

# Study on the effectiveness of Extreme Cold Mist MQL system on turning process of stainless steel AISI 316

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**Abstract.** Cutting process of difficult-to-cut material such as stainless steel, generates immensely excessive heat, which is one of the major causes related to shortening tool life and lower quality of surface finish. It is proven that application of cutting fluid during the cutting process of difficult-to-cut material is able to improve the cutting performance, but excessive application of cutting fluid leads to another problem such as increasing processing cost and environmental hazardous pollution of workplace. In the study, Extreme Cold Mist system is designed and tested along with various Minimum Quantity Lubrication (MQL) systems on turning process of stainless steel AISI 316. In the study, it is obtained that, Extreme Cold Mist system is able to reduce cutting force up to 60N and improve the surface roughness of the machined surface significantly.

## 1. Introduction

Several approaches are proposed to improve the cutting process difficult-to-cut materials, especially in improving the tool life and higher surface finish. It is necessary to understand about the mechanic of heat generation and temperature increment during the machining process. Basically, lubricating process can be considered as successful when the cutting fluid penetrated the sticking-sliding zone of tool-chip contact. It is proven that, cutting process assisted by cutting fluid is able to improve the tribological properties at the interfaces through alteration of normal, shear stresses, and their distribution, and/or by removing the excessive heat, thus improving the machined surface roughness and tool wear etc. [1-8].

Previous studies had shown that dry machining is the optimum solution in most of material removal processes for soft material, but less effective in machining difficult-to-cut material. Thus, a near-dry cutting system is proposed by implementing the Minimum Quantity Lubrication (MQL) method. This MQL system utilizes only a tiny amount of cutting fluid, with flowrate unit of ml/h compared to conventional cutting fluid supplying method. The cutting fluid is turn into microscale droplet and supplied to the cutting [4, 7].

There are various types of cutting fluids available nowadays that can be utilized for MQL system, which are lubrication purpose oil-based cutting fluid, cooling purpose of emulsion-based cutting fluid (made of soluble oil in water and hopefully to be able to reduce oxidation on the surface of material), water or cold air that are mostly for cooling application [4,7]. Various studies had shown

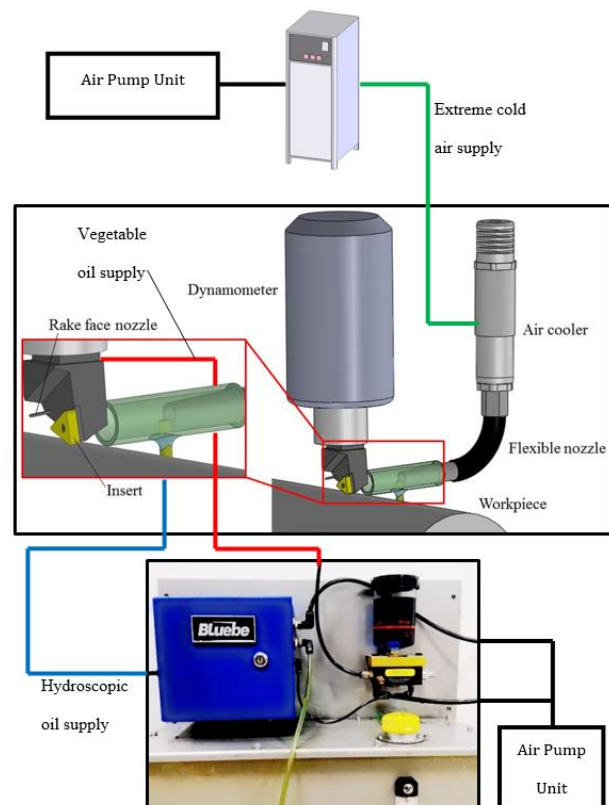


that MQL system capability in reducing the frictional contact between tool, chip and workpiece and able to provide efficient heat exchange through conduction [5].

In this study, Extreme Cold Mist system is proposed along with various types of MQL method in turning process of difficult-to-cut materials, stainless steel AISI 316. Stainless steel, AISI 316 is a commonly available stainless steel along with AISI 304, where this stainless steel is austenitic chromium nickel stainless steel, as shown in Table 1 [6]. The molybdenum content of the material elevates the resistance to corrosion and pitting from chloride ion solutions, along with sustaining extreme temperatures. Stainless steel AISI 316 is utilized mostly in industrial sector involving processing chemicals, as well as under-sea (high saline) such as coastal regions and outdoor areas [6]. Thus, it is considered as a valuable effort in improving the knowledge of machining process of AISI 316 effectively.

**Table 1.** Stainless steel AISI 316 general chemical composition.

Chemical Composition	%
Cr	16-18
Ni	10-14
C	0.08
Mn	2.0
Si	0.75
P	0.045
S	0.03
N	0.10
Mo	2.0-3.0



**Figure 1.** Hybrid lubrication-coolant Minimum Quantity Lubrication (MQL) supplier

## 2. EXPERIMENTAL PROCEDURES

In the study, a system that capable of supplying heterogeneous Minimum Quantity Lubrication (MQL) is designed, where the MQL mist is supplied to the rake and flank surface of the cutting tool (Figure 1). The specification of MQL systems and cutting fluids applied in the study are shown in Table 2 and Table 3, respectively. In the study, the effectiveness of each MQL system in machining stainless steel AISI 316 is analyzed in terms of cutting force and surface finish.

**Table 2.** MQL system specification

System Type	MQL type for rake face	Fluid rate (mL/h)	MQL type for flank face	Fluid rate (mL/h)	Total fluid rate (mL/h)
Dry	Dry	-	Dry	-	-
A	Oil A	30	Dry	-	30
B	Oil B	100	Dry	-	100
C	Oil A	30	Cold air	-	30
D	Oil A	30	Oil B	100	130
<b>E</b>	<b>Oil A</b>	<b>30</b>	<b>Cold air + Oil B</b>	<b>100</b>	<b>130</b>

**Table 3.** Characteristic of the MQL oil

MQL oil	Oil A (Lubrication)	Oil B (Coolant)
Fluid type	Vegetable oil	Hydroscopic oil
Viscosity	37	
Oil contents (%)	99	30
Oil pressure (MPa)		0.6
Cold air pressure (MPa)		0.6
Cold Air temperature (°C)		-13.6

In the study, MQL with lubrication characteristic (Oil A) is supplied onto rake face of the tool by rake face nozzle, while hydroscopic mist (Oil B) with coolant characteristic is supplied onto flank face with the application of flexible nozzle (Figure 1) in MQL system Type D. For MQL system Type C and E, the flexible nozzle is connected to an air cooler, which is connected to an air dryer to supply extreme cold air (-13.6°C). MQL system Type E is the proposed MQL system for the study called Extreme Cold Mist system. Material properties and cutting conditions are shown in Tables 4 and 5.

**Table 4.** Material properties

Materials	TiCN-coated Cermet	AISI 316
Young Modulus, $E$ (GPa)	650	205
Poisson Ratio, $\epsilon$	0.25	0.30
Thermal Conductivity, $k$ (W/(m·K))	59	17
Density, $\rho$ (kg/m <sup>3</sup> )	14900	8070
Volumetric Heat Capacity, $c$ (x 10 <sup>6</sup> J/(m <sup>3</sup> ·K))	15.0	2.78
Hardness Vickers, HV <sub>0.3</sub> (GPa)	13.7	2.2

**Table 5.** Cutting condition

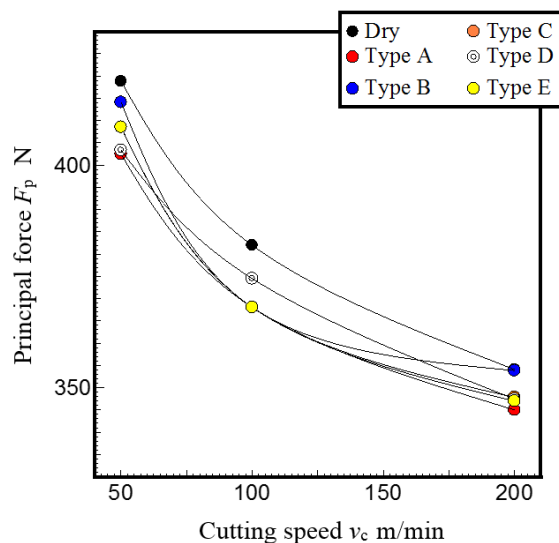
Cutting Speed $v_c$ (m/min)	:	50 ~ 200
Depth-of-cut $a$ (mm)	:	0.5
Feed $f$ (mm/rev)	:	0.3

### 3. Results and discussions

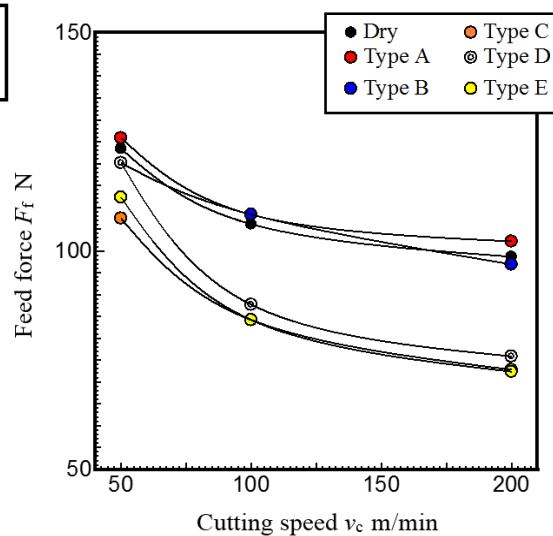
#### 3.1. Cutting force comparison with the application of various MQL system

During the experimental procedure for turning process of stainless steel (AISI 316) with TiCN-coated cermet cutting tool with the proposed MQL system, principal force  $F_p$ , thrust force  $F_t$ , and feed force  $F_f$  is observed and plots in Figures 2, 3 and 4. Reduction of 50N of the principal force  $F_p$  is observed with the application of MQL Type A and E, while reduction of feed force  $F_f$  and thrust force  $F_t$  up to nearly 30N and 60N, respectively with the application of MQL Type E only.

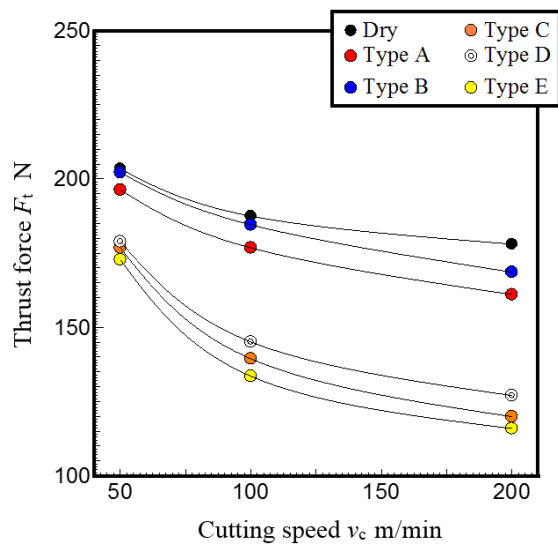
It is assumed that, the oil mist is able to penetrate the tool-chip and tool-machined surface contact effectively for MQL system Type A and Type E, as observed from the force reduction. However, only MQL system Type E is able to reduce feed force  $F_f$  and thrust force  $F_t$  with higher effectiveness. It is believed that, reduction of temperature at the tool flank with its extremely low temperature cold mist and higher total fluid rate is occurring effectively during the experiment.



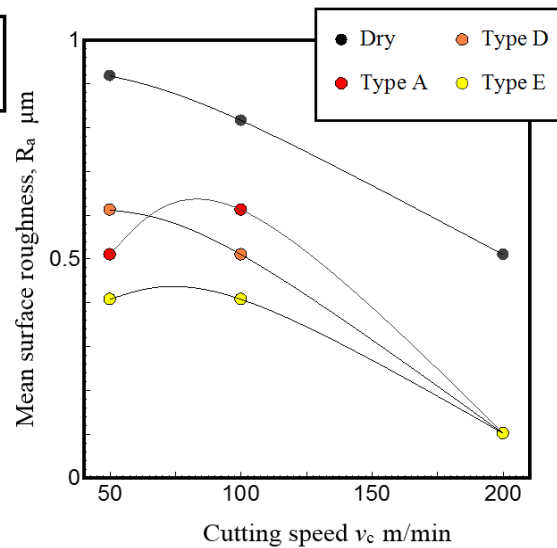
**Figure 2.** Relationship between cutting speed  $v_c$  and principal force  $F_p$  for various MQL systems.



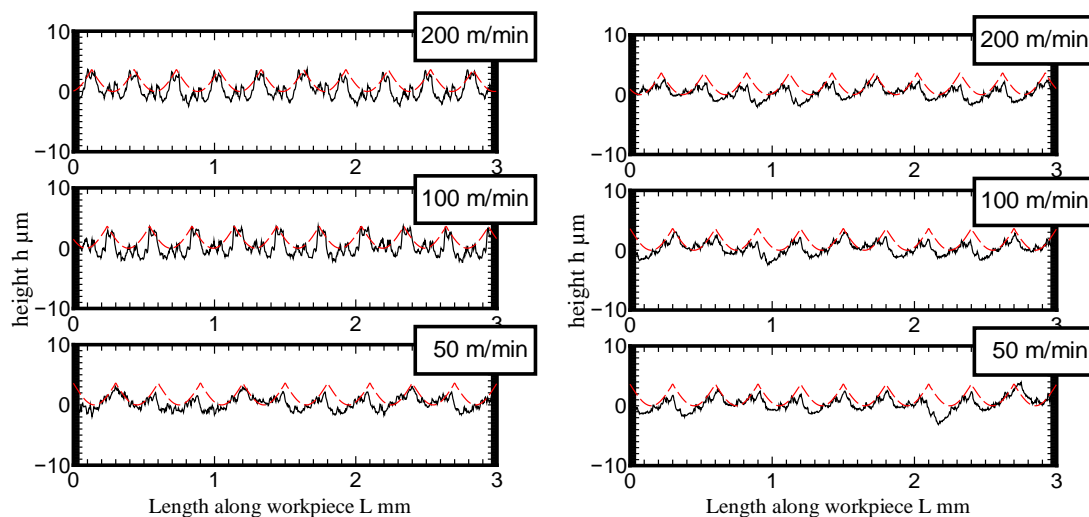
**Figure 3.** Relationship between cutting speed  $v_c$  and feed force  $F_f$  for various MQL systems.



**Figure 4.** Relationship between cutting speed  $v_c$  and thrust force  $F_t$  for various MQL systems.



**Figure 5.** Relationship between cutting speed  $v_c$  and mean surface roughness,  $R_a$



**Figure 6.** Surface roughness profile comparison between MQL system Type A (left), MQL system Type E (right) and ideal surface roughness profile (red line)

### 3.2. Surface roughness comparison with the application of various MQL system

During the experiment with the application of MQL system Type A, C and E (depth of cut  $a=0.5$  mm, feed rate  $f=0.3$  mm/rev), it is observed that, the mean surface roughness  $R_a$  decreases as cutting speed increases, but MQL system Type E shows the lowest mean surface roughness  $R_a$ .

It is believed that, at lower temperature, cutting tool integrity is increased, especially with the application of MQL System type E. Plus, the chip is able to flow smoothly by reducing the frictional coefficient through hybrid lubrication-cooling method. It is concluded that Extreme Cold Mist System (MQL system type E) has high effectiveness for cutting process difficult-to-cut material.

#### 4. Conclusions

In this study, turning process experiments were conducted on stainless steel (AISI 316) with the application of various MQL conditions. Cutting force were measured and the effect of cold air was studied. Several conclusions can be made as following.

- a. Supplying vegetable oil to the rake face is able to reduce principal cutting force component  $F_p$  up to 50N compared to the dry type, whereas the vegetable oil mist able to lubricate the contact surface between tool and chip.
- b. By supplying cold air ( $-13.6^{\circ}\text{C}$ ) + hydroscopic oil (Extreme Cold Mist system) at 100mL/h volume rate, the system is able to decrease feed force  $F_f$  and thrust force  $F_t$  component up to 30N and 60N compared to dry type, respectively.
- c. By supplying cold air ( $-13.6^{\circ}\text{C}$ ) to the flank face (Extreme Cold Mist system), the finished surface roughness is greatly improved compared with the dry type.
- d. It can be concluded at current stage, the Extreme Cold Mist system is the best MQL system in the study. It is needed to study the mechanism of MQL onto cooling process of cutting tool during cutting process in the future.

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