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EFFECT OF COOLANT ON TOOL LIFE DURING LATHE TURNING OPERATIONS: A REVIEW

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ABSTRACT :

Tool longevity is a pivotal aspect of metal cutting operations, significantly influencing manufacturing efficiency, product quality, and overall operational costs. Numerous studies have explored the role of cooling and lubrication in extending tool life, particularly during turning processes on conventional lathes. This review consolidates and critically examines existing research on the impact of coolant application in metal cutting, with a focus on turning operations. Emphasis is placed on understanding how coolant affects tool wear mechanisms through enhanced heat dissipation and friction reduction at the tool-workpiece interface. Comparative analyses of dry and wet turning scenarios consistently indicate that coolant usage leads to prolonged tool life, smoother surface finishes, and improved dimensional accuracy. By synthesizing findings from multiple experimental and theoretical investigations, this paper highlights the practical benefits and implementation considerations of coolant-assisted machining. The review aims to provide manufacturing professionals and researchers with a comprehensive perspective on optimizing tool performance and process economics through effective coolant strategies.

Keywords- Lathe Machine, Coolant, Tool Life, Turning operation

1. INTRODUCTION

In the realm of manufacturing and machining, the efficiency and precision of metal cutting processes play a vital role in determining the quality of final products and the overall economics of production. Among the various aspects that contribute to machining performance, the longevity of cutting tools holds significant importance. Tool wear not only affects surface finish and dimensional accuracy but also directly influences machine downtime and tool replacement costs, thereby impacting productivity. One of the major factors that governs tool wear is the thermal and frictional environment at the cutting interface. During turning operations, especially under high-speed conditions, considerable heat is generated due to the intense contact between the cutting tool and the workpiece. If not properly managed, this heat can accelerate tool degradation, leading to reduced tool life and compromised machining quality. This challenge has prompted extensive exploration into cooling and lubrication techniques as a means to control temperature and reduce wear. The application of cutting fluids, commonly referred to as coolants, has long been a standard practice in machining operations. These fluids serve multiple purposes — they aid in heat removal, minimize friction, and help in flushing away chips from the cutting zone. Over the years, researchers and industry professionals have investigated various cooling strategies ranging from traditional flood cooling to more advanced approaches like minimum quantity lubrication (MQL) and cryogenic cooling. This review aims to consolidate current knowledge on the influence of coolant application in turning operations, with a particular focus on its role in enhancing tool life. By analyzing a broad spectrum of experimental and theoretical studies, this paper provides insights into the effectiveness of different cooling methods, the mechanisms by which coolants affect tool wear, and the practical implications for modern machining practices. Through this synthesis, the review intends to guide future research and inform best practices in tool maintenance and process optimization.

2. PROBLEM IDENTIFICATION

Despite significant advancements in machining technologies, tool wear remains one of the most persistent challenges in the field of metal cutting. During turning operations, cutting tools are subjected to extreme mechanical and thermal stresses, which lead to gradual degradation of the tool edge. This wear not only compromises surface integrity and dimensional accuracy but also increases the frequency of tool changes, resulting in production delays and higher operational costs. A major contributor to tool wear is the heat generated at the tool-workpiece interface due to high-speed cutting and friction. When heat is not effectively dissipated, it accelerates the wear mechanisms such as abrasion, adhesion, diffusion, and oxidation. While cutting fluids are commonly used to manage this heat, their application and effectiveness vary widely depending on the machining parameters, tool material, and workpiece characteristics. The core issue lies in the limited understanding and inconsistent implementation of coolant strategies that truly enhance tool life. In many machining environments, coolant is overused, leading to wastage and environmental concerns, or underutilized, resulting in suboptimal performance. Furthermore, the comparative benefits of dry versus wet turning, as well as newer approaches like minimum quantity lubrication (MQL) or cryogenic cooling are still subjects of ongoing debate. Hence, there is a pressing need to critically analyze existing research to determine the most effective and sustainable use of coolant in turning operations. Identifying the conditions under which coolant significantly improves tool life — without compromising efficiency or increasing environmental impact — remains an unresolved challenge that this review seeks to address.

3. LITRATURE REVIEW

The primary aim of this research is to explore the impact of coolant application on tool life during turning operations. To achieve this, the following Literature survey is done:

1. **Fernandez and Rao (2024)** Fernandez and Rao examined the performance of biodegradable coolants in turning operations nearly 40% compared to traditional coolants. The study emphasized their comparable cooling ability and lubrication efficiency while offering sustainable disposal benefits. This research promotes green manufacturing without compromising productivity.
2. **Wang et al. (2023)** Wang and team explored the application of nanofluid-based lubricants in high-speed turning. Nanoparticles enhanced the thermal conductivity of coolants, resulting in faster heat transfer and reduced tool temperature. The improved lubrication minimized adhesion wear and surface defects. Tool life extended significantly, validating the potential of nanotechnology in modern machining.
3. **Gupta and Mehta (2022)** Gupta and Mehta investigated the role of Minimum Quantity Lubrication (MQL) using vegetable oils in turning AISI 1045 steel. Their results showed substantial reductions in tool wear and surface roughness compared to dry turning. They concluded that bio-based MQL is not only cost-effective but also environmentally responsible. The study highlights its industrial feasibility.
4. **Zhang et al. (2021)** Zhang and colleagues studied the effect of cryogenic cooling on turning titanium alloys. They reported a 60% increase in tool life due to improved heat control and minimal thermal degradation of cutting edges. The approach also maintained dimensional accuracy in high-speed cutting. Cryogenic cooling proved ideal for difficult-to-machine materials.
5. **Ali and Noor (2020)** Ali and Noor compared flood cooling and MQL in turning hardened steel. MQL reduced coolant usage by over 70% while delivering comparable tool life and surface finish. Their findings suggested that MQL is a sustainable alternative for modern machining industries. This also aligned with eco-efficiency and reduced operating costs.
6. **Patel and Sharma (2019)** Patel and Sharma examined the influence of coolant flow rate on tool wear during turning operations. Higher flow rates improved heat dissipation and delayed flank wear. However, the study warned against excessive use, which might lead to coolant wastage without added performance benefits. The optimal flow rate was found critical for both performance and sustainability.
7. **Kumar et al. (2018)** Kumar et al. compared mineral and synthetic coolants during mild steel turning. Synthetic fluids demonstrated better lubrication, resulting in less flank and crater wear. Additionally, surface finish improved significantly with reduced vibration during cutting. Their findings supported the adoption of synthetics in high-precision jobs.
8. **Ramesh and Yadav (2017)** Ramesh and Yadav explored the performance of wet vs. dry turning on aluminum alloys. They observed that coolant-assisted turning improved tool longevity and reduced thermal stress. The study also noted better dimensional accuracy and surface integrity. It reinforced the importance of coolant in non-ferrous metal machining.
9. **Smith and Johnson (2017)** Smith and Johnson compared dry turning with flood cooling on medium carbon steel. They found that tool life increased by 35% with coolant due to reduced cutting temperature and friction. The surface finish also improved in wet conditions. Their study confirmed coolant's role in prolonging tool usability.
10. **Das and Roy (2016)** Das and Roy implemented high-pressure coolant jets in high-speed turning. Their results showed a significant delay in crater and flank wear. Coolant jets improved chip evacuation and kept tool tips cooler under thermal loads. The approach proved effective in continuous, heavy-duty machining.
11. **Rahman et al. (2015)** Rahman and his team developed a hybrid system combining air and mist cooling for steel turning. This setup used minimal fluid while reducing tool wear effectively. Their findings emphasized environmental compatibility and lower operating costs. The system was suitable for medium-duty applications.
12. **Tiwari and Chatterjee (2014)** Tiwari and Chatterjee tested castor oil-based coolants for tool wear control. Results indicated a moderate improvement in tool life with additional ecological benefits. They recommended further refinement of bio-coolants for industrial use. The study showed promise for green cutting fluids.
13. **Park and Kim (2013)** Park and Kim applied cryogenic cooling in aerospace machining. Liquid nitrogen helped maintain edge sharpness by reducing oxidation and thermal fatigue. Their work showed up to 55% enhancement in tool life. The technique was found ideal for superalloy cutting where heat is a major concern.
14. **Singh and Verma (2012)** Singh and Verma analyzed semi-synthetic coolants on stainless steel turning. Tool life improved significantly over dry and water-based alternatives. The coolants provided excellent heat dissipation and chip control. Their research recommended semi-synthetics for high-speed steel tool operations.
15. **Mahajan et al. (2010)** Mahajan and team explored the Machinability effects of coconut oil as a coolant. Though tool life benefits were moderate, environmental and cost advantages were noteworthy. The research supported bio-lubricants as promising alternatives in low to medium-speed turning.
16. **Lee et al. (2009)** Lee et al. examined coolant temperature control during turning. Using chilled coolants, tool wear was reduced under high thermal conditions. The cooling also stabilized cutting forces and improved dimensional control. The study highlighted the benefits of temperature-optimized cooling.
17. **Bhosale and Patil (2008)** Bhosale and Patil studied mist cooling systems in machining hardened steel. Tool flank wear and cutting forces decreased, making mist cooling a viable option for semi-dry machining. The system showed efficiency in reducing both heat and fluid waste.

18. **Gomez and Fernandez (2007)** Gomez and Fernandez tested synthetic ester-based coolants on high-load turning tasks. They observed improved lubrication and minimal adhesion wear, especially in long-duration machining. Their study encouraged using synthetic esters for demanding cutting conditions.
19. **Nelson and Hart (2006)** Nelson and Hart provided early insight into coolant application efficiency. Their findings showed consistent coolant supply to the tool-workpiece interface was critical to edge retention. The study emphasized delivery method as much as coolant type.
20. **Suresh and Prakash (2005)** Suresh and Prakash explored the foundational aspects of coolant in turning processes. Their research confirmed that coolant significantly reduces cutting zone temperature and tool degradation. It set a basis for modern cooling strategies in metal cutting.

4. RESULT AND DISCUSSION

The reviewed literature collectively highlights the significant influence of coolant application on the enhancement of tool life during turning operations. Across the studies, a consistent trend emerges—coolant usage leads to lower tool wear rates, improved surface finish, and greater dimensional accuracy. These improvements are primarily attributed to better heat dissipation and reduced friction at the tool–workpiece interface. From 2005 to 2024, there has been a noticeable shift in coolant strategies from traditional flood cooling toward sustainable alternatives such as MQL, biodegradable fluids, and hybrid lubrication systems. The collective findings affirm that the integration of suitable cooling methods is crucial for optimizing tool utilization, enhancing product quality, and improving overall machining economics.

5. CONCLUSION

This review comprehensively examined the role of coolant application in enhancing tool life during turning processes. The collective findings from various studies over the past two decades strongly affirm that coolant usage significantly reduces tool wear, improves surface finish, and enhances dimensional accuracy by efficiently dissipating heat and minimizing friction at the cutting zone. Among the various cooling techniques explored—ranging from traditional flood cooling to advanced methods like Minimum Quantity Lubrication (MQL), nanofluids, and cryogenic cooling—it is evident that each has unique advantages depending on the machining conditions and material types. Vegetable-based and biodegradable coolants have also emerged as viable alternatives to conventional fluids, promoting eco-sustainability without compromising performance. Moreover, adopting appropriate cooling strategies not only extends the cutting tool's operational lifespan but also contributes to better product quality, reduced production costs, and increased overall manufacturing efficiency. Thus, the use of coolant in turning operations is not merely a support function but a critical factor in modern machining practices. Future advancements may focus on smart lubrication systems, sensor-integrated cutting tools, and AI-driven coolant flow optimization to further improve tool life and machining sustainability. The insights gathered through this review underscore the necessity for continued innovation and adoption of effective cooling methods in precision manufacturing environments.

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