for increase material removal rate.

### 3.2 Influence of various input parameters on surface roughness

The surface roughness was measured by a surface roughness tester and the results are recorded at various combinations of input parameters and machining environments (dry machining and cryogenic machining).

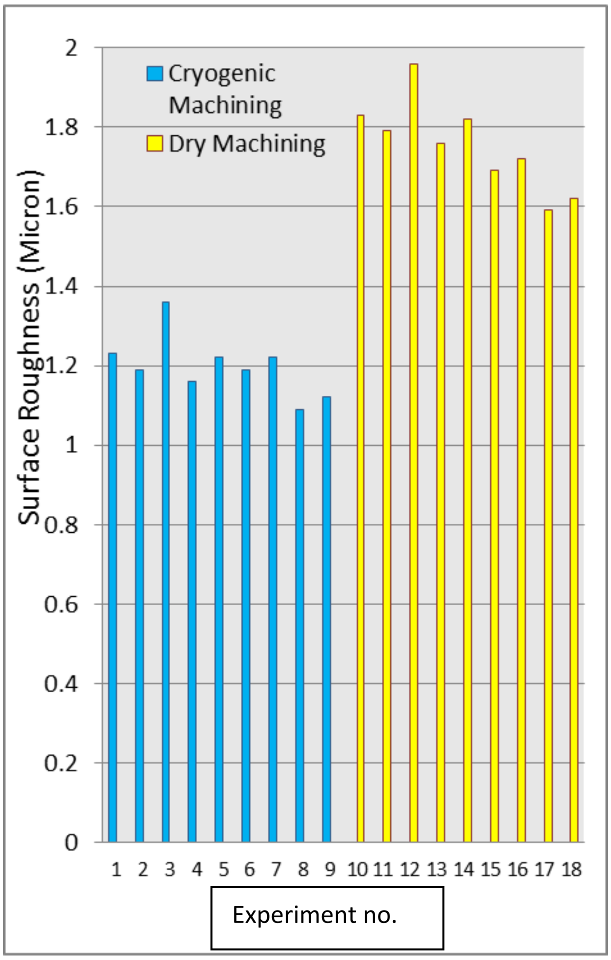


**Fig 6: Surface roughness at different machining parameters**

Figure 6 shows the graph for surface roughness at various machining parameters. Results have been plotted on graph. The graph clearly reveals the significance of cryogenic machining, as the results shown are far better than the results obtained from dry machining. Surface quality has been found best at moderate feed rate, moderate speed rate and lowest depth of cut during cryogenic machining. Cryogenic technique can be considered as good technique for improving surface quality.

## 4. CONCLUSION

The results from experimental tests are summarized here. It can thus be concluded that the cutting temperature can be decreased with the help of liquid nitrogen as coolant which carry heat from the cutting zone and cool the cutting tool resulting improves tool life and improved machining properties. The surface finish also improves due to reduction of cutting zone temperature with the cryogenic machining. Although the surface quality improvement had been reported using cryogenic machining when compared to dry machining, but it could be still consider significant. The material removal rate is increased with cryogenic machining, because cryogenic machining helps to maintain the cutting edge of tool. So liquid nitrogen used as coolant in cryogenic machining has shown promising results but further research in this direction is still suggested.

## 5. FUTURE SCOPE

Even with the numerous findings that were made in this study, there are still some areas in which further investigation could lead to a greater understanding of the effect of cryogenic machining on EN31 steel. Analysis of the results obtained from the current work suggests several feasible extensions to the research. Some of these are listed below:

1. Combined effect of cryogenic machining and input parameters may be further enhance the tool life.
2. Different Coated and uncoated tool can be tested on EN31 steel with cryogenic machining. Also optimize the cutting parameters and conditions for good environment.

# 6. REFERENCES

[1] Byers, J.P., Metalworking fluids. 2006. Crc Press.

[2] Lawal, S., I. Choudhury, and Y. Nukman. 2012, Application of vegetable oil-based metalworking fluids in machining ferrous metals—a review. International Journal of Machine Tools and Manufacture, 52(1). p. 1-12.

[3] Adler, D., et al. 2006, Examining the role of cutting fluids in machining and efforts to address associated environmental/health concerns. Machining Science and technology, 10(1). p. 23-58.

[4] Cohen, H. and E.M. White. 2006, Metalworking fluid mist occupational exposure limits: a discussion of alternative methods. Journal of occupational and environmental hygiene, 3(9). p. 501-507.

[5] Soković, M. and K. Mijanovic. 2001, Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes. Journal of Materials Processing Technology, 109(1). p. 181-189.

[6] Gauthier, S.L. 2003, Metalworking fluids: oil mist and beyond. Applied occupational and environmental hygiene, 18(11). p. 818-824.

[7] Kaynak, Y., et al. 2013, Analysis of Tool-wear and Cutting Force Components in Dry, Preheated, and Cryogenic Machining of NiTi Shape Memory Alloys. Procedia CIRP, 8. p. 498-503.

[8] Cryogenic Hard Turning brought to you by ICEFLY. Archived Press Releases, 2006.