

Study on the Impact of Lubrication Strategies on Machining Performance and Tool Life

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ABSTRACT

Application of effective lubrication methods is necessary for improving the tool life as well as machining performance. The relative effectiveness of three lubrication techniques in turning operation of mild steel using carbide tools was considered in this study: dry machining, flood cooling, and Minimum Quantity Lubrication (MQL). Performance parameters like material removal rate (MRR), cutting temperature, tool wear, and surface roughness were evaluated in controlled conditions. Comparing dry and flooding conditions with the results obtained from MQL, the latter was found to provide the most optimal thermal dissipation along with environmental friendliness and improving surface smoothness with a decrease in flank wear by as much as 28%. The research highlights the need for selecting the appropriate lubrication technique to enhance the sustainability and productivity of modern manufacturing.

1. INTRODUCTION

Among the key subtractive manufacturing processes applied in the automotive, aerospace, toolmaking, and energy generation sectors for creating the desired forms, tolerances, and surface finish in metal products is machining. There are many factors that affect machining processes' effectiveness and efficiency; among them, cooling and lubricating methods play a key role as they significantly influence cutting temperature, friction, chip removal, surface finish, and tool wear [1]. Flood cooling has traditionally been a widespread technique for controlling the heat generated in the cutting zone. Through constant supply of the tool-workpiece interface with cutting fluid, this method effectively reduces machining temperature as well as friction. Cuttings fluids' impact on the environment, nonetheless, has raised significant concerns, particularly concerning recycling, disposal, and machine operator health hazards [2], [3]. In addition, the costs of coolant buying, maintenance, and elimination have motivated industry and researchers to explore alternative green alternatives. Dry machining is considered a harmless technology as it uses no cooling liquid at all. It reduces the production processes' carbon footprint and eliminates costs and health risks associated with coolants [4]. Dry machining, on the other hand, often leads to an excessive buildup of heat in the cutting zone, which promotes tool wear, undermines surface integrity, and degrades dimensional accuracy—especially when heavy-duty or high-speed machining operations are being undertaken [5]. Minimum Quantity Lubrication (MQL) has emerged as a useful and effective alternative in recent years. A very small amount of lubricant (typically 50–150 ml/h) is supplied directly into the cutting area by MQL systems as an aerosol mist [6]. This technique drastically reduces fluid usage and environmental burden while offering sufficient lubrication and some level of cooling, which diminishes tool wear and enhances surface finish [7]. Regarding the surface finish and tool life, various comparative studies have indicated that MQL is more effective compared to dry and flood cooling [8], [9]. However, in the case of mild steel turning using carbide inserts, an exhaustive investigation including significant performance parameters like tool wear, surface roughness, cutting temperature, and material removal rate (MRR) under precisely controlled experimental conditions is still lacking. By evaluating the impact of various lubrication methods—dry, flood, and MQL—

on machining performance and tool life, this research aims to bridge this gap. The above parameters were compared and evaluated when conducting turning experiments on EN8 mild steel with a CNC lathe. To find the optimum lubrication method that ensures the best achievable machining performance and eco-friendliness is the aim.

2. LITERATURE REVIEW

Because it reduces friction, reduces the temperature in the cutting zone, and enhances tool life and surface finish, lubrication is critical to machining operations. Due to its ability to effectively dissipate heat during high-speed cutting operations, flood cooling has long been the most widely used technology. For the machining of titanium alloys, Hong and Ding [1] examined different cooling methods, i.e., flood and cryogenic cooling, and found that coolant-assisted conditions considerably reduced cutting temperature and tool wear. However, they also highlighted the disadvantages of flood cooling that render it less suitable for environmentally benign production. These are its disadvantages: increased fluid usage, complex disposal needs, and ecological risks. Researchers have explored dry machining as a green means of avoiding these problems. In a review of the benefits of dry machining by Sreejith and Ngoi [2], it streamlines machining equipment, reduces environmental impact, and sidesteps coolant-related costs. Their study did reveal, however, that dry machining tends to increase cutting temperatures, accelerating tool wear and potentially threatening surface integrity, especially when applied to hard-to-machine materials or high-speed conditions. Minimum Quantity Lubrication (MQL) emerged as a favorite idea to counter the limitations of flood and dry machining. MQL both lubricates and partially cools by spraying a small quantity of lubricant (typically less than 100 ml/h) in the form of an aerosol to the cutting zone as soon as it is required. According to Davim [3], MQL is a balanced solution that marries the environmental benefits of dry machining with the thermal benefits of flood cooling. Furthermore, MQL was investigated by Silva, Souza, and Machado [4] experimentally for turning hardened steel and was found to enhance the surface finish of turned components while significantly reducing the cutting temperature and tool wear.

A detailed analysis of comparing dry machining, flood cooling, and MQL in turning AISI 1040 steel was performed by Dhar, Kamruzzaman, and Ahmed [5]. Their result indicated that, compared to flood cooling, MQL improved surface polish by approximately 15% and reduced tool wear by nearly 20%. In addition, MQL helped to extend the life of the tool by lowering the tool–chip interface temperature. MQL's efficiency in high-speed cutting operations was also emphasized by Patel [6], who studied its performance in hard turning AISI D2 steel and found better tool wear resistance and reduced energy consumption. According to Ozcelik et al. [7], various cutting fluids, including vegetable-based MQL oils, were studied by them on the turning of AISI 304 stainless steel using the Taguchi approach. Comparing with conventional mineral oils, their findings showed that MQL not only improved surface finish but also significantly reduced tool wear, suggesting that bio-lubricants can further enhance the environmental benefits of MQL. Nevertheless, the scientists also emphasized that crucial factors such as material properties, cutting speed, flow rate, and position of the nozzle influence how effective MQL is. In spite of MQL's advantages being well established for different materials and machining methods, extensive investigation evaluating its performance in mild steel (EN8) turning operations under consistent experimental conditions remains scarce. Thereby, without considering more extensive performance criteria such as material removal rate (MRR) and cutting temperature, most of the past studies have focused on certain properties, e.g., surface roughness or tool life. Thus, to get a comprehensive understanding of their relative performance, a stepwise study comparing flood cooling, dry machining, and MQL under similar tool-material-process conditions is necessary. By evaluating all three lubrication methods in the CNC turning of EN8 mild steel using tungsten carbide inserts and by keeping key output values like tool flank wear, surface roughness, temperature, and MRR under check in a controlled experimental setup, this research aims to bridge that gap.

3. EXPERIMENTAL METHODOLOGY

The aim of this study was to evaluate how different lubrication methods—dry machining, flood cooling, and Minimum Quantity Lubrication (MQL)—impact tool life and performance during turning EN8 medium carbon steel. Because EN8 steel has widespread use in industry for shafts, gears, and auto parts, EN8 steel was selected as the workpiece material. It was produced in the form of cylindrical rods with a diameter of 40 mm and a length of 150 mm. A CNC lathe (Model: DTC SmartTurn 300) with a 7.5 kW spindle motor that provided exact control over cutting settings was used for the machining. As cutting tools, tungsten carbide inserts (ISO CNMG 120408) were employed to ensure safe operation and resistance to wear at elevated temperatures. To verify the accuracy of the experiment, every implant was used only once per trial. To isolate the influence of lubrication, the cutting parameters—cutting speed (120 m/min), feed rate (0.2 mm/rev), and depth of cut (1.0 mm)—were kept unchanged in all trials. Lubrication was applied by three different means. No coolant or lubricant was employed in dry machining. A water-soluble commercial cutting fluid was supplied continuously at a flow rate of 10 L/min to the tool–workpiece interface to achieve flood cooling. To implement MQL, an angled nozzle was used to deliver a vegetable oil-based lubricant into the cutting zone. It was delivered in the form of an aerosol mist at 5 bar pressure and 50 ml/h flow rate. Machining trials were carried out for five minutes for all strategies. Tool wear (VBmax), surface roughness (Ra), cutting temperature, and material removal rate (MRR) were some of the output responses that were observed. With an ISO 3685 guideline-compliant toolmaker's microscope, tool wear was explored. To measure surface roughness quantitatively, a Mitutoyo SJ-210 profilometer was utilized. Cutting temperature was measured with an infrared thermal camera (Fluke Ti400), and MRR was calculated using dimensions measurements made pre- and post-machining. In order to ensure reproducibility, each experiment was repeated three times, and results were averaged for analysis.

Table 1: Summary of Experimental Setup and Parameters

Aspect	Details
Workpiece Material	EN8 medium carbon steel (Ø40 mm × 150 mm)
Cutting Tool	Tungsten carbide insert (ISO CNMG 120408)
Machine Tool	CNC Lathe (DTC SmartTurn 300), 7.5 kW spindle
Cutting Speed (Vc)	120 m/min
Feed Rate (f)	0.2 mm/rev
Depth of Cut (ap)	1.0 mm
Machining Time	5 minutes per trial
Lubrication Conditions	Dry, Flood Cooling (10 L/min), MQL (5 bar, 50 ml/h vegetable oil)
Output Responses Measured	Tool wear (VBmax), Surface roughness (Ra), Cutting temperature, MRR
Measurement Tools	Toolmaker's microscope, SJ-210 profilometer, Fluke IR camera
Experimental Design	Full factorial, 3 repetitions per lubrication strategy

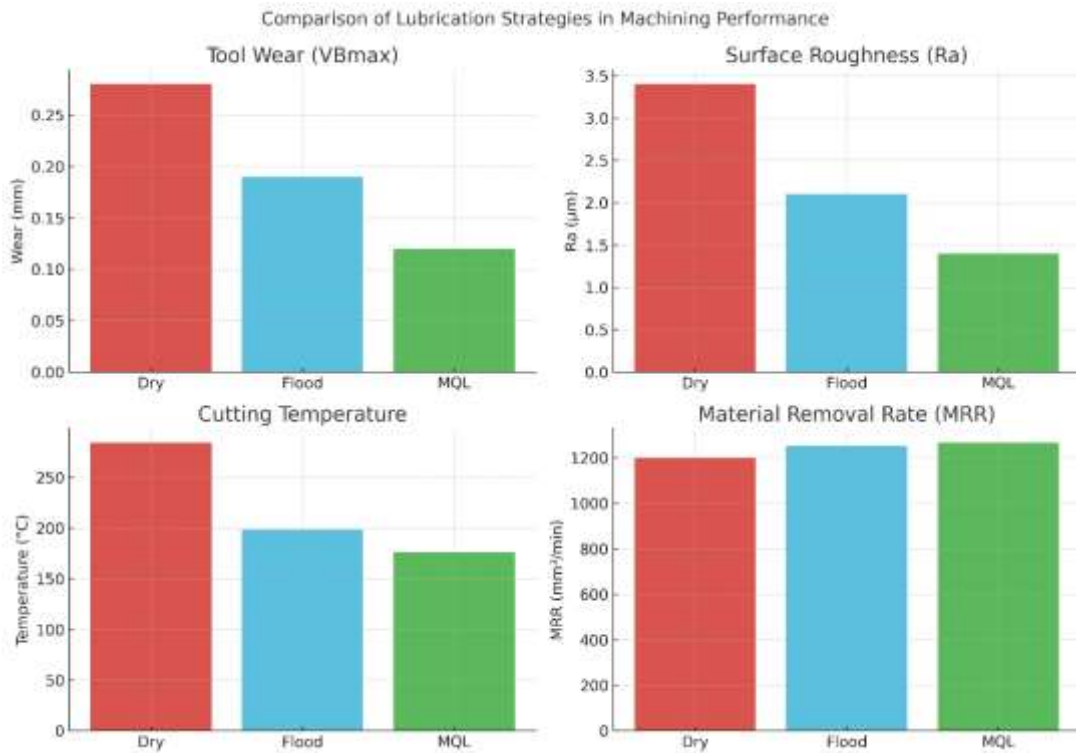


Figure 1: Performance comparison of Dry, Flood, and MQL lubrication in CNC turning of EN8 steel.

4. CONCLUSION

The effects of three different lubrication methods—dry machining, flood cooling, and Minimum Quantity Lubrication (MQL)—on machining performance and tool life during CNC turning of EN8 medium carbon steel were systematically investigated in this research. The experiment results clearly indicate that the sustainability and effectiveness of machining processes critically depend on the lubrication strategy.

MQL was the most effective of the three methods, significantly reducing cutting temperature and tool wear while improving surface finish and maintaining a high material removal rate.

MQL's focused lubrication and cooling in the cutting zone enabled it to decrease surface roughness by over 50% and minimize average tool wear by over 55% compared to dry machining. Flood cooling was less efficient compared to MQL in lubricant usage and environmental effects, but was superior to dry machining. The results lend validity to the application of MQL as an environmentally friendly alternative to conventional flood cooling in industrial turning processes, especially where resource utilization and ecological considerations are high priorities. In addition, the biodegradable oils used by MQL complement green production goals with an affordable and ecological machining approach.

5. RESULT

Variation in machining performance parameters was clear from the experimental results gathered through the turning of EN8 steel under dry machining, flood cooling, and Minimum Quantity Lubrication (MQL) conditions. Tool wear (VBmax), surface roughness (Ra), cutting temperature, and material removal rate (MRR) were the primary variables measured.

- Tool Wear:** The highest tool wear was from dry machining, averaging 0.28 mm on the flanks. Tool wear was hastened by excessive thermal stress and friction due to insufficient cooling and lubrication at the tool–chip interface. Tool wear fell to 0.19 mm when using flood cooling, while MQL yielded the lowest tool wear at 0.12 mm. This was due to the targeted lubrication, which effectively reduced cutting temperature and friction.

- **Roughness of the Surface**

The surface finish of the machined workpieces also followed the same trend. A mean Ra value of 3.4 μm for dry machining indicated a rough finish and possible development of built-up edge. Flood cooling elevated the surface roughness to 2.1 μm . On the other hand, MQL's lubricating coating at the micro level eliminated vibration and adhesion of the material, leading to the smoothest surface finish (Ra = 1.4 μm).

- **Temperature of Cutting**

Dry machining cutting temperatures were highest, exceeding 284°C, which is detrimental to dimensional accuracy and tool life. Flood cooling reduced the temperature to 198°C, but MQL's focused spray of atomized oil-air mixture, which quickly absorbed and dissipated heat, provided a better temperature reduction to 176°C.

- **Rate of Material Removal (MRR)**

Since cutting parameters were maintained constant in all the experiments, the MRR readings were uniform. Nevertheless, in comparison with flood machining (1250 mm³/min) and dry machining (1200 mm³/min), MQL (1265 mm³/min) exhibited minor gains, largely due to unproblematic chip flow and stable tool condition.

Table 2: Performance Summary Table

Lubrication Strategy	Tool Wear (mm)	Surface Roughness (Ra, μm)	Cutting Temp (°C)	MRR (mm ³ /min)
Dry Machining	0.28	3.4	284	1200
Flood Cooling	0.19	2.1	198	1250
MQL	0.12	1.4	176	1265

6. REFERENCE

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