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Research article

Enhancing high-speed drilling efficiency with an eco-friendly sunflower oil as a cutting fluid

José Aécio Gomes de Sousa[1,*], Antônio Santos Araújo Junior[2], Feliciano Cangue[3] and Luiz Leroy Thomé Vaughan[4]

[1] Federal Technological University of Paraná, Londrina-PR, Brazil
[2] Federal Institute of Education Science and Technology of Maranhão, São Luiz, MA, Brazil
[3] TotalEnergies Angola, Metallurgy and Corrosion Department, Luanda, Angola
[4] Federal University of Itajubá, Itajubá-MG, Brazil

* **Correspondence:** Email: josesousa@utfpr.edu.br.

Abstract: This study investigates the performance of sunflower oil as a cutting fluid applied through the minimum quantity fluid (MQF) technique in drilling processes with high-speed steel drills. The results reveal that sunflower oil significantly reduces torque compared to dry machining, with a 7.59% reduction in torque when cutting speed increased from 17 to 25 m/min. Additionally, sunflower oil shows competitive results in comparison to LB2000 commercial oil, with a slight decrease in torque of 2.04%. The study also found that sunflower oil outperforms dry machining, particularly when used at lower feed rates and higher cutting speeds, suggesting that sunflower oil could be a viable and environmentally friendly alternative in machining processes. These findings offers a promising solution for reducing friction and improving machining efficiency, while also addressing environmental and health concerns.

Keywords: cutting fluids; sunflower oil; high-speed drilling; sustainable machining; MQL

1. Introduction

One of the main challenges in machining operations is the heat generated at the tool–workpiece interface, which significantly compromises cutting tool performance and workpiece integrity [1]. Excessive heat in this zone can lead to microstructural changes, geometric distortions, metallurgical defects, cracks, and residual stresses [2]. In this context, cutting fluids are widely used to reduce temperature and friction, improve chip evacuation, and minimize the extent of thermally affected zones [3].

Despite their relevance in the metalworking industry, the use of conventional cutting fluids has been increasingly restricted due to high operational costs, environmental concerns, and potential health risks for operators [4,5]. Nevertheless, in many machining operations, especially those involving high cutting temperatures, fluid application remains essential for prolonging tool life and ensuring surface and dimensional quality [6].

To mitigate the environmental and health drawbacks of traditional coolants, the minimum quantity lubrication (MQL) technique has gained prominence. This method employs small amounts of lubricant, typically in aerosol form, which significantly reduces fluid consumption while still lowering friction and minimizing material adhesion at the tool–chip interface [7,8]. In MQL systems, lubrication is provided by the oil, while compressed air contributes a limited cooling effect.

Krishna et al. (2010) emphasize the increasing demand for eco-friendly and operator-safe alternatives to conventional cutting fluids, citing their negative impact on both the environment and human health [9]. Rios (2005) further notes that stricter environmental regulations reflect a societal shift toward sustainability and pollution control [10]. As a result, industries have been urged to reduce the use of mineral oil-based lubricants in favor of more sustainable solutions [11,12].

Within this sustainability-driven context, manufacturing industries seek to improve their processes while reducing costs. Drilling plays a crucial role in industrial manufacturing, accounting for approximately 40% of all machining operations and commonly representing the final step in component production [13,14]. Due to its widespread use, drilling requires high reliability and precision, making performance optimization essential.

Understanding the forces acting on the cutting edge is vital for estimating power requirements and informing tool design [15,16]. Unlike turning or milling tools, drills possess a unique tip geometry, presenting additional challenges for force management and heat dissipation. Consequently, improving drilling efficiency remains a key research focus in machining science [17–20].

Simultaneously, the importance of sustainability in manufacturing, encompassing factories, processes, and products, has grown significantly over the last decade [21]. It now represents a competitive advantage in industrial sectors, particularly within machining processes [22].

2. Materials and methods

Experiments were conducted to evaluate the effect of different lubrication conditions on the torque generated during drilling. The tests compared the performance of three cutting conditions: LB2000 commercial vegetable oil, VONDER emulsifiable oil (both applied via the MQL technique) and dry drilling, to serve as a baseline for comparison. The workpiece material used was AISI 1045 medium-carbon steel (205 HB), a commonly employed alloy in the manufacturing of components requiring higher mechanical strength than low-carbon steels, such as machine shafts, pneumatic cylinders, clamps, and collets [23]. The dimensions of the specimens are presented in Figure 1.

The drilling operations were performed using 10 mm diameter uncoated high-speed steel (HSS) twist drills on a ROMI DISCOVERY 560 vertical machining center. The spindle is powered by a 12.5 HP AC motor, with a total installed power of 15 kVA, and offers variable rotational speeds ranging from 7 to 7500 rpm.

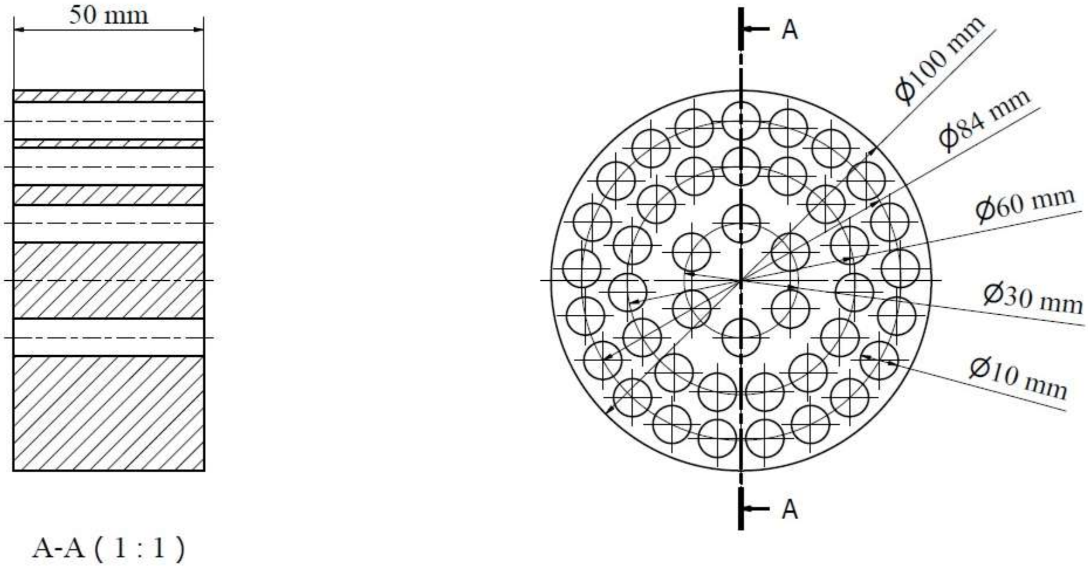

Figure 1. Specimen's dimensions.

For the MQL conditions, an O2AO-STD lubrication system manufactured by ITW Fluids Products Group was employed (Figure 2). This system operated with a continuous compressed air supply at approximately 4 bar and delivered an intermittent fluid spray at a frequency of one pulse per second. The system includes a manually filled reservoir, a pressure gauge, and separate flow control valves for both air and oil. The lubricant was transported via a small-diameter hose inside a larger compressed air conduit, yielding a fluid flow rate of 50 mL/h. For the jet application condition, the machining center's built-in delivery system was used, providing a fluid flow of approximately 540 L/h through two nozzles, with the emulsion prepared at a recommended 5% concentration.

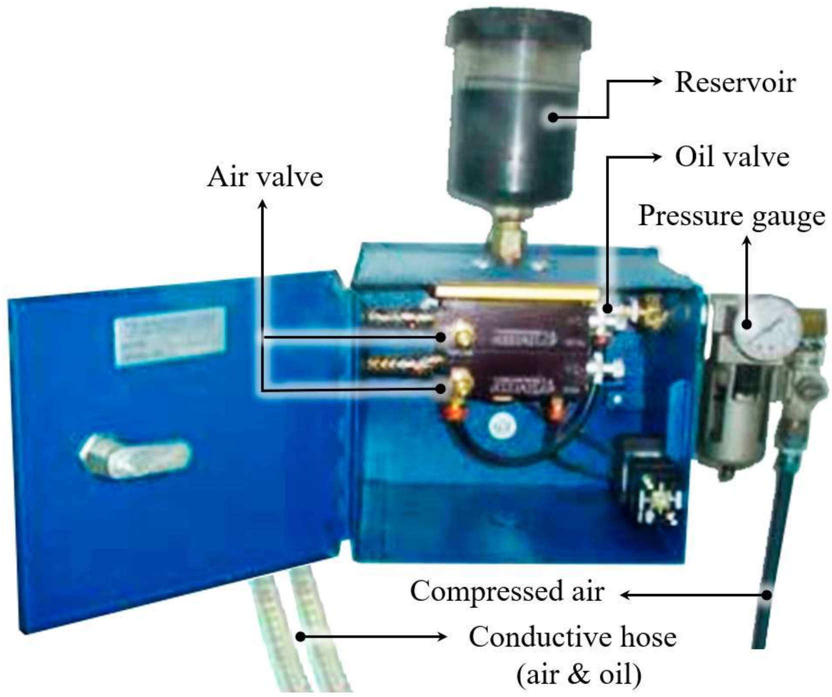

Figure 2. MQL technique application system.

Torque measurements were recorded using a Kistler 9271A piezoelectric dynamometer coupled with a 5006 charge amplifier. The output signals were digitized via a USB data acquisition card (Model 1208FS), processed, and stored on a microcomputer. Custom-developed software in Delphi was used to visualize and record the torque data graphically. Figure 3 shows the dynamometer setup in the machining center.

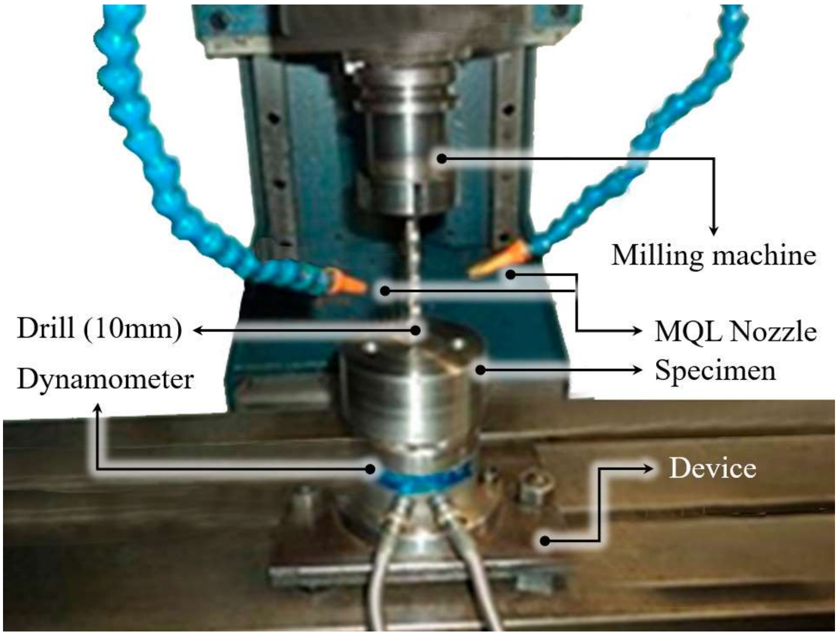

Figure 3. Legend of the figure. System for the acquisition of power and torque: desk, electrical machine and dynamometer.

To ensure tool consistency, flank wear was monitored throughout the tests. Whenever the average flank wear (VB_B) exceeded 0.1 mm, the cutting tool was replaced with a new one, according to ISO 8688. Three quantitative input parameters were defined: cutting speed (v_c = 17 m/min and v_c = 25 m/min), feed rate (f = 0.1 mm/rev and f = 0.2 mm/rev), and hole depth (L = 15 mm and L = 50 mm). Theses parameters were determined based on recommendations from tool manufacturers, previous studies in the literature and preliminary tests to ensure safe and stable drilling conditions for AISI 1045 steel with HSS drills. In addition, four lubrication conditions were evaluated: sunflower oil, LB2000 oil, VONDER emulsifiable oil, and dry cutting. A preliminary test and two replicates were performed for each combination of experimental variables.

3. Results and discussions

Figures 4 and 5 present the torque behavior for bore depths of 15 and 50 mm, respectively, under different lubrication and cooling conditions. The results represent the average values obtained from three repetitions (test, replicate, and triplicate) for each combination of variables. As shown in Figure 5, the dry drilling condition consistently exhibited higher torque values at the lower feed rate (f = 0.1 mm/rev). At the higher feed rate (f = 0.2 mm/rev), sunflower oil tended to result in higher torque values, regardless of the cutting speed.

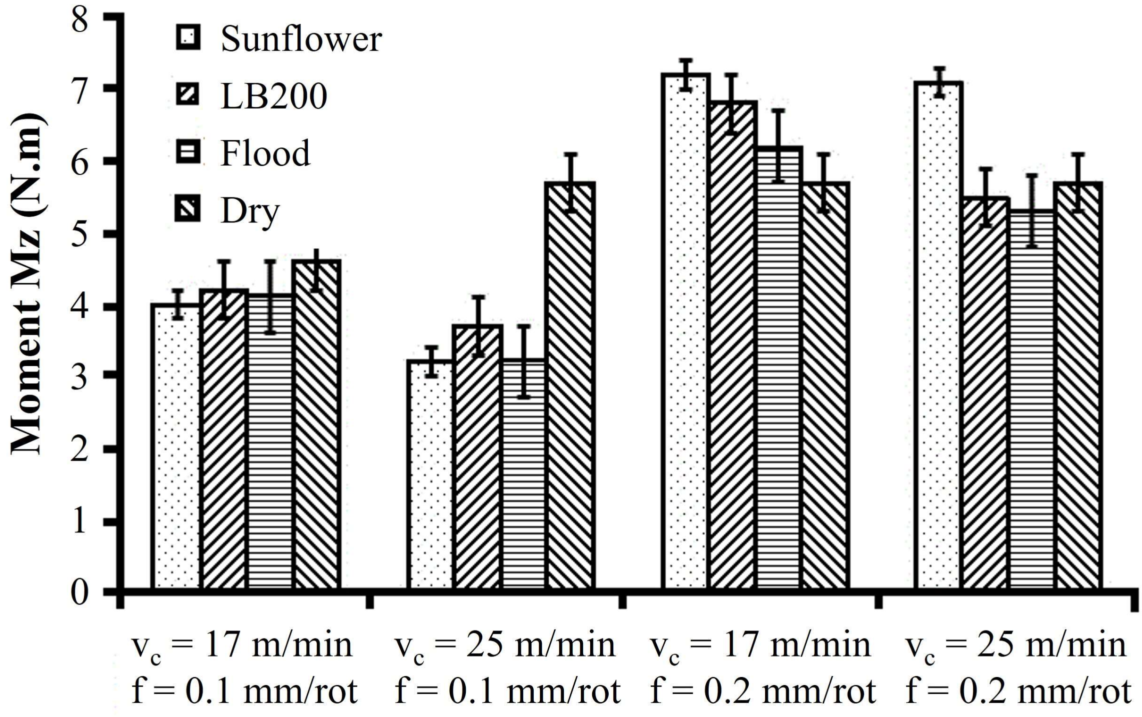

Figure 4. Torque behavior for L = 15 mm.

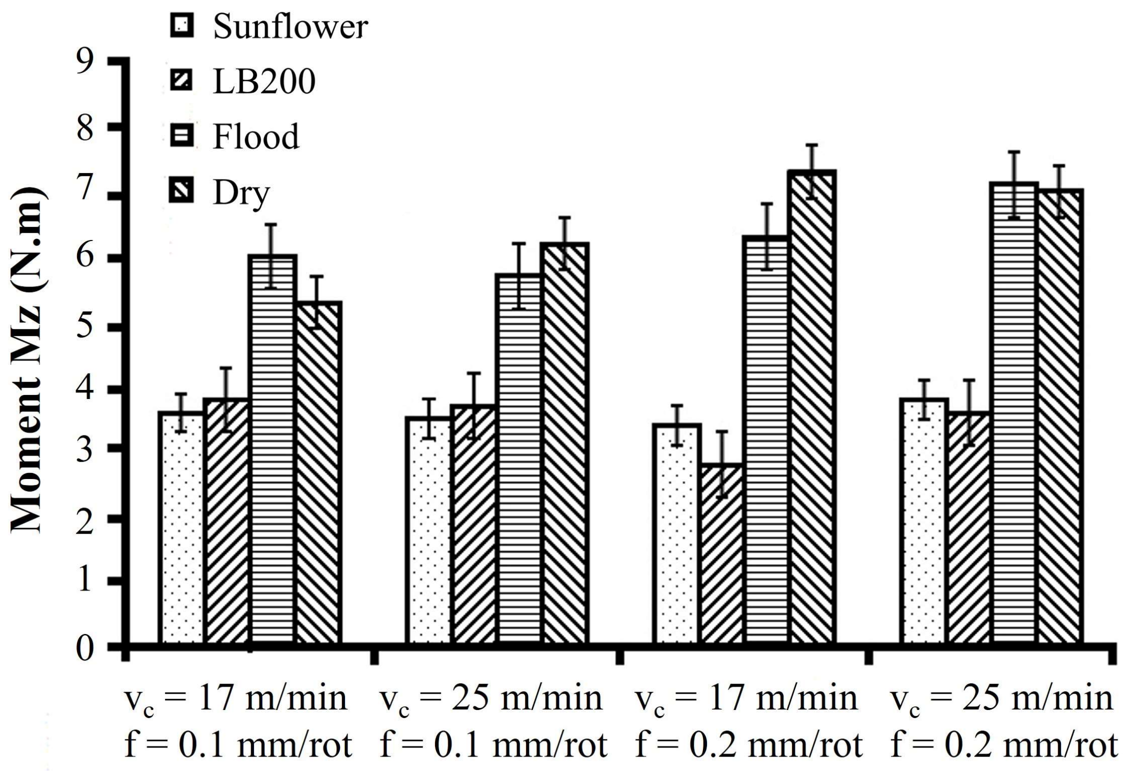

Figure 5. Torque behavior for L = 50 mm.

The most significant statistical difference was observed for the combination "f = 0.1 mm/rev" and "v_c = 25 m/min", particularly when comparing the dry condition with the other lubrication strategies. Table 1 shows the ANOVA results for torque (Mz) when drilling with edible sunflower oil and dry cutting. The analysis emphasizes the significant influence of the feed rate (f), which was confirmed with 95% confidence, as indicated by the p-value.

Table 1. Main effects of input variables, sunflower oil and dry conditions.

Sunflower/Dry	Effect	p-value
Average	5.0725	0.0001
v_c	−0.3850	0.3416
f	2.5250	0.0009
L	−0.5251	0.6946
Atm	0.1000	0.7959

Trend analyses based on Table 1 are illustrated in Figure 6. An increase in cutting speed from 17 to 25 m/min resulted in a reduction in torque of 0.385 Nm or 7.59% (Figure 6a). Conversely, increasing the feed from 0.1 to 0.2 mm/rev led to a torque increase of 2.525 Nm (49.78%), which was statistically significant (Figure 6b). Increasing the bore length from 15 to 50 mm resulted in a slight, non-significant torque reduction of 0.525 Nm (10.34%) (Figure 6c). Replacing dry cutting with sunflower oil in the MQL configuration led to a small torque reduction of 0.1 Nm (1.97%, Figure 6d). Although this difference was not statistically significant, the use of sunflower oil indicated a tendency toward lower feed-direction torque compared to conventional dry machining.

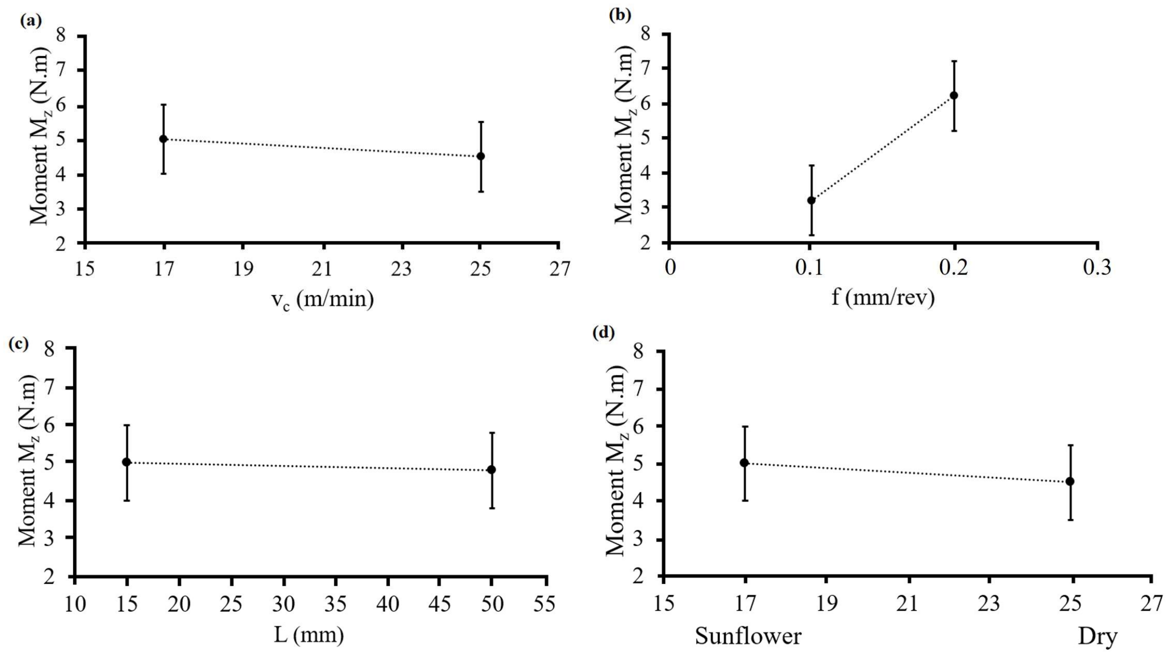

Figure 6. Mz trends: (a) v_c, (b) f, (c) L, (d) sunflower oil and dry conditions.

Table 2 presents the ANOVA results comparing the performance of sunflower oil and LB2000 under MQL conditions. Similar to previous findings, the feed rate was shown to be the most influential factor at a 95% confidence level. The trends derived from Table 2 are depicted in Figure 7.

Increasing cutting speed from 17 to 25 m/min resulted in a torque decrease of 0.31125 Nm (6.25%, Figure 7a), while increasing the feed from 0.1 to 0.2 mm/rev caused a torque increase of 2.48875 Nm (50.06%, Figure 7b), which was statistically significant. An increase in bore length from 15 to 50 mm led to a minor torque decrease of 0.47875 Nm (9.62%, Figure 7c), not deemed statistically significant. Comparing the two fluids, LB2000 exhibited slightly lower torque values than sunflower oil, with a decrease of 0.10125 Nm (2.04%, Figure 7d), although this difference was also not statistically significant.

Table 2. Main effects of input variables, sunflower oil and LB2000.

Sunflower/LB2000	Effect	p-value
Average	4.9718	0.0001
v_c	−0.3112	0.2970
f	2.4887	0.0002
L	−0.4787	0.1334
Atm	0.1012	0.7205

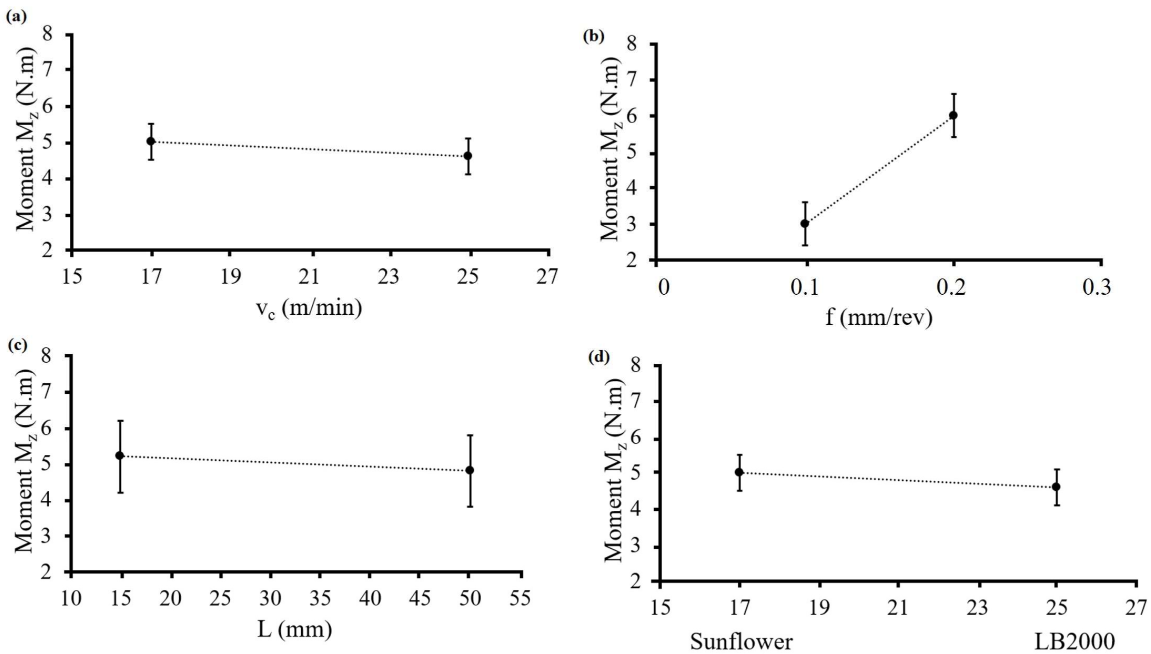

Figure 7. Mz trends: (a) v_c, (b) f, (c) L, (d) sunflower oil and LB2000.

Table 3 summarizes the ANOVA analysis comparing sunflower oil and conventional jet fluid application. Again, the feed rate had a significant impact, as confirmed by the p-value. The trend analysis in Figure 8 shows that increasing the cutting speed led to a torque reduction of 0.325 Nm (6.59%, Figure 8a), and increasing the feed from 0.1 to 0.2 mm/rev led to a torque increase of 2.7775 Nm (56.31%, Figure 8b), which was statistically significant. The increase in bore depth led to a small torque decrease of 0.225 Nm (4.56%, Figure 8c), not statistically significant. Switching from sunflower oil (MQL) to fluid application by jet produced a slight torque reduction of 0.18 Nm (3.65%,

Figure 8d), again without statistical significance. However, the results suggest a small tendency for jet-applied fluid to reduce feed forces more effectively than edible sunflower oil.

Table 3. Main effects of input variables, sunflower oil and flood conditions.

Sunflower/flood	Effect	p-value
Average	4.9325	0.0001
v_c	–0.3250	0.4673
f	2.7775	0.0011
L	–0.2251	0.6095
Atm	0.1800	0.6813

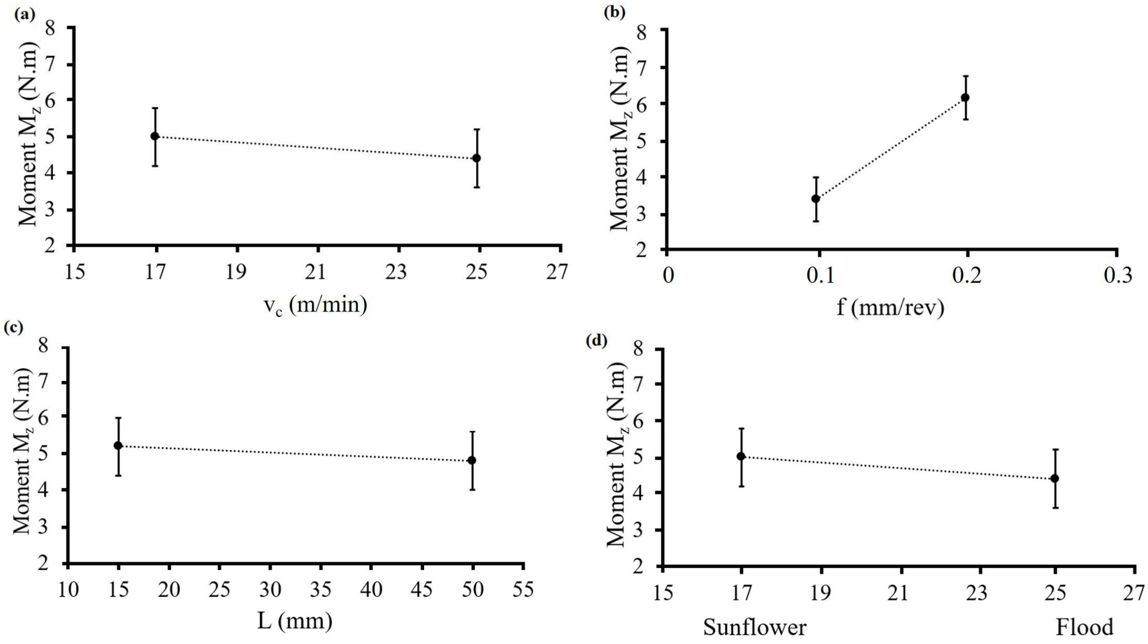

Figure 8. Mz trends: (a) v_c, (b) f, (c) L, (d) sunflower oil and flood conditions.

4. Conclusions

The main conclusions of this study are listed below:

1. The use of cutting fluids such as sunflower oil in combination with the MQF technique has proved to be an effective alternative for reducing torque during the drilling process. This indicates a reduction in friction at the chip/tool interface and, consequently, an improvement in machining performance.

2. Sunflower oil showed particularly good performance when compared to dry machining, especially in combinations of lower cutting feed and higher cutting speed.

3. Compared to LB2000 commercial oil, sunflower oil showed competitive results in terms of torque, indicating that it could be an effective choice to replace the commercial oils traditionally used in the metalworking industry.

4. Overall, this study highlights the importance of using environmentally friendly and healthy alternatives to conventional cutting fluids, considering the growing environmental challenges and human health concerns.

5. The minimum quantity fluid (MQF) technique applied with sunflower oil shows the potential to contribute positively to the efficiency of machining processes, while minimising negative impacts on the environment.

It is worth noting that the present study focused exclusively on torque as the primary output parameter, given its relevance to energy consumption and tool–chip interaction. However, machining performance is a multifaceted phenomenon, and further studies incorporating additional metrics such as surface integrity, tool wear, and temperature are necessary to fully assess the effectiveness of sunflower oil in real-world applications.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

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Author contributions

José Aécio Gomes de Sousa: validation, investigation, data curation, writing—review & editing; Antônio Santos Araújo Junior: funding acquisition, writing—review & editing, methodology, validation, investigation, writing—original draft; Luiz Leroy Thomé Vaughan: supervision, conceptualization, methodology, validation, formal analysis, investigation; Feliciano José Ricardo Cangue: formal analysis, investigation, writing—original draft, visualization.

Conflict of interest

The authors declare no conflict of interest.

References

1. Klocke F (2011) *Manufacturing Processes 1: Cutting*, Heidelberg: Springer Berlin. https://doi.org/10.1007/978-3-642-11979-8
2. Machado AR, Coelho RT, Abrãao AM, et al. (2018) *Theory of the materials machining*, 3 Eds., São Paulo: Edgard Blücher, 407.

3. dos Reis A, Fernandes GHN, de Sousa JAG, et al. (2024) Tool life assessing of high strength cast iron alloys in dry face milling operations. *J Manuf Process* 11: 180–193. https://doi.org/10.1016/j.jmapro.2024.01.014
4. Boswell B, Islam MN, Davies IJ, et al. (2017) A review identifying the effectiveness of minimum quantity lubrication (MQL) during conventional machining. *Int J Adv Manuf Technol* 92: 321–340. https://doi.org/10.1007/s00170-017-0142-3
5. Matin A, Islam R, Wang X, et al. (2023) AIoT for sustainable manufacturing: Overview, challenges, and opportunities. *Internet Things* 24: 100901. https://doi.org/10.1016/j.iot.2023.100901
6. Teti R, D'addona DM, Segreto T, et al. (2021) Microbial-based cutting fluids as bio-integration manufacturing solution for green and sustainable machining. *CIRP J Manuf Sci Tec* 34: 16–25. https://doi.org/10.1016/j.cirpj.2020.09.016
7. Weinert K, Inasaki I, Sutherland JW, et al. (2004) Dry machining and minimum quantity lubrication. *CIRP Ann* 53: 511–537. https://doi.org/10.1016/S0007-8506(07)60027-4
8. Miehe R, Bauernhans T, Beckett M, et al. (2020) The biological transformation of industrial manufacturing—Technologies, status and scenarios for a sustainable future of the German manufacturing industry. *J Manuf Syst* 54: 50–61. https://doi.org/10.1016/j.jmsy.2019.11.006
9. Krishna PV, Srikant RR, Rao DN (2010) Experimental investigation on the performance of nanoboric acid suspensions in SAE-40 and coconut oil during turning of AISI 1040 steel. *Int J Mach Tool Manu* 50: 911–916. https://doi.org/10.1016/j.ijmachtools.2010.06.001
10. Rios MRS (2005) Desempenho de emulsão leitosa e fluido sintético na furação de aço inoxidável. *Revista Máquinas e Metais*, São Paulo, Brazil. https://doi.org/10.47749/T/UNICAMP.2002.253800
11. Rapeti P, Pasam VK, Rao Gurram KM, et al. (2018) Performance evaluation of vegetable oil-based nano cutting fluids in machining using grey relational analysis—A step towards sustainable manufacturing. *J Clean Prod* 172: 2862–2875. https://doi.org/10.1016/j.jclepro.2017.11.127
12. dos Reis A, de Ataide MG, de Souza JAG, et al. (2022) Machinability of high strength molybdenum-refined graphite grey cast iron and conventional vermicular automobile engine heads using heptagonal and double-sided carbide inserts. *Res Sq* 2: 13–18. https://doi.org/10.21203/rs.3.rs-2118414/v1
13. López de Lacalle LN, Fernández A, Oliveira D, et al. (2011) Monitoring deep twist drilling for a rapid manufacturing of light high-strength parts. *Mech Syst Signal Pr* 25: 2745–2752. https://doi.org/10.1016/j.ymssp.2011.02.008
14. Dornfeld DA (2013) *Green Manufacturing: Fundamentals and Applications*, New York: Springer New York. https://doi.org/10.1007/978-1-4419-6016-0
15. Al-Hamdan A (2002) Effect of misalignment on the cutting force signature in drilling. *J Mater Process Technol* 124: 83–91. https://doi.org/10.1016/S0924-0136(02)00051-1
16. Xing Y, Luo C, Zhu M, et al. (2023) Assessment of self-lubricating coated cutting tools fabricated by laser additive manufacturing technology for friction-reduction. *J Mater Process Technol* 318: 118010. https://doi.org/10.1016/j.jmatprotec.2023.118010
17. Shouckry AS (1982) The effect of cutting conditions on dimensional accuracy. *Wear* 80: 197–205. https://doi.org/10.1016/0043-1648(82)90217-4

18. Kazeem RA, Fadare DA, Ikumapayi OM, et al. (2022) Advances in the application of vegetable-oil-based cutting fluids to sustainable machining operations—A review. *Lubricants* 10: 69. https://doi.org/10.3390/lubricants10040069
19. Shaikh MBN, Rosenkranz A, Ali M, et al. (2024) Improving the performance of cutting fluids by using ZnO and ZrO_2 nanoparticles. *Proc Inst Mech Eng Part N*. https://doi.org/10.1177/23977914241263453
20. Zhang X, Li C, Zhou Z (2023) Vegetable oil-based nanolubricants in machining: From physicochemical properties to application. *Chin J Mech Eng* 36: 76–91. https://doi.org/10.1186/s10033-023-00895-5
21. Jaafar IH, Venkatachalam A, Joshi K, et al. (2007) Product design for sustainability: A new assessment methodology and case studies，In: Kutz M, *Environmentally Conscious Mechanical Design*, New York: John Wiley & Sons, 54: 25–65. https://doi.org/10.1002/9780470168202.ch2
22. Jawahir IS, Dillon Jr OW (2007) Sustainable manufacturing processes: New challenges for developing predictive models and optimization techniques. Proceedings of the 1st International Conference on Sustainable Manufacturing, Montreal, Canada. Available from: https://www.researchgate.net/publication/312891958_Sustainable_manufacturing_processes_New_challenges_for_developing_predictive_models_and_optimization_techniques.
23. Akhyar I, Sayuti M (2015) Effect of heat treatment on hardness and microstructures of AISI 1045. *Adv Mat Res* 1119: 575–579. https://doi.org/10.4028/www.scientific.net/AMR.1119.575

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