

Economic Aspects of Minimum Quantity Lubrication (MQL) in Milling of Magnesium Alloy*

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Abstract

This paper examines the applicability of minimum quantity lubrication (MQL) in the milling of magnesium alloys. The experimental procedure involved the progressive introduction of additional MQL nozzles to assess the influence of the aerosol on surface roughness and production costs. The results indicate that increasing the number of dosing nozzles does not yield a significant improvement in surface quality, while it markedly increases manufacturing costs. Furthermore, it was observed that dry machining, conducted without any coolant, leads to higher surface roughness values. These findings support the application of MQL in the milling of magnesium alloys as an effective compromise between surface quality and economic efficiency.

Keywords: cost of the process, MQL, magnesium alloys, roughness surface

Introduction

Scientific studies and experimental investigations have shown that the complete elimination of cutting fluids is not feasible without compromising the quality of the final products or the efficiency of machining processes (Baldin, V. and da Silva, L.R.R. 2023). The absence of cooling also reduces the tool life of the cutting edge (e.g., milling cutter) (Kuntoglu, M. and Saglam, H. 2021). The deterioration (blunting) of the cutting edge leads to increased cutting forces and the potential occurrence of mechanical vibrations, which in turn elevates the energy demand of the process (Kuntoglu, M. and Saglam, H. 2019). For these reasons, ensuring adequate lubrication is of critical importance. However, conventional flood cooling generates additional costs associated with fluid cleaning and disposal (Gupta, M.K. and Song, Q. 2021). The use of cutting fluids also raises environmental and occupational health concerns due to the petroleum-based nature of many oils. Therefore, the application of Minimum Quantity Lubrication (MQL) technology represents a promising alternative. This method reduces the drawbacks of dry machining, lowers fluid-related operating costs, and mitigates negative environmental impacts (Mannekote, J.K. and Kailas, S.V. 2018).

The application of minimum quantity lubrication (MQL) in the form of an aerosol can enhance the lubri-cooling effect at the chip-tool-workpiece interface. This approach reduces friction and, consequently, decreases the

likelihood of built-up edge formation, thereby improving the dimensional accuracy of the finished component (Sen, B. and Mia, M. 2019).

Considering these aspects, investigations into milling operations conducted under MQL conditions are fully justified.

Magnesium alloys are widely used in the aerospace and automotive industries due to their low density and favorable mechanical properties. The ability to properly select technological parameters during their machining facilitates significant improvements in surface quality, enhances process efficiency, and ultimately reduces the overall cost of final products. Therefore, the selection of an appropriate machining strategy – including cutting speed, feed rate, depth of cut, and cooling/lubrication method – plays a decisive role in determining on the final outcome of the process.

Overview of Existing Research

According to a research study by Li et al (2017) provided on the website of SKF, a manufacturer of MQL systems, experimental results for milling stainless steel demonstrated that the application of internal MQL reduced the overall machining cost by 54% compared to conventional flood cooling. Moreover, tool wear was observed to progress more slowly when MQL was employed.

In another study Kui et al (2022), the authors reported that conventional coolants constitute a significant portion of production costs, often accounting for 10–17% of total manufacturing expenses in industry. The study also emphasized the environmental and occupational health aspects associated with MQL, such as reduced waste generation, lower aerosol and mist emissions, and diminished risks for machine operators. These factors may lead to long-term savings, for example, in insurance premiums or costs related to workplace accidents.

A research team Garcia-Martinez et al (2024), in their investigation of titanium alloy milling, compared not only fluid costs and tool consumption but also the ecological impact and energy demand of different lubrication methods. Their findings revealed that MQL enables machining at cutting speeds exceeding 70 m/min, resulting in a fourfold increase in tool life compared to dry machining. Furthermore, carbon dioxide emission analyses confirmed that MQL exhibits the lowest carbon footprint, thereby identifying it as the most sustainable machining strategy.

The Need for Investigating Multi-Nozzle Oil Mist Delivery in MQL Applications

A review of the existing literature reveals a lack of studies addressing the application of oil mist lubrication using multiple dosing nozzles. While numerous investigations have examined the general effectiveness of MQL in machining processes, the influence of directional multi-nozzle delivery on both surface quality and process economics remains largely unexplored. Therefore, the objective of the present study is to evaluate whether increasing the number and adjusting the orientation of MQL nozzles has a significant effects on the surface roughness of machined components as well as the overall manufacturing costs.

Research Plan

In this paper, milling experiments were conducted on AZ31 magnesium alloys using a 16 mm diameter cutting tool. The machining was performed with an HM90 E90A-10 end mill equipped with two HM90 APCR 100304PDFR-P/DP inserts. This tool is specifically designed for machining non-ferrous materials such as aluminum and magnesium alloys. Machining was performed on a Brother Speedio S700Xd1 milling machine, using a Unisys 320Trio MQL generator system. The research plan was as follows: the input data included feed rates per tooth ranging from 0.05 to 0.30 mm/tooth, with a 0.05 mm increment, and cutting speeds of 600, 900, and 1200 m/min. The axial depth of cut (ap) was set to 3 mm, while the cutting width (ae) was equal to the cutter width, i.e., 16 mm. The oil mist output per nozzle was 40 ml/h. Motultech Supracut MQL 45, a biodegradable oil based on synthetic esters, was used during the tests. The cost of 20 liters is approximately €230, while the cost of using oil mist per nozzle per hour is approximately €4.60. The surface roughness of the machined specimens was measured using a Mitutoyo Surftest SV-2100M4 (178-636-01D) profilometer.

Machining Process Plan

The configuration of the oil mist dosing nozzles is presented in Figure 1.

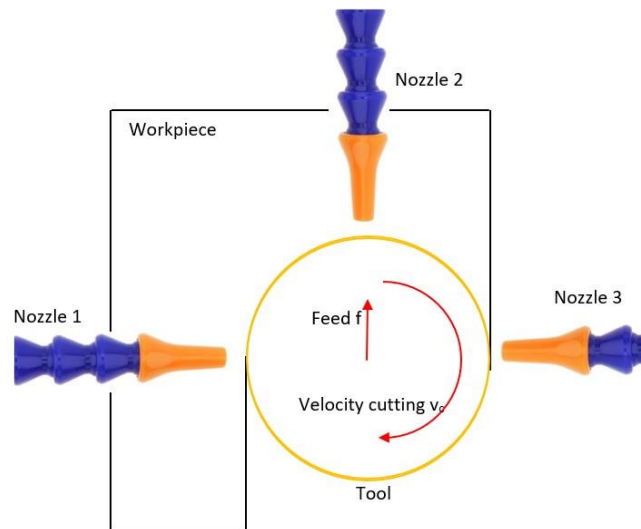


Fig 1. Schematic arrangement of MQL dosing nozzles

The schematic illustrates the dosing nozzles numbered 1, 2, and 3, the feed direction, and cutting speeds (indicated by red arrows). The end mill is highlighted in yellow, while the workpiece is shown in black. Milling operations were conducted under following conditions:

- Dry machining without any nozzles (no coolant),
- Using a single nozzle – Nozzle 1,
- Using two nozzles – Nozzle 1 and Nozzle 3,
- Using three nozzles – Nozzle 1, Nozzle 2, and Nozzle 3.

Results

The results obtained during the tests are presented in Figure 2 and Figure 3.

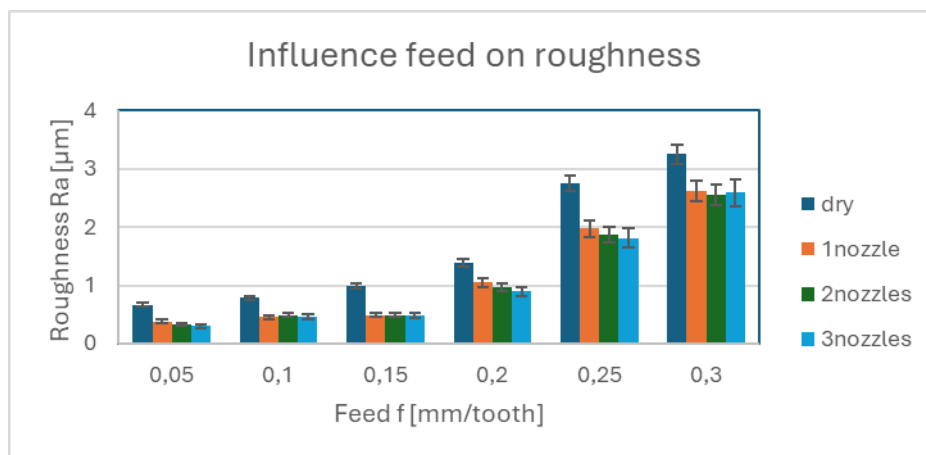


Fig. 2. Graph of the dependence of feed on the obtained roughness

The analysis of the effect of feed per tooth on surface roughness indicates that a threefold increase in feed (from 0.05 to 0.15 mm/tooth) does not significantly influence the Ra values when one or more MQL nozzles are used. In contrast, dry machining results in a 20 – 50% increase in surface roughness compared to MQL-assisted operations. These findings suggest that MQL enables the production of components with surface quality comparable to that achieved under dry conditions, but at higher cutting speeds, potentially lowering unit production cost.

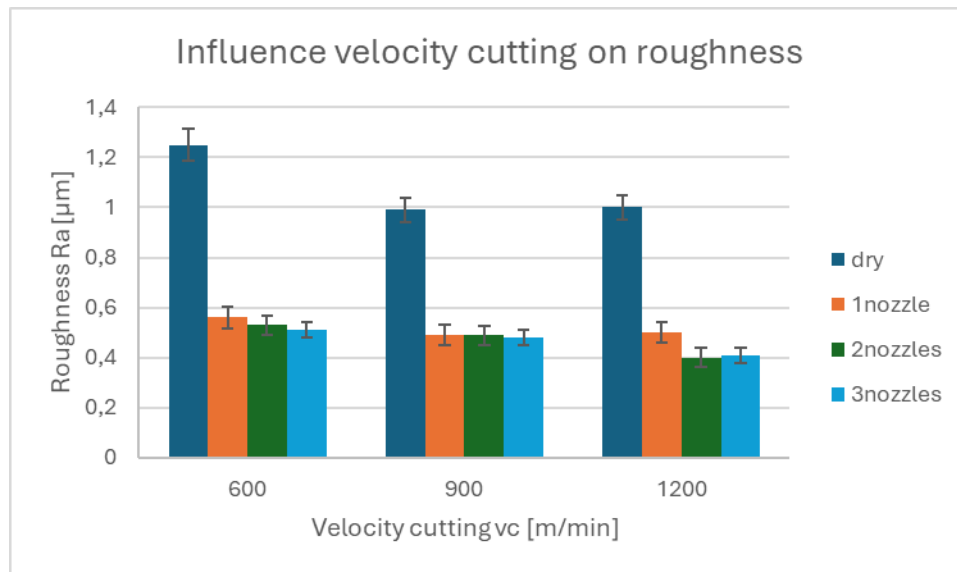


Fig. 3. Graph of the dependence of cutting speed on the obtained roughness

The analysis of the effect of cutting speed on surface roughness indicates that the use of MQL reduces Ra values by approximately 50%. Moreover, it was observed that increasing the cutting speed significantly decreases surface roughness under dry machining conditions, by up to about 25%, whereas under MQL-assisted conditions, the reduction is less pronounced, at approximately 15%.

Conclusions

Based on the conducted research, the following conclusions were drawn:

1. The number of MQL dosing nozzles has no significant effect on surface quality. Increasing the number of nozzles from one to three results in only a negligible improvement in surface finish. Therefore, the use of more than one nozzle may not be economically justified.
2. The cost of purchasing an MQL system is approximately €1,000, with an operational cost of around €4.60 per hour. MQL enables the doubling of production speed (from $v_c = 600$ m/min to $v_c = 1200$ m/min) without significantly compromising surface quality compared to dry machining. As a result, unit production cost can be substantially reduced.
3. The results concerning surface quality at varying feed rates indicate that the use of MQL can reduce surface roughness (Ra) by an average of 20 – 50% compared to dry machining. This improvement may eliminate the need for additional finishing operations (e.g., finishing milling or grinding). Consequently, components can achieve final geometric characteristics directly after milling, enabling significant reductions in production costs.

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