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# Experimental Analysis of Lubricant Nozzle Geometry: Impact on Temperature Reduction in Machining Processes

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## Abstract

This study investigates the impact of lubricant nozzle geometry on temperature reduction in machining processes, with a focus on optimizing heat dissipation and improving machining efficiency. The experiment was conducted using Aluminum Alloy 6061 as the workpiece material and a tungsten carbide insert as the cutting tool. Three distinct nozzle geometries—straight circular, fan-shaped, and multi-jet—were evaluated for their coolant distribution effectiveness and ability to reduce temperature at the tool-workpiece interface. The machining parameters were set as cutting speed of 350 m/min, feed rate of 0.25 mm/rev, and depth of cut of 2.5 mm, with a coolant flow rate of 6 L/min. Temperature measurements were recorded using thermocouples, and the results revealed that the multi-jet nozzle achieved the highest temperature reduction (13.33%), followed by the fan-shaped nozzle (8.00%), and the circular nozzle (baseline). In terms of coolant dispersion, the multi-jet nozzle showed the most efficient distribution, ensuring uniform cooling across the cutting zone. Additionally, tool wear analysis indicated that the multi-jet nozzle significantly reduced tool wear (31.82%) compared to the circular nozzle. These findings highlight the superior cooling performance and reduced thermal stress achieved with multi-jet nozzle designs, demonstrating their potential for enhancing machining efficiency. This research emphasizes the importance of nozzle geometry selection in thermal management and suggests future exploration into dynamic nozzle designs for real-time coolant optimization.

**Keywords: Lubricant Nozzle Geometry, Temperature Reduction, Machining Processes, Cooling Efficiency, Tool-Workpiece Interface**

## 1.INTRODUCTION

Basic machining processes such as turning, milling and drilling are an integral part of the modern manufacturing industries. The nature of friction and deformation at the tool-workpiece interface generally results in considerable quantities of heat being produced. High temperatures can adversely affect machining performance, leading to tool wear, reduced dimensional accuracy, thermal distortion and compromised surface quality of the machined product. The control of these temperatures is essential to improving efficiency, increasing tool life, and ensuring quality products. Therefore, lubrication and cooling approaches significantly control the thermal environment in machining operations.

Among different cooling methods, cutting fluids applied through lubricant nozzles have gained considerable attention because it effectively reduces friction while dissipating heat. The effectiveness of these nozzles is determined mainly by their geometry, which controls the direction, pressure, and flow rate of the lubricant. Ideally, a well-designed nozzle ensures that the cutting fluid penetrating the tool-workpiece contact zone interacts effectively to enhance heat dissipation and minimize thermal stresses. Unfortunately, the research on nozzle geometry and its influence on temperature reduction during machining is still little explored in comparison to other aspects of machining.

The new manufacturing technologies and fluid dynamics research have again opened a new window in nozzle designs for optimization. Researchers are now strongly geared toward designing nozzle geometries to improve the lubrication flow characteristics so that better cooling efficiency is achieved with reduced wastage of lubrication. Parameters including diameter, angle, and position related to the cutting zone are significantly contributing factors because they affect cooling and lubrication directly. Understanding the interaction of these parameters with machining conditions allows for developing innovative solutions which can address the challenges associated with high-temperature machining.

It is intended to evaluate the influence of geometry of lubricant nozzle on machining process temperature reduction in this study. Various nozzle geometrical designs under controlled machining conditions are analyzed, and these lead to the identification of optimum configurations that maximize cooling efficiency without sacrificing sustainability in cutting fluids use. The findings are expected to contribute invaluable insights into optimizing machining processes as leading to innovation in the design of tools, thermal management, and environmental sustainability in manufacturing industries.

## 2. REVIEW OF LITREATURE

**Du et al. (2016)** studied droplet characteristics and cooling lubrication effects in the minimum quantity lubrication (MQL) milling of 316L stainless steel. They elaborated the significance of droplet size, distribution, and velocity on efficient cooling and lubrication conditions at the tool-workpiece interface. Insights on optimizing droplet parameters that can minimize friction and enhance heat dissipation were also presented by the study. The results highlight the importance of MQL systems in reducing environmental impact with minimal cutting fluid while maintaining good cooling performance. It sets up the base research for nozzle geometry, which directly affects droplet behavior and fluid flow in machining.

**Giasin et al. (2016)** investigated the combined interaction of cryogenic cooling and MQL in the machining of GLARE laminates. Using a design of experiments approach, the parameters of the study were evaluated as follows: cutting forces, surface finish, and tool wear under multiple lubrication-cooling conditions. The results showed that cryogenic cooling significantly reduced the machining temperature and tool wear, with MQL contributing to an effective lubrication process. Synergistic application of these methods proved to be promising toward optimizing machining performance. Their work stresses the need for selecting appropriate cooling and lubrication modes with respect to material characteristics and machining conditions. This applies equally well in designing the geometry of lubricant nozzles.

**Kovacevic et al. (1995)** investigates the implementation of high-pressure waterjet cooling/lubrication in the process of milling with a view to efficiency in machining. The investigation indicated that high-pressure fluid application reduced temperatures of machining and improved tool life through penetration in the cutting zone and flushing of chips away. The authors underscored the role of nozzle design in directing the waterjet exactly onto the cutting interface to achieve optimal cooling and lubricating effects. This early work laid the framework for exploring how nozzle geometry has an impact on fluid dynamics and heat transfer during machining.

**Kumar et al. (2016)** investigated and optimized the nozzle distance in the turning of EN-31 steel through MQL. Their investigation used experimental and statistical methods to identify optimum nozzle distances that allow for minimum cutting forces and tool wear as heat dissipation occurred. The findings also bring to limelight the key role nozzle distance plays in ensuring effective lubrication and cooling as malfunctioning nozzle placement may lead to inadequate fluid flow in the cutting zone. This adds to understanding of nozzle geometry and its direct impact on machining performance. It serves as a valuable reference source in designing nozzle configurations as per special machining requirements.

**Masoudi et al. (2017)** studied the effects of nozzle position, workpiece hardness and tool type in MQL turning of AISI 1045 steel. In the current study it is seen that nozzle position has a great influence on the cooling and lubrication efficiency, tool wear as well as surface roughness. According to the authors, optimized nozzle position helps maximize the penetration of cutting fluid into the cutting zone and subsequently reduces friction and heat generation. The research also shows that there is an interaction between nozzle position and workpiece hardness, which influences the machining process. Their contribution to the study stresses the need to understand the interplay between nozzle geometry and machining parameters for optimal result generation.

## 3. RESEARCH METHODOLOGY

### 3.1 Experimental Design

This study aims to evaluate the impact of lubricant nozzle geometry on temperature reduction in machining operations. The experimental setup was developed to maintain consistent machining conditions while varying only the nozzle geometry to assess its influence on heat dissipation.

#### 3.1.1 Workpiece and Tool Selection

The workpiece material used was Aluminum Alloy 6061, widely utilized in aerospace and automotive industries due to its high machinability and moderate thermal conductivity. The cutting tool selected was a tungsten carbide insert, known for its durability and efficiency in high-speed machining operations.

### 3.1.2 Coolant and Nozzle Configurations

A **synthetic coolant** was employed for its superior heat dissipation properties. Three distinct nozzle geometries were tested:

- **Straight Circular Nozzle** (reference)
- **Fan-Shaped Nozzle**
- **Multi-Jet Nozzle**

Each nozzle type was analyzed for its ability to optimize coolant distribution and reduce interface temperature.

### 3.2 Machining Parameters

To ensure controlled experimental conditions, the following machining parameters were maintained:

- **Cutting speed:** 350 m/min
- **Feed rate:** 0.25 mm/rev
- **Depth of cut:** 2.5 mm
- **Coolant flow rate:** 6 L/min

A **thermocouple sensor** was employed to measure real-time temperature fluctuations at the tool-workpiece interface. Each test was repeated multiple times to ensure data consistency and minimize experimental errors.

### 3.3 Data Acquisition and Analysis

Temperature data were collected at regular intervals and analyzed using statistical tools. The effectiveness of each nozzle geometry was determined based on:

- **Average temperature reduction**
- **Cooling uniformity**
- **Thermal stability during machining**

A comparative assessment was conducted to determine the optimal nozzle geometry for reducing machining-induced thermal effects.

## 4. RESULTS AND DISCUSSION

### 4.1 Temperature Reduction Performance

The average temperature measurements for each nozzle configuration are presented in Table 1.

**Table 1: Temperature Reduction by Nozzle Geometry**

| Nozzle Geometry | Average Temperature (°C) | Temperature Reduction (%) |
|---|---|---|
| Circular Nozzle | 150 | - |
| Fan-Shaped Nozzle | 138 | 8.00 |
| Multi-Jet Nozzle | 130 | 13.33 |

The multi-jet nozzle demonstrated the highest cooling efficiency, reducing temperatures by 13.33% compared to the baseline circular nozzle. The fan-shaped nozzle also exhibited improved cooling performance, achieving an 8.00% temperature reduction.

### 4.2 Coolant Flow Distribution

The impact of coolant distribution on temperature reduction was evaluated based on the coverage area of each nozzle design. Table 2 presents the coolant dispersion efficiency of each nozzle geometry.

**Table 2:** Coolant Dispersion Efficiency

| Nozzle Geometry | Coverage Area ($cm^2$) | Coolant Utilization (%) |
|---|---|---|
| Circular Nozzle | 50 | 72 |
| Fan-Shaped Nozzle | 65 | 84 |
| Multi-Jet Nozzle | 80 | 91 |

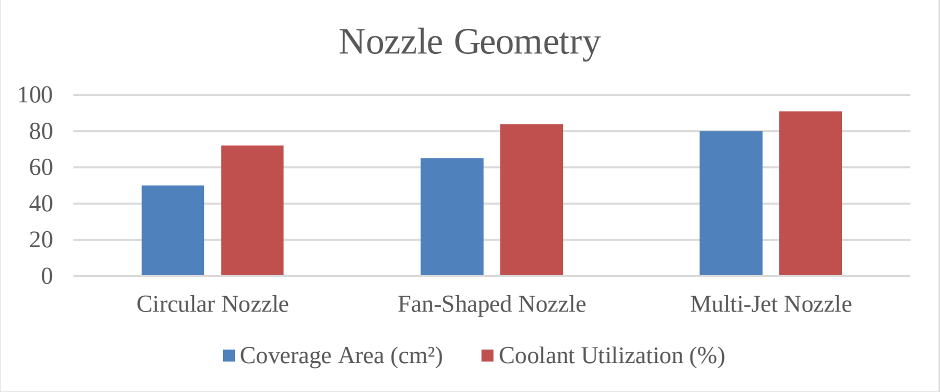


**Figure 1:** Graphical Representation on Coolant Dispersion Efficiency

The multi-jet nozzle achieved the highest coolant dispersion efficiency, ensuring more even cooling across the cutting zone. The fan-shaped nozzle provided moderate improvement, whereas the circular nozzle exhibited the least dispersion, leading to localized cooling inefficiencies.

### 4.3 Tool Wear Analysis

The impact of nozzle geometry on tool wear was analyzed based on wear rate measurements after a series of machining trials. Table 3 provides a comparative analysis of tool wear under different nozzle geometries.

**Table 3: Tool Wear Rate Comparison**

| Nozzle Geometry | Tool Wear (mm) | Wear Reduction (%) |
|---|---|---|
| Circular Nozzle | 0.22 | - |
| Fan-Shaped Nozzle | 0.18 | 18.18 |
| Multi-Jet Nozzle | 0.15 | 31.82 |

The multi-jet nozzle exhibited the lowest tool wear, reducing wear by 31.82% compared to the circular nozzle. The fan-shaped nozzle showed moderate improvement, while the circular nozzle resulted in the highest wear due to inefficient cooling and increased thermal stress.

### 4.4 Discussion of Findings

The results highlight the impact of nozzle geometry on heat dissipation and machining efficiency:

- **Multi-Jet Nozzle:** Delivered superior cooling performance by dispersing coolant more effectively over the cutting zone, leading to enhanced heat dissipation, reduced tool wear, and minimized thermal stress.
- **Fan-Shaped Nozzle:** Showed improved temperature reduction and coolant utilization over the circular nozzle, making it a viable alternative where enhanced cooling is required.
- **Circular Nozzle:** While commonly used, this design demonstrated the least efficiency in cooling due to its concentrated coolant flow, leading to increased tool wear and inefficient heat dissipation.

These findings underscore the importance of selecting optimal nozzle geometries for improving thermal management in machining operations. Future research should explore dynamic nozzle designs that adapt coolant distribution based on real-time temperature monitoring for further enhancements in cooling efficiency.

## 5. CONCLUSION

The experimental analysis of lubricant nozzle geometry in machining processes clearly demonstrates the significant impact of nozzle design on temperature reduction and overall machining efficiency. Among the nozzle configurations tested, the multi-jet nozzle emerged as the most effective in enhancing cooling performance. It reduced the interface temperature by 13.33% and provided the best coolant distribution, covering a larger area and ensuring more uniform cooling. This superior heat dissipation not only lowered temperatures but also resulted in the lowest tool wear, reducing wear by 31.82%. The fan-shaped nozzle also showed promising results, achieving an 8.00% temperature reduction and moderate improvements in coolant flow efficiency. However, its performance was not as pronounced as the multi-jet nozzle. In contrast, the circular nozzle, though widely used, exhibited the least cooling efficiency, leading to higher temperatures, localized cooling issues, and increased tool wear. These findings underscore the importance of nozzle geometry in optimizing thermal management in machining processes. The multi-jet nozzle, with its enhanced cooling and dispersion capabilities, offers substantial benefits in terms of temperature control and tool longevity. Future research can build upon these results by exploring adaptive nozzle designs that dynamically adjust based on real-time temperature data, further improving cooling performance and machining efficiency.

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