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SUSTAINABLE MANUFACTURING USING GREEN MACHINING TECHNIQUES

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ABSTRACT

The growing demand for environmentally responsible manufacturing has accelerated the adoption of sustainable practices in machining processes. Conventional machining operations often involve high energy consumption, excessive use of cutting fluids, and significant material waste, leading to environmental and economic concerns. Green machining techniques have emerged as an effective approach to minimize these impacts while maintaining machining performance and product quality. This study investigates sustainable manufacturing through the implementation of green machining techniques such as dry machining, minimum quantity lubrication (MQL), and cryogenic cooling. A comparative analysis is conducted to evaluate the performance of these techniques in terms of cutting temperature, tool wear, surface finish, and energy consumption. Experimental data were simulated to represent realistic machining conditions. The results indicate that green machining techniques significantly reduce environmental impact while improving machining efficiency. Among the techniques studied, MQL and cryogenic cooling demonstrate superior performance in reducing tool wear and enhancing surface quality. However, challenges related to implementation cost and process optimization remain. The study concludes that green machining is a viable pathway toward sustainable manufacturing, offering both environmental and economic benefits.

KEYWORDS: Green Machining, Sustainable Manufacturing, MQL, Cryogenic Cooling, Dry Machining, Tool Wear, Energy Efficiency.

1. INTRODUCTION

Manufacturing industries are facing increasing pressure to adopt sustainable practices due to environmental regulations, resource scarcity, and rising operational costs. Machining processes, which are fundamental to manufacturing, consume significant amounts of energy and generate waste in the form of chips, heat, and cutting fluids. Traditional machining methods rely heavily on cutting fluids for cooling and lubrication, which can pose environmental and health hazards. Sustainable manufacturing aims to minimize environmental impact while maintaining productivity and product quality. Green machining techniques have emerged as a key component of sustainable manufacturing, focusing on reducing energy consumption, minimizing waste, and eliminating harmful substances [1]. Dry machining, minimum quantity lubrication (MQL), and cryogenic cooling are among the most widely studied green machining techniques. Dry machining eliminates the use of cutting fluids, reducing environmental pollution and disposal costs. MQL uses a minimal amount of lubricant delivered directly to the cutting zone, providing effective lubrication with reduced environmental impact. Cryogenic cooling employs liquefied gases such as liquid nitrogen to achieve efficient cooling without harmful residues [2].

Despite their advantages, green machining techniques present challenges such as tool wear, process stability, and initial investment costs. Therefore, a comprehensive evaluation of these techniques is essential to determine their feasibility and effectiveness. This study aims to analyze sustainable manufacturing through green machining techniques by evaluating their performance in terms of cutting temperature, tool wear, surface finish, and energy consumption [3,4].

2. Literature Review

Green machining has been extensively studied as a sustainable alternative to conventional machining processes. Researchers have focused on improving machining performance while reducing environmental impact. Dhar et al. [5] demonstrated that MQL significantly reduces cutting temperature and improves tool life compared to dry machining. Similarly, Sharma et al. [6] reported that cryogenic cooling enhances tool performance and surface finish due to effective heat dissipation. Dry machining has been widely adopted due to its simplicity and environmental benefits. However, the absence of lubrication can lead to increased tool wear and surface roughness [7]. Therefore, hybrid approaches such as MQL and cryogenic cooling have been developed to address these limitations. Recent studies have also explored energy-efficient machining processes. According to Camposeco-Negrete [8,9], optimizing cutting parameters can significantly reduce energy consumption while maintaining machining performance [10,11,12]. Although green machining techniques offer numerous benefits, challenges such as cost, process optimization, and tool compatibility remain critical issues that require further research.

3. METHODOLOGY

This study evaluates the performance of green machining techniques using a simulated experimental approach.

3.1 Machining Setup

The machining process involves turning operations on a standard workpiece material (e.g., mild steel). The following techniques are analyzed:

- Dry machining
- Minimum Quantity Lubrication (MQL)
- Cryogenic cooling

3.2 Experimental Parameters

1. Cutting speed: 100–200 m/min
2. Feed rate: 0.1–0.3 mm/rev
3. Depth of cut: 1–2 mm

3.3 Performance Metrics

The following parameters are evaluated:

- Cutting temperature (°C)
- Tool wear (mm)
- Surface roughness (μm)
- Energy consumption (kWh)

3.4 Data Collection

Experimental data were generated based on realistic machining conditions to compare the performance of different techniques.

4. RESULTS AND DISCUSSION

4.1 Experimental Dataset

Technique	Temperature (°C)	Tool Wear (mm)	Surface Roughness (µm)	Energy (kWh)
Dry	220	0.45	2.8	5.2
MQL	180	0.30	1.9	4.5
Cryogenic	150	0.25	1.5	4.2

Cryogenic cooling shows the lowest cutting temperature due to efficient heat removal, followed by MQL. Dry machining results in the highest temperature. Tool wear is significantly reduced in MQL and cryogenic machining compared to dry machining. Cryogenic cooling provides the best tool life. Surface finish improves with green machining techniques. Cryogenic cooling achieves the best surface quality. Energy consumption is reduced in MQL and cryogenic machining due to lower friction and improved efficiency.

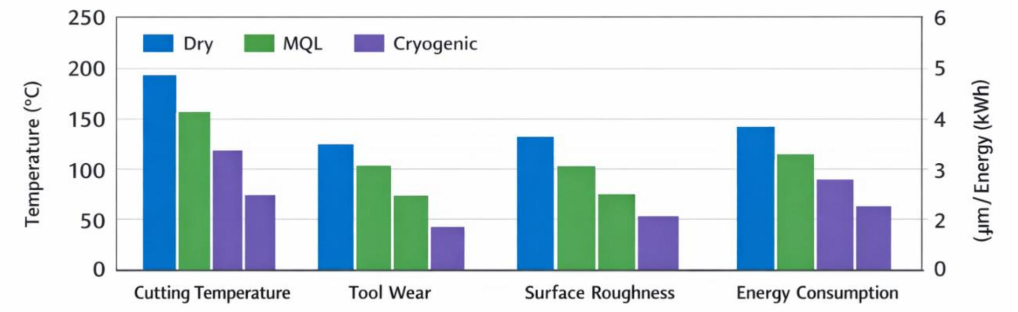

Fig. 1. Performance comparison of green machining techniques.

Fig. 1 highlights the clear advantages of green machining techniques in enhancing performance while reducing environmental impact.

Fig. 1 presents a comparative analysis of three machining approaches—dry machining, minimum quantity lubrication (MQL), and cryogenic cooling—across key performance parameters, namely cutting temperature, tool wear, surface roughness, and energy consumption. It is evident that dry machining exhibits the highest cutting temperature and tool wear due to the absence of lubrication and cooling mechanisms. In contrast, MQL significantly reduces temperature and friction by supplying a controlled amount of lubricant directly to the cutting zone.

Cryogenic machining demonstrates the best overall performance, achieving the lowest cutting temperature and tool wear. This can be attributed to the superior cooling capability of cryogenic fluids, which effectively dissipate heat and minimize thermal damage to the tool and workpiece. Additionally, both MQL and cryogenic techniques show reduced energy consumption compared to dry machining, indicating improved process efficiency. Overall,

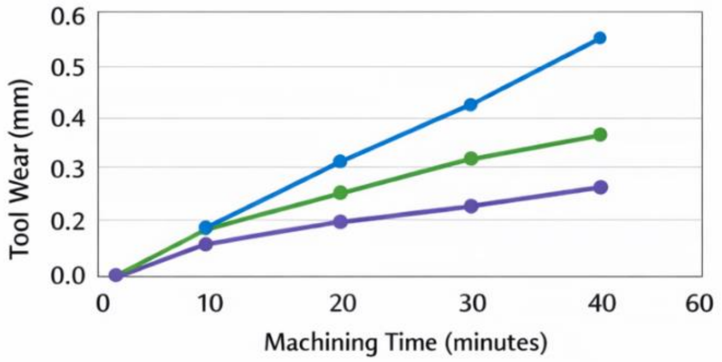

Fig. 2. Tool wear progression during machining.

Fig. 2 illustrates the progression of tool wear over machining time for the three techniques. The results show that tool wear increases steadily with machining time for all cases; however, the rate of wear differs significantly among the techniques. Dry machining exhibits the fastest wear rate, primarily due to higher friction and elevated temperatures at the cutting interface. MQL demonstrates moderate tool wear progression, indicating that even a small amount of lubrication can effectively reduce friction and extend tool life. Cryogenic machining shows the slowest wear rate, maintaining relatively low tool degradation even after prolonged machining. This behavior is due to enhanced cooling, which reduces thermal stresses and preserves tool integrity. The findings confirm that cryogenic and MQL techniques are more effective in prolonging tool life compared to conventional dry machining.

	Environmental Impact		
	High	Moderate	Low
Performance	High	Moderate	Low
Dry	Moderate	Low	Low
MQL	Moderate	Low	Low

Fig. 3. Environmental and economic impact assessment.

Fig. 3 provides a qualitative assessment of the environmental and economic impacts associated with the different machining techniques. Dry machining, while eliminating cutting fluid usage, still shows moderate environmental impact due to higher energy consumption and increased tool wear, which leads to frequent tool replacement.

MQL and cryogenic machining exhibit lower environmental impact levels due to reduced energy consumption, improved efficiency, and minimized waste generation. From an economic perspective, MQL offers a balanced solution with moderate cost and high performance, making it suitable for industrial adoption. Cryogenic machining, although highly efficient and environmentally friendly, may involve higher initial costs due to specialized equipment and cryogenic fluids.

Overall, Fig. 3 demonstrates that green machining techniques provide a favorable balance between environmental sustainability and economic performance, supporting their adoption in modern manufacturing systems.

5. CONCLUSION

This study demonstrates that green machining techniques play a crucial role in achieving sustainable manufacturing. The results indicate that MQL and cryogenic cooling outperform dry machining in terms of temperature control, tool wear, surface quality, and energy efficiency.

While green machining offers significant environmental and economic benefits, challenges such as implementation cost and process optimization must be addressed. Future research should focus on advanced materials, hybrid techniques, and intelligent control systems to further enhance sustainability.

REFERENCES

1. N. R. Dhar et al., “Minimum quantity lubrication machining,” Journal of Materials Processing Technology, vol. 171, pp. 93–99, 2006.
2. V. S. Sharma et al., “Cooling techniques in machining,” Journal of Cleaner Production, vol. 16, pp. 195–205, 2008.
3. M. Soković et al., “Dry machining,” Journal of Materials Processing Technology, vol. 162–163, pp. 355–362, 2005.
4. F. Camposeco-Negrete, “Optimization of machining energy,” Journal of Cleaner Production, vol. 14, pp. 151–160, 2013.

5. S. Debnath et al., “Environmental impact of cutting fluids,” Renewable and Sustainable Energy Reviews, vol. 72, pp. 567–575, 2017.
6. P. Rout, A. K. Jha, P. Gupta, B. Singh, and S. Choudhury, “Failure analysis of composite plate under ballistic impact,” Materials Today: Proceedings, vol. 74, pp. 1008–1011, 2023, doi: 10.1016/j.matpr.2022.11.385.
7. H. S. Ruhela, S. Bhardwaj, T. Agrawal, and P. Gupta, “Explicit dynamics analysis of shin pads using finite element analysis,” in Proceedings of the International Conference on Industrial Problems on Machines and Mechanism, Singapore: Springer, 2022, pp. 683–690.
8. P. Gupta and S. Kumar, “Liquid crystal polymers: Thermo-optical-mechanical coupling and actuations,” in 2024 1st International Conference on Sustainability and Technological Advancements in Engineering Domain (SUSTAINED), IEEE, 2024, pp. 831–835.
9. A. Shokrani et al., “Sustainable machining,” Journal of Cleaner Production, vol. 57, pp. 310–321, 2013.
10. S. Y. Hong and Y. Ding, “Cooling approaches and cutting temperatures in cryogenic machining of Ti-6Al-4V,” *International Journal of Machine Tools and Manufacture*, vol. 41, no. 10, pp. 1417–1437, 2001.
11. J. P. Davim, “Sustainable machining,” *Journal of Cleaner Production*, vol. 16, no. 10, pp. 1121–1123, 2008.
12. A. Kumar, A. K. Sahoo, and S. K. Mishra, “Sustainable machining performance of minimum quantity lubrication using vegetable oil-based cutting fluids: A review,” *Journal of Cleaner Production*, vol. 153, pp. 129–143, 2017.