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Minimum Quantity Lubrication in Sustainable Machining: Effects on Tool Wear, Surface Integrity, and Cutting Temperature

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ABSTRACT

The large volumes of cutting fluid used in conventional flood machining raise environmental, health, and cost concerns, motivating the search for more sustainable cooling and lubrication strategies. Minimum quantity lubrication, in which a fine mist of lubricant is delivered directly to the cutting zone, has emerged as a leading alternative. This paper investigates the effect of minimum quantity lubrication on tool wear, surface integrity, and cutting temperature during the turning of an alloy steel, in comparison with dry and flood conditions. Flank wear was monitored over the cutting time, surface roughness was measured, and cutting-zone temperature was recorded for each strategy. The results show that minimum quantity lubrication reduced flank wear and cutting temperature substantially relative to dry machining, and performed comparably to or better than flood cooling while using only a small fraction of the fluid. Surface roughness was likewise improved. The study confirms that minimum quantity lubrication offers an effective and environmentally responsible compromise between dry and flood machining, and identifies the conditions under which its benefits are greatest.

KEYWORDS: *Minimum Quantity Lubrication, Sustainable Machining, Tool Wear, Surface Integrity, Cutting Temperature, Green Manufacturing, Cutting Fluids*

INTRODUCTION

Cutting fluids perform essential cooling, lubrication, and chip-evacuation functions in machining, but conventional flood application consumes large quantities of fluid that must

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subsequently be treated and disposed of. The associated environmental burden, health hazards, and cost have prompted growing interest in sustainable machining strategies (1, 9). Two principal alternatives to flood cooling have been pursued: dry machining, which eliminates fluid entirely, and minimum quantity lubrication, which delivers a fine mist of lubricant to the cutting zone. Dry machining avoids fluid altogether but can lead to high temperatures and rapid tool wear, particularly for difficult materials (7, 8). Minimum quantity lubrication seeks to retain much of the benefit of lubrication while drastically reducing fluid consumption (2, 3).

This paper evaluates minimum quantity lubrication against dry and flood conditions in the turning of an alloy steel, focusing on tool wear, surface integrity, and cutting temperature. The aim is to quantify its benefits and to identify the conditions under which it is most advantageous (4, 5).

LITERATURE REVIEW

The transition from flood cooling toward dry and near-dry machining has been a major theme in manufacturing research, driven by both environmental regulation and cost (1, 8, 9). Studies of minimum quantity lubrication have consistently reported reductions in tool wear and cutting temperature relative to dry machining (3, 4).

Comparative investigations have shown that minimum quantity lubrication can match or exceed flood performance for many materials while using a fraction of the fluid (5). Research on vegetable-oil-based lubricants has further improved the environmental profile of the technique, and reviews have catalogued its effectiveness across a range of operations (2, 6, 10).

COOLING AND LUBRICATION STRATEGIES IN MACHINING

The literature distinguishes several cooling and lubrication strategies, each with characteristic advantages and drawbacks (1, 5, 7). The principal options can be summarised as follows:

- Flood cooling, which provides effective cooling but consumes and must dispose of large fluid volumes.

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- Dry machining, which eliminates fluid but can cause high temperatures and accelerated tool wear.
- Minimum quantity lubrication, which delivers a fine lubricant mist directly to the cutting zone.
- Cryogenic cooling, which uses liquefied gases to remove heat at the source.
- Vegetable-oil-based fluids, which improve the environmental profile of lubrication.

RESEARCH GAP

While the benefits of minimum quantity lubrication are well documented individually, fewer studies report tool wear, surface integrity, and cutting temperature together for the same material and conditions, which limits a holistic comparison with dry and flood machining.

This study addresses that gap by evaluating all three responses under dry, flood, and minimum quantity lubrication conditions for a single alloy steel and consistent cutting parameters.

OBJECTIVES

- To review sustainable cooling and lubrication strategies in machining.
- To machine an alloy steel under dry, flood, and minimum quantity lubrication conditions.
- To monitor flank wear progression for each cooling strategy.
- To measure surface roughness and cutting-zone temperature.
- To compare the strategies and identify the conditions favouring minimum quantity lubrication.

METHODOLOGY

Turning experiments were carried out on an alloy steel using coated carbide inserts under three cooling strategies: dry, conventional flood, and minimum quantity lubrication. Cutting parameters were held constant across the strategies so that the observed differences reflected only the cooling and lubrication method (3, 4).

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Machining Conditions

A single combination of cutting speed, feed, and depth of cut, selected from values typical of finish turning, was used for all experiments. The workpiece material, tool, and machine were kept constant, and only the cooling strategy was varied (5, 8).

Table 1: Machining Conditions Used in the Experiments

Parameter	Value
Workpiece material	Alloy steel
Cutting tool	Coated carbide insert
Cutting speed (m/min)	150
Feed rate (mm/rev)	0.12
Depth of cut (mm)	1.0
Cooling strategies	Dry, Flood, MQL

Minimum Quantity Lubrication System

The minimum quantity lubrication system delivered a fine mist of vegetable-oil-based lubricant to the cutting zone through a nozzle directed at the tool-chip interface, using compressed air as the carrier. The flow rate and air pressure were set to values reported as effective in the literature (2, 6).

Table 2: Minimum Quantity Lubrication System Settings

Parameter	Setting
Lubricant type	Vegetable-oil-based
Lubricant flow rate (ml/h)	60
Air pressure (bar)	5
Nozzle position	Directed at tool-chip interface

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Measurement Procedure

Flank wear was measured at intervals over the cutting time using a toolmaker's microscope, surface roughness was measured with a stylus profilometer, and the cutting-zone temperature was recorded with a thermocouple arrangement. Each measurement was averaged over repeated trials to limit scatter (3, 4).

RESULTS AND FINDINGS

The progression of flank wear under the three cooling strategies is shown in Figure 1. Dry machining produced the most rapid wear, reaching the wear criterion well before the other strategies, whereas minimum quantity lubrication and flood cooling both extended tool life considerably, with minimum quantity lubrication giving the lowest wear over most of the cutting time (3, 4).

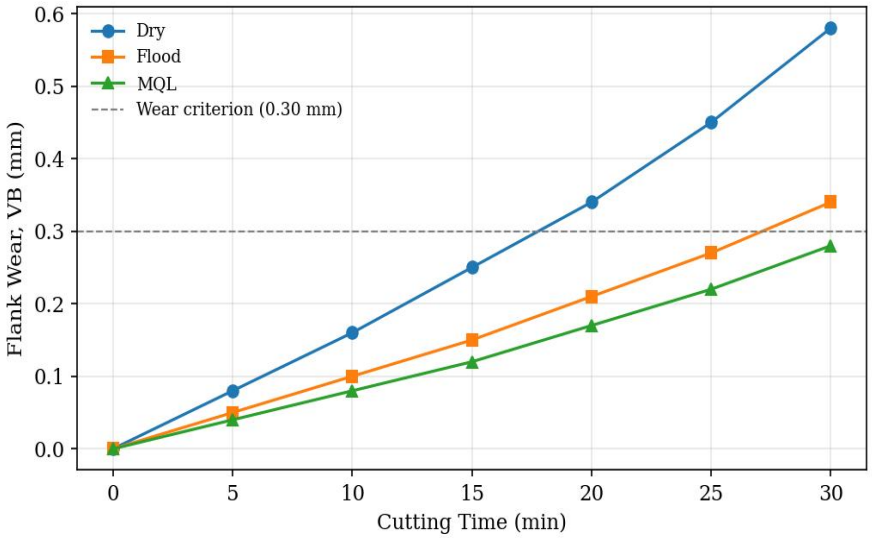


Figure 1: Progression of Flank Wear under Dry, Flood, and MQL Conditions

Table 3 compares the three strategies in terms of flank wear, surface roughness, and cutting temperature at a fixed cutting time. Minimum quantity lubrication achieved the lowest flank wear and surface roughness and a cutting temperature close to that of flood cooling, while consuming only a small fraction of the fluid.

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Table 3: Comparison of Performance under Dry, Flood, and MQL Conditions

Cooling Strategy	Flank Wear, VB (mm)	Surface Roughness, Ra (µm)	Cutting Temperature (°C)	Fluid Use
Dry	0.45	2.6	640	None
Flood	0.27	1.7	410	High
MQL	0.22	1.5	440	Very low

DISCUSSION

The results demonstrate the clear advantage of minimum quantity lubrication over dry machining in controlling both tool wear and cutting temperature (3, 4). By delivering lubricant directly to the tool-chip interface, the technique reduces friction and adhesion at the point where heat is generated, limiting the thermal softening and abrasion that drive flank wear (2, 5).

Compared with flood cooling, minimum quantity lubrication achieved comparable surface roughness and slightly lower tool wear while using only a small fraction of the fluid. Its cutting temperature was marginally higher than that of flood cooling, reflecting the lower bulk cooling capacity of a mist, but this did not translate into inferior wear or finish under the conditions tested (5, 8).

These findings support the wider literature that positions minimum quantity lubrication as an effective and environmentally responsible compromise between dry and flood machining (1, 9, 10). Its benefits are greatest where lubrication, rather than bulk cooling, governs performance, as in the finishing of moderately difficult materials.

CONCLUSION

This study compared minimum quantity lubrication with dry and flood machining during the turning of an alloy steel. Minimum quantity lubrication substantially reduced flank wear,

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surface roughness, and cutting temperature relative to dry machining, and matched or exceeded flood cooling in tool wear and finish while consuming only a small fraction of the fluid.

The findings confirm that minimum quantity lubrication is an effective and sustainable alternative to conventional flood cooling. It is particularly advantageous where lubrication is the dominant requirement, and it offers clear environmental and cost benefits without sacrificing machining performance.

LIMITATIONS

- A single workpiece material and one set of cutting parameters were used.
- Only one lubricant flow rate and air pressure were investigated.
- Cutting forces and chip morphology were not measured.
- The economic and life-cycle analysis of fluid use was qualitative.

FUTURE SCOPE

- Evaluation across additional materials, including difficult-to-machine alloys.
- Optimisation of lubricant flow rate, air pressure, and nozzle position.
- Comparison with cryogenic and hybrid cooling strategies.
- Assessment of cutting forces, residual stress, and subsurface integrity.
- Life-cycle cost and environmental analysis of the cooling strategies.

REFERENCES

1. Weinert, K., Inasaki, I., Sutherland, J. W., & Wakabayashi, T. (2004). Dry machining and minimum quantity lubrication. *CIRP Annals*, 53(2), 511-537.

2. Sharma, V. S., Dogra, M., & Suri, N. M. (2009). Cooling techniques for improved productivity in turning. *International Journal of Machine Tools and Manufacture*, 49(6), 435-453.

3. Dhar, N. R., Kamruzzaman, M., & Ahmed, M. (2006). Effect of minimum quantity lubrication on tool wear and surface roughness in turning AISI-4340 steel. *Journal of*

Page 17-25 © MANTECH PUBLICATIONS 2026. All Rights Reserved

Materials Processing Technology, 172(2), 299-304.

4. Khan, M. M. A., Mithu, M. A. H., & Dhar, N. R. (2009). Effects of minimum quantity lubrication on turning AISI 9310 alloy steel. *Journal of Materials Processing Technology*, 209(15-16), 5573-5583.

5. Boswell, B., Islam, M. N., Davies, I. J., Ginting, Y. R., & Ong, A. K. (2017). A review identifying the effectiveness of minimum quantity lubrication. *The International Journal of Advanced Manufacturing Technology*, 92(1-4), 321-340.

6. Lawal, S. A., Choudhury, I. A., & Nukman, Y. (2012). Application of vegetable oil-based metalworking fluids in machining ferrous metals: a review. *International Journal of Machine Tools and Manufacture*, 52(1), 1-12.

7. Sreejith, P. S., & Ngoi, B. K. A. (2000). Dry machining: machining of the future. *Journal of Materials Processing Technology*, 101(1-3), 287-291.

8. Shokrani, A., Dhokia, V., & Newman, S. T. (2012). Environmentally conscious machining of difficult-to-machine materials. *International Journal of Machine Tools and Manufacture*, 57, 83-101.

9. Debnath, S., Reddy, M. M., & Yi, Q. S. (2014). Environmental friendly cutting fluids and cooling techniques in machining: a review. *Journal of Cleaner Production*, 83, 33-47.

10. Trent, E. M., & Wright, P. K. (2000). *Metal Cutting* (4th ed.). Butterworth-Heinemann.

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