Effect of Pressure and Nozzle Angle of Minimal Quantity Lubrication on Cutting Temperature and Tool Wear in Turning

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Abstract. This paper presents an experimental investigation on effects of pressure and nozzle angle of minimal quantity lubrication (MQL) on cutting temperature and flank wear in turning. In manufacturing industries, there are always demands for the optimum cutting conditions for the most economical manufacturing cost. Hence, reduction in tool wear is essential for less expenditure with the knowledge of optimum cutting conditions of MQL. MQL, also known as near dry machining, has been acknowledged as an effective cooling technique in machining by applying vegetable oils in replacing the conventional flooding method due to environmental issues. By varying the operating pressures and nozzle angle with respect to the cutting zone, cutting temperature and flank wear are measured using a calibrated tool work thermocouple and SPG video microscope. Comparison was made between dry cutting, water mist cooling and MQL method with palm oil. Results showed that MQL with palm oil exhibits best cooling efficiency at 5 bar pressure and nozzle angle of 20° with reduction of 35% in tool wear and 23% in cutting temperature at higher cutting speeds.

Introduction

Productivity is always the main concern in the manufacturing industries as it also determines the manufacturing costs itself. In order to compromise costs from both tooling and cooling techniques, solutions of more efficient and inexpensive cooling method are demanded all the time in order to reduce the cost from cooling technique used and also the tool wear rate as cutting fluid and tooling comprise 17% and 4% of total manufacturing cost respectively [1]. As high speed machining has been introduced and practiced recently for difficult-to-cut materials, tooling cost has become more significant in manufacturing industries now. Thus, cooling methods are being invented to solve this problem.

First cooling method introduced was the conventional flooding method. This method employs a large amount of cutting fluid into tool and workpiece interface for cooling purpose with the aim to reduce temperature of the tool bits and consequently reduce tool wear rate. However, this method had been deteriorating the environment, mainly caused by the large amount of discharge of cutting fluids into the river streams. This had brought into the concern of the authorities to establish rules and regulations to minimize its effect to the environment. They are enforced to make the manufacturers to filter the cutting fluid before discharge to ensure that the rivers are not polluted. These rules and regulations have made the cooling techniques more expensive, so alternatives have to be sought.
In the later stage of research in cooling techniques, MQL had come to play its important role in this field. This metalworking fluid delivery system is recognized as a very effective lubricating and cooling method to solve the problems that are brought by the conventional flooding method. MQL, also known as near-dry machining [2], applies a very small amount (<80 ml/h) of cutting fluids into cutting zone to lubricate and cool down the cutting tool. Great reduction in amount of metalworking fluids resolves the needs of cleaning up and filtering up the discharged excessive cutting fluids and also reduces the cost for cutting fluids as of flooding method. Initially when MQL was introduced to the industries, mineral oils were used as the cutting fluid in the MQL system. These mineral oils were found out to be the main cause to the respiratory illness of the operators. Pressurized mineral oil impinged into the cutting zone will create airborne particles [3] resulting in inhalation into human respiratory system. Thus, researches are carried out corresponding to the complication. Usage of vegetable oils [4] is then being brought out into attention of the researchers, which results in reduction of health hazard factor [5]. Many researches [6,7,8,9] were performed on MQL with vegetable oils. The researches illustrated positive results from this technique. From its micro-lubricating mechanism, it has successfully increase tool life in machining processes.

This present study experimentally investigates the effect of pressure and nozzle angle used in MQL with palm oil on cutting temperature and flank wear in plain turning of AISI 1045 mild steel by cemented carbide insert with comparison to dry and water mist cutting.

**Experimental Setup**

For the present experimental studies, AISI 1045 mild steel rod with initial diameter 38 mm and length 600 mm was plain turned in a Numerical Control (NC) lathe machine, by cemented carbide insert QK25C (K15-K30) at different pressures under water mist and MQL conditions to study the effect of pressure on cutting temperature at different cutting speeds. The ranges of cutting speeds were chosen based on the data given by cutting tool manufacturer. Cutting speeds used range from 50 m/min to 175 m/min with constant feed rate of 0.2 mm/rev and 0.2 mm depth of cut. Diameter of nozzle used is 1 mm for delivering cutting fluids. Throttled air was supplied with pressures range from 1 bar to 5 bar by compressor to accelerate the mixture of air and coolant. This mixture was dashed through the small diameter nozzle at tool flank face entering tool chip interface. A simple, cheap and reliable temperature technique, tool work thermocouple [10] was developed to measure the average cutting temperature of tool chip interface under dry, water mist and MQL with palm oil by using cemented carbide tool inserts. Flank wear was observed under a SPG video microscope after each consecutive 50 mm of cutting length while using different nozzle angles as shown in Figure 2. Angles that are used in the experiment are 5°, 20°, 30°, and 50°.

![Fig. 2 Perspective and side view of nozzle angle measurement](image)
Experimental Results and Discussion

The effect of MQL pressure on average cutting temperature of tool work interface is illustrated in Figure 3. Apparently, with increasing operating pressure of MQL, the cutting temperature decreases. Impact of change in MQL pressure is more noticeable at higher cutting speeds, especially at 150 m/min with approximately reduction of 10% in cutting temperature using 5 bar if compared to that of 1 bar. This is due to change in water droplet size influences the accessibility to the cutting zone. At higher cutting speeds, smaller size water droplets produced at high pressure can penetrate cutting zone more effectively and thus, cooling effect is more significant as shown in the reduction of cutting temperature at 5 bar operating pressure. Figure 4 shows the comparison of cutting temperature obtained for dry cutting, water mist and MQL with palm oil using 5 bar pressure. MQL with palm oil demonstrated its effectiveness in reducing cutting temperature in turning with 23% lower cutting temperature than dry cutting. On the other hand, change in nozzle angle is consequent to different flank wear. Table 1 displays the flank wear measured for different nozzle angles employed. The outcome recorded that nozzle angle of 20° gives best performance in term of flank wear obtained at cutting length of 1000 mm. This might be the consequence of 20° nozzle angle enables the cutting fluid to be sprayed most efficiently into cutting zone, especially the contact between the tool and the workpiece.
Table 1 Flank wear measured for different nozzle angles of MQL water mist and palm at 125 m/min and cutting length of 1000 mm

<table>
<thead>
<tr>
<th></th>
<th>5°</th>
<th>20°</th>
<th>30°</th>
<th>50°</th>
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<tbody>
<tr>
<td>Palm oil</td>
<td>67 µm</td>
<td>63 µm</td>
<td>65 µm</td>
<td>71 µm</td>
</tr>
<tr>
<td>Water mist</td>
<td>83 µm</td>
<td>71 µm</td>
<td>81 µm</td>
<td>85 µm</td>
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<tr>
<td>Dry cutting</td>
<td>97 µm</td>
<td>97 µm</td>
<td>97 µm</td>
<td>97 µm</td>
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</table>

Conclusion

Conclusions can be drawn with respect to the experimental investigation in this study that MQL operating pressure and nozzle angle are important cutting parameters to be considered in order to obtain optimum cutting conditions. Different pressures applied in MQL result in dissimilar cutting temperatures. Higher MQL pressure produced better cooling efficiency than the lower pressure. Nozzle angle of MQL also affects the tool wear rate in turning. From the study, it was found out that nozzle angle of 20° is the optimum nozzle angle which yields the lowest flank wear.

References

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