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TO INVESTIGATE THE IMPACT OF MOS_2 COATING ON SINGLE-POINT CUTTING TOOL PERFORMANCE IN MACHINING

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ABSTRACT

This study explores the impact of MoS2 coating on single-point cutting tool performance during machining. It evaluates several key parameters, comparing coated and uncoated tools, and examines the health implications of MoS2 coatings versus traditional liquid lubricants. Results show that coated tools significantly enhance machining efficiency, demonstrating better cutting precision, reduced friction, and improved chip evacuation. These improvements lead to increased productivity and cost-effectiveness. The study also highlights the advantages of solid lubricant coatings like MoS2 in promoting workplace safety and environmental sustainability, as they minimize exposure to harmful chemicals. MoS2 coatings effectively reduce tool wear at high temperatures by forming a protective layer, lowering frictional forces, and extending tool lifespan. This resilience enhances the reliability and durability of cutting tools, optimizing performance and reducing maintenance costs. In conclusion, MoS2 coatings significantly improve single-point cutting tool performance, enhance efficiency, promote safety, and prolong tool lifespan, presenting a promising solution for advancing machining processes.

Keywords: MoS2 Coating, Single-Point Cutting Tools, Machining Efficiency, Tool Wear Reduction, Workplace Safety

1. INTRODUCTION

In the realm of modern manufacturing, the performance and longevity of cutting tools are pivotal factors influencing productivity and cost-efficiency. Single-point cutting tools, essential for various machining operations, face significant challenges such as wear and tear, which directly impact the quality of the finished product and overall machining efficiency. Molybdenum disulfide (MoS_2) has emerged as a promising coating material due to its exceptional lubricating properties and high-temperature stability. This study aims to investigate the impact of MoS_2 coating on the performance of single-point cutting tools. By comparing the wear resistance, cutting forces, surface finish, and tool life of MoS_2-coated tools with their uncoated counterparts; this research seeks to provide comprehensive insights into the potential benefits and drawbacks of using MoS2 in industrial applications. The findings are expected to contribute to the development of more durable and efficient cutting tools, enhancing manufacturing processes and reducing operational costs. This paper presents the experimental methods, results, and implications for future tool design and material science advancements.

2. LITERATURE REVIEW

2.1 Research on various lubricants used in various machining Industry

In a study by Gurpreet Singh, Vivek Aggarwal, and Sehijpal Singh, it was evaluated that the conventional flood lubrication technique is commonly used in machining operations to reduce friction, wear, heat, and cutting power. This method relies on large quantities of metalworking fluids for cooling and lubrication, which leads to the discharge of contaminated effluents, thereby polluting water, air, and soil. The excessive use of these fluids also creates an unpleasant and uneconomical work environment. The handling and disposal of these fluids pose significant challenges due to strict environmental regulations, government policies, and increased public awareness. Addressing these issues is crucial in the era of Industry 4.0, considering the current concerns over water footprints, pollution levels, and global warming.

To address the challenges of dry machining, particularly with harder materials, industries have turned to minimum quantity lubrication (MQL) with biodegradable fluids as a more economical and sustainable solution. This study critically analyzed various cooling and lubrication methods used in machining operations to assess their potential for sustainable machining. The review highlighted significant advancements in cooling and lubrication techniques, noting their contribution to economical, ecological, and sustainable machining practices. Recent trends emphasize the use of nano-fluids, ionic liquids, and biodegradable oils in cooling technologies and hybrid machining, enhancing their application for machining harder materials at higher speeds.

Further analysis by O. Pereira and colleagues focused on the environmental benefits of using natural biodegradable oils in MQL instead of traditional canola oils. They compared five alternatives: sunflower oil, high oleic sunflower oil, castor oil, and ECO-350 recycled oil. MQL machining, using these vegetable-based oils, offers advantages such as reduced fluid waste, energy consumption, and environmental contamination. It also minimizes workers' exposure to toxic substances and produces nearly dry, clean, and recyclable metal chips. The study aimed to evaluate the feasibility of these oils by examining their tribological and rheological properties and validating their performance in cutting Inconel 718, a difficult-to-machine material used in aeronautics. A life cycle assessment was also conducted to analyze their environmental viability, essential for achieving a truly feasible machining process.

2.1 Review on Solid Lubrication System

Molybdenum disulfide (MoS2) is a widely used solid lubricant with applications spanning various industries, particularly aerospace and space. This review focuses on MoS2, detailing its structure, synthesis, applications, and the fundamental mechanisms behind its lubricative properties. It also examines how environmental factors and temperature affect its performance. An extensive overview of doped MoS2's structure and tribological properties is included, followed by potential future research directions. Given that significant economic losses in developed nations are attributed to friction and wear, tribology research aims to design and apply methods to minimize these issues. Efforts are directed towards understanding and improving current lubricants and developing new, more effective lubrication methods to reduce friction, wear, and enhance component longevity.

Liquid lubricants, such as oils and greases, are commonly used in industrial settings due to their effectiveness in reducing friction and wear, ease of replenishment, and simple application. However, certain conditions necessitate the use of solid lubricants. For instance, aerospace applications require solid lubricants due to low temperatures that make liquid lubricants too viscous or cause them to solidify. Significant advancements in solid lubricants occurred in the latter half of the 20th century with the space age. Solid lubricants are also beneficial in dry machining operations to reduce costs associated with liquid lubricants, and in the food processing and textile industries to avoid contamination and health hazards.

MoS2, a lamellar solid material with atomically-thin planes that slide easily against each other, has been used as a solid lubricant since the last century. Similar to graphite, MoS2 can function as a dry lubricant, an additive in oils or greases, or as part of a composite coating. Unlike graphite, MoS2 does not need humid conditions to perform well and actually enhances its lubricative properties in oxygen-deficient environments. MoS2 operates effectively across a wide temperature range, from cryogenic levels to several hundred degrees Celsius, and performs well in vacuum, making it particularly useful for aerospace applications. Extensive research on MoS2's synthesis, properties, and applications has been conducted since the 1960s. Current research focuses on enhancing its lubricative properties through incorporation into nano-composite coatings and controlled doping.

3. EXPERIMENTAL SETUP

The research employs a precision-controlled environment for machining experiments. Single-point cutting tools, carefully selected for uniformity, are subjected to MoS2 coating application using precise techniques. Machining parameters, including cutting speed, feed rate, and depth of cut, are systematically varied. This setup ensures consistency and repeatability in the experiments, allowing for accurate evaluation of the impact of MoS2 coating on tool performance.

3.1 Single Point Cutting Tool

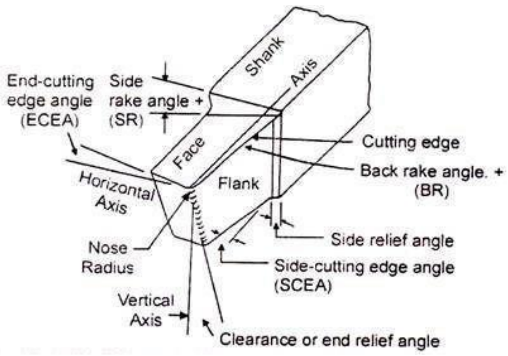

Figure 1: Tool Geometry - Single Point Cutting tool

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A single-point cutting tool is a fundamental component in machining operations, designed to remove material from a workpiece through a cutting action. Its structure typically consists of a sharp cutting edge, which interacts with the workpiece, generating chips and shaping the material to the desired dimensions. These tools are distinguished by their simplicity and versatility, allowing for precise control over the cutting process. Single-point cutting tools are utilized across various industries, including automotive, aerospace, and manufacturing, for tasks ranging from turning and facing to boring and threading. Their efficiency and effectiveness in material removal make them indispensable assets in the realm of machining, enabling the creation of intricate components with high precision and accuracy.

3.2 Coating Techniques

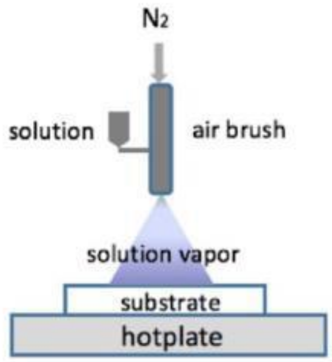

Figure 2: General Setup for Coating Process

Coating techniques play a pivotal role in enhancing the performance and durability of various industrial tools and components. These techniques involve the application of thin layers of protective or functional materials onto the surface of substrates, ranging from cutting tools to electronic devices. By carefully selecting and depositing coatings, engineers can impart properties such as increased hardness, wear resistance, corrosion protection, and thermal stability to the substrate materials. From physical vapor deposition (PVD) to chemical vapor deposition (CVD) and thermal spraying, a diverse array of coating methods exists, each offering unique advantages and applications. In this introductory study, we explore the significance of coating techniques, focusing on their impact on the performance of single-point cutting tools in machining operations. PVD involves depositing a thin film of solid lubricant onto the surface of a material through the use of physical processes such as sputtering or evaporation. This technique is commonly used for enhancing the wear resistance and lubricity of surfaces.

Whereas, CVD, on the other hand, involves a chemical reaction between gaseous precursors and the surface of the material to form a solid lubricant coating. This technique allows for precise control of coating thickness and composition. In addition, Sol-gel coating involves the formation of a solid lubricant coating through the hydrolysis and condensation of metal alkoxides. This technique is known for its simplicity and versatility in creating thin and uniform coatings. Electroplating is a process where a solid lubricant is deposited onto the surface of a material through the use of an electric current. This technique is commonly used for coating small and complex-shaped parts. And spray coating involves applying a solid lubricant onto the surface of a material using a spray gun. This technique is cost-effective and allows for the coating of large and irregularly shaped parts.

3.3 Physical Vapor Deposition (PVD) Technique

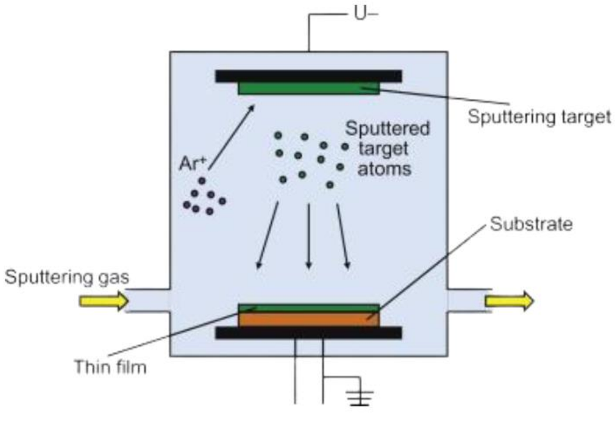

Figure 3: Experimental Setup for Physical Vapor Deposition Technique

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Physical vapor deposition (PVD), also known as physical vapor transport (PVT), encompasses various vacuum deposition methods used to create thin films and coatings on substrates like metals, ceramics, glass, and polymers. The PVD process involves transitioning the coating material from a condensed phase to a vapor phase and then back to a condensed phase as a thin film. Common PVD methods include sputtering and evaporation. PVD coatings are often harder, more corrosion-resistant, and more durable than those applied by electroplating, eliminating the need for protective topcoats. These coatings, which can be applied to a wide range of materials and substrates, enhance wear resistance, reduce adhesion and sticking, and are particularly beneficial for steel cutting tools and plastic injection molding. PVD is also more environmentally friendly compared to traditional methods like electroplating and painting. The coatings are typically thin ceramic layers, less than 4µm thick, with high hardness and low friction, which ensures dimensional stability and prevents brittleness in the work pieces.

3.4 Actual Experimental Setup

Figure 4: Actual Experimental Arrangement

4. RESULT AND DISCUSSION

4.1 Work piece Temperature

Table 1: Temperature Readings

Cutting velocity (m/min)	Feed (mm/rev)	Workpiece Temperature (°C)
7	0.12	59
9	0.06	75
44	0.12	171
15	0.12	107
15	0.04	89

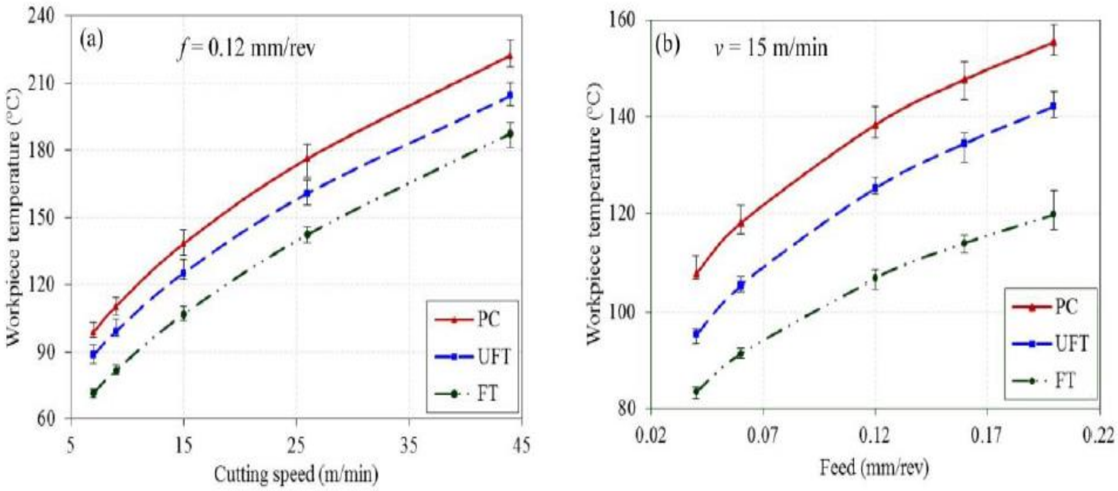

Figure 5: Variation in workpiece Temperature with (a) Cutting Speed and (b) Feed

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4.2 Machining Force

Table 2: Variation in feed force

Cutting velocity (m/min)	Feed (mm/rev)	Cutting Force (N)	Feed Force (N)
7	0.12	109	44
9	0.06	73	35
44	0.12	89	34
15	0.12	85	39
15	0.04	47	25

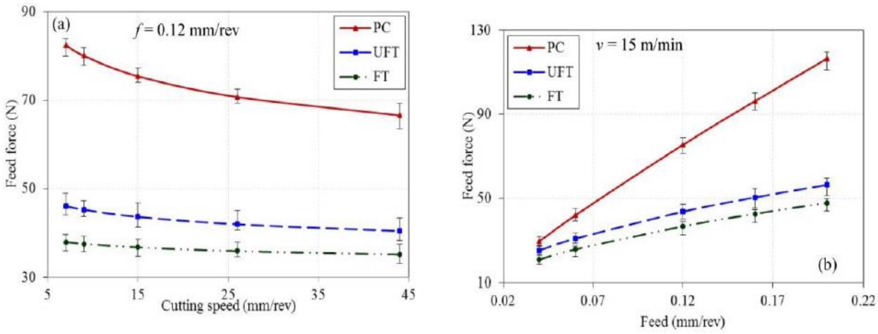

Figure 6: Variation in feed force with (a) Cutting Speed and (b) Feed

5. DISCUSSION

5.1 Workpiece Temperature

The study utilized infrared thermography to measure workpiece temperatures near the chip-tool interface for different cutting tools: UFT, FT, and PC. Experimental results, particularly for the FT tool, are summarized in Table 2, highlighting variations in cutting speed and feed rate. Increasing cutting speed led to higher workpiece surface temperatures, a trend supported by temperature models showing a power exponent relationship with cutting speed. Similarly, increasing feed rate also raised workpiece temperatures due to elevated material removal rates and heat generation on the tool's rake face. PC and UFT tools exhibited significant differences: PC tools, with extended tool-chip contact, generated more heat and higher temperatures. Conversely, UFT tools, featuring micro channel arrays on the rake face, reduced tool-chip contact and trapped air, acting as a lubricant to lower workpiece temperatures. FT tools benefited from solid lubricants on the chip's back surface, reducing chip flow resistance, albeit with lower shearing ability. Findings from related pin-on-disc tests suggested that MoS2, under high temperatures and pressures, could migrate from textures and form a lubricating film on the tool's rake face, further influencing tool performance in machining scenarios.

5.2 Machining Forces on Workpiece

In machining, machining forces are found to be a more reliable indicator of lubrication effectiveness compared to CLA surface roughness. As cutting speed increases, the feed force gradually decreases for PC, UFT, and FT cutting tools, a common trend observed. This relationship results in a negative power exponent of cutting speed in fitted models. Higher cutting speeds lead to elevated temperatures in the cutting zone due to built-up edge (BUE) formation at intermediate speeds. The use of a UFT tool results in lower feed force compared to a PC tool, attributed to microchannels containing air prior to machining, which enhance natural convection and reduce tool temperature and subsequent feed force. Effective lubrication with MoS2 and microchannel-induced air further decreases feed force. Among cutting tools, FT tools exhibit the lowest feed force, decreasing further at high cutting speeds due to thermal softening of the workpiece material. With increased feed, feed force increases uniformly across all three cutting tools, with the FT tool demonstrating the lowest values. Higher cutting speeds also elevate the cutting zone temperature, thereby reducing the flow stress of the workpiece material in the secondary shear zone and subsequently lowering cutting force. Chip thickness decreases with higher cutting speeds due to an increased shear plane angle. Maximum and minimum effective frictions occur during machining with PC and FT tools, respectively, resulting in corresponding maximum and minimum cutting forces. This observation is supported by the lower power exponent of cutting speed for the FT tool compared to the PC tool. Moreover, increased feed leads to thicker chips, thereby increasing chip load and cutting force accordingly.

6. CONCLUSION

The investigation into MoS2 coating's impact on single-point cutting tool performance in machining reveals substantial benefits. The study demonstrates that MoS2-coated tools outperform traditional uncoated ones across various parameters. They exhibit enhanced efficiency and productivity under identical machining conditions, potentially reducing operational costs. Moreover, MoS2 coating offers a safer alternative to liquid lubricants, mitigating health risks and environmental impact. Key findings highlight significant reductions in tool wear, especially at higher temperatures, due to MoS2's self-lubricating properties. This minimizes friction-induced wear, prolongs tool lifespan, and maintains dimensional accuracy and surface finish of machined components, thereby enhancing product quality. Additionally, MoS2 coating promotes sustainable manufacturing by reducing lubricant consumption and waste generation, aligning with environmental stewardship principles. Overall, these findings underscore MoS2 coating's transformative potential in advancing machining technologies towards greater efficiency, safety, and sustainability. Continued research and development could further enhance these benefits, positioning MoS_2 coating as a pivotal element in modern machining practices.

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