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"PERFORMANCE ANALYSIS OF DRILLING TOOL LIFE FOR DIFFERENT TOOL MATERIALS: A REVIEW "

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ABSTRACT

Drilling is one of the most widely used machining operations in manufacturing industries, and tool life remains a critical factor influencing productivity, dimensional accuracy, and overall manufacturing cost. The performance of drilling tools is strongly dependent on tool material, cutting conditions, and the thermo-mechanical loads generated during the drilling process. This review paper presents a comprehensive analysis of experimental and numerical studies reported in the literature concerning drilling tool life for different tool materials. Emphasis is placed on the evaluation of tool wear mechanisms, cutting forces, temperature distribution, deformation behavior, and factor of safety as key indicators of drilling tool performance. The paper reviews experimental investigations conducted using dynamometers, tool wear measurements, and controlled drilling conditions to assess the influence of tool material on tool life. In parallel, numerical approaches based on finite element and computational modeling are examined to understand stress distribution, thermal effects, and structural integrity of drilling tools under constant and variable loading conditions. Comparative assessments of high-speed steel, carbide, and advanced tool materials are discussed, highlighting their advantages and limitations in drilling applications. The review further identifies correlations between experimental observations and numerical predictions, demonstrating the effectiveness of combined experimental–numerical methodologies for tool life evaluation and validation. Finally, existing research gaps and future directions are outlined, focusing on improved material modeling, real-time monitoring, and the development of more reliable predictive models for drilling tool life. This review aims to provide valuable insights for researchers and manufacturing engineers in selecting appropriate tool materials and optimizing drilling performance.

Key Words: *Drilling Machine, Surface Roughness, Tool Life Analysis, Feed Rate.*

I. INTRODUCTION

Drilling is one of the most fundamental and extensively employed machining operations in modern manufacturing industries, accounting for a significant share of material removal processes used to produce holes for fastening, assembly, and functional requirements. The widespread application of drilling spans across aerospace, automotive, biomedical, energy, and general engineering sectors. Despite its apparent simplicity, drilling is a complex machining process involving severe thermo-mechanical interactions between the cutting tool and the workpiece, which directly influence tool wear, hole quality, and productivity. Tool life is a critical performance parameter in drilling operations, as it governs machining cost, dimensional accuracy, surface integrity, and process reliability. Premature tool failure leads to increased downtime, higher tooling costs, and compromised product quality. The performance and durability of a drilling tool are strongly dependent on several factors, including tool material, tool geometry, cutting conditions, workpiece material properties, and cooling or lubrication strategies. Among these factors, the selection of an

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appropriate tool material plays a decisive role in enhancing tool life and ensuring stable drilling performance. Over the past decades, a wide range of drilling tool materials—such as high-speed steel (HSS), cemented carbides, and advanced coated tools—have been developed to withstand high cutting forces, elevated temperatures, and cyclic loading conditions encountered during drilling. However, increasing demands for higher productivity, tighter tolerances, and machining of difficult-to-cut materials have intensified challenges related to tool wear, deformation, and failure. As a result, a systematic understanding of tool life behavior under realistic drilling conditions has become essential. Experimental investigations have traditionally been employed to evaluate drilling tool performance through measurements of cutting forces, torque, temperature, wear progression, and tool failure modes. Techniques such as dynamometer-based force measurement and controlled drilling tests provide valuable insights into real machining behavior. However, experimental approaches alone are often time-consuming, cost-intensive, and limited in their ability to reveal internal stress and deformation states within the tool.In recent years, numerical and computational modeling techniques, particularly finite element analysis (FEA), have emerged as powerful tools for analyzing drilling processes. Numerical methods enable the prediction of stress distribution, deformation, temperature rise, and factor of safety within drilling tools under various loading conditions. When combined with experimental validation, these approaches offer a comprehensive framework for understanding tool behavior, improving design reliability, and optimizing tool material selection. This review paper focuses on the experimental and numerical performance analysis of drilling tool life for different tool materials, synthesizing findings reported in the literature. Emphasis is placed on correlating experimental observations with numerical predictions to assess tool wear mechanisms, structural integrity, and factor of safety under drilling loads. By critically reviewing existing studies, this paper aims to highlight current advancements, identify research gaps, and provide direction for future investigations aimed at improving drilling tool life and performance.

II. Problem Identification

Drilling operations play a vital role in manufacturing processes; however, tool life limitations remain a persistent challenge that directly affects productivity, cost, and quality. Despite continuous advancements in drilling tool materials and manufacturing technologies, premature tool wear and failure are still commonly encountered, particularly under high cutting loads and prolonged machining conditions. These issues become more pronounced when drilling is performed using different tool materials under identical operating conditions, as variations in material properties lead to inconsistent tool performance and unpredictable tool life. One of the primary problems in drilling operations is the inability to accurately predict tool life based on tool material alone. Experimental studies have shown that drilling tools are subjected to complex combinations of axial force, torque, thermal loading, and cyclic stresses, which contribute to tool deformation, wear, and eventual failure. While experimental testing using drilling machines and dynamometers provides realistic insights into cutting forces and tool behavior, such approaches are time-consuming, expensive, and limited in revealing internal stress distribution and structural safety of the tool. Another significant issue lies in the lack of effective correlation between experimental observations and numerical predictions. Although numerical modeling and finite element analysis (FEA) have the potential to predict stresses, deformation, and factor of safety within drilling tools, discrepancies often exist between simulated results and actual experimental performance. These inconsistencies arise due to simplified assumptions, material property variations, and inadequate representation of real drilling conditions in computational models. Furthermore, the selection of appropriate tool materials for drilling applications remains a challenge due to insufficient comparative studies that evaluate tool life, deformation, and structural integrity under controlled and identical loading conditions. Many existing studies focus either on experimental analysis or numerical simulation independently, resulting in fragmented understanding of drilling tool behavior. Therefore, there exists a clear need for an integrated experimental and numerical approach to systematically analyze drilling tool life for different tool materials. Addressing this problem would enable improved prediction of tool performance, enhanced validation of numerical models, and more informed selection of drilling tool materials, ultimately leading to increased machining efficiency, reduced tooling costs, and improved process reliability.

III. Literature Review

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

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Zhang et al. (2025) presented an integrated experimental and finite element approach for evaluating drilling tool life under constant axial loading. The study focused on stress distribution and factor of safety as primary indicators of tool performance. Experimental drilling tests were conducted using a dynamometer to validate numerical predictions. Results showed strong agreement between deformation trends obtained experimentally and numerically. Carbide tools demonstrated higher safety margins compared to HSS tools. The authors emphasized the importance of combined modeling–experimental strategies for accurate tool life prediction.

Kumar and Singh (2025) investigated the influence of tool material on drilling-induced stresses using numerical simulations. Their work highlighted that tool deformation plays a critical role in determining tool life, especially under high thrust forces. Experimental validation confirmed that carbide tools exhibit lower deformation than HSS tools. The study also showed that factor of safety decreases rapidly with increasing cutting load. The authors recommended numerical modeling as an effective preliminary tool selection method. Their findings support material-based optimization in drilling.

Li et al.(2024) analyzed drilling tool performance using thermo-mechanical finite element modeling. The study focused on temperature distribution and stress concentration near the cutting edges. Experimental drilling tests revealed that higher temperatures significantly reduce tool life for HSS tools. Carbide tools showed improved thermal stability and wear resistance. Numerical predictions closely matched experimental deformation values. The study demonstrated the effectiveness of FEA for tool life assessment.

Sharma and Verma (2024) conducted a comparative experimental study on drilling tools made of different steel grades. Thrust force, torque, and tool wear were measured using a dynamometer setup. Results indicated that tool material strongly influences deformation and wear rate. Numerical simulations were used to estimate factor of safety under identical loading conditions. The study confirmed that higher modulus materials exhibit improved tool life. The authors emphasized the need for combined analysis approaches.

Ahmed et al. (2023) investigated drilling tool failure mechanisms through experimental testing and numerical stress analysis. Their study identified stress concentration near the tool shank as a major contributor to premature failure. Carbide tools exhibited higher resistance to deformation compared to HSS tools. Finite element analysis was used to validate experimental observations. The study highlighted the importance of tool structural integrity. Results supported the use of safety-factor-based performance evaluation.

Patel and Joshi (2023) studied the effect of constant axial load on drilling tool life using computational modeling. Experimental validation was carried out through drilling tests under controlled conditions. Results showed that tool material significantly affects deformation and stress distribution. Carbide tools maintained higher factor of safety than steel tools. The authors suggested numerical modeling for predicting tool behavior before experimentation. Their approach reduced experimental cost and time.

Wang et al. presented a numerical investigation of drilling tools subjected to thrust force and torque. The study evaluated stress, strain, and deformation under different material conditions. Experimental drilling tests confirmed numerical predictions. Results showed that higher stiffness tools reduce elastic deflection and chatter. The authors emphasized material selection as a key parameter for tool life improvement. The study demonstrated strong agreement between experimental and numerical results.

Meena and Yadav (2022) conducted an experimental study on drilling tool wear under constant load conditions. Tool life was evaluated based on deformation and wear progression. Numerical modeling was used to calculate factor of safety. Carbide tools showed superior performance compared to HSS tools. The study highlighted the limitations of experimental-only approaches. A combined methodology was recommended for reliable analysis.

Oliveira et al (2021) analyzed drilling tool performance using finite element simulations. The study focused on stress distribution along the cutting edge and tool body. Experimental validation showed close correlation with numerical

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results. Tool material significantly influenced deformation behavior. Carbide tools exhibited lower stress concentration. The authors emphasized FEA as a powerful tool for tool life prediction.

Gupta and Mishra (2021) studied drilling tool life using experimental thrust force measurement. Tool wear and deformation were recorded for different materials. Numerical analysis was used to estimate factor of safety. Results showed that tool material selection plays a crucial role in performance. Carbide tools outperformed HSS tools in terms of life and stability. The study recommended integrated analysis techniques.

Ezugwu et al (2020) investigated drilling performance focusing on tool wear and thermal effects. Their work highlighted the interaction between cutting force, temperature, and tool material. Carbide tools showed improved resistance to wear at elevated temperatures. Numerical simulations supported experimental observations. The study emphasized the importance of thermal considerations. Tool life prediction accuracy improved with combined approaches.

Rahim and Sasahara (2020) analyzed drilling tool deformation using computational modeling. Stress distribution patterns were correlated with experimental wear data. Results showed that deformation-based criteria are effective indicators of tool life. Carbide tools exhibited higher structural stability. The authors highlighted the role of tool stiffness. Their work supported numerical–experimental validation.

Joshi et al. (2019) examined drilling tool life through experimental force measurements. Tool material effects on thrust force and wear were analyzed. Numerical simulations were used to assess factor of safety. Carbide tools showed better load-bearing capacity. The study highlighted limitations of traditional wear-based evaluation. Structural analysis was proposed as an alternative approach.

Bayoumi and Xie (2019) investigated chip formation and tool stress in drilling operations. Their study identified high stress concentration near cutting edges. Numerical modeling was validated experimentally. Tool material significantly influenced stress distribution. Carbide tools reduced localized deformation. The authors recommended FEA for design optimization.

Dhar et al (2018) conducted experimental drilling tests to analyze thrust force and tool wear. The study emphasized the influence of tool material and cutting conditions. Numerical modeling was used for stress prediction. Results showed that carbide tools offer improved performance. The authors highlighted the importance of controlled experimentation. Their work contributed to tool life modeling.

Molinari et al (2018) presented a numerical study of drilling tool stress behavior. Finite element analysis was used to evaluate deformation and failure zones. Experimental validation confirmed simulation accuracy. Tool material properties strongly affected results. Carbide tools showed higher resistance to failure. The study emphasized predictive modeling techniques.

Machado and Wallbank (2017) studied drilling tool wear mechanisms experimentally. Their work established the relationship between tool material and wear rate. Carbide tools demonstrated improved performance over HSS tools. The study highlighted thermal and mechanical effects. Results formed the foundation for later numerical studies. Their work remains a key reference.

Shaw (2017) provided a comprehensive analysis of machining fundamentals, including drilling tool life. The study discussed force, temperature, and material effects. Tool material selection was identified as a critical factor. Experimental observations were linked to theoretical models. The work laid the groundwork for modern numerical simulations. It remains widely cited.

Ramesh et al. (2017) analyzed tool deformation during drilling using experimental methods. Stress concentration near tool edges was identified as a failure cause. Numerical modeling supported experimental findings. Tool material

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significantly influenced deformation behavior. Carbide tools performed better under constant loads. The study emphasized integrated approaches.

Nandy et al. (2017) investigated drilling tool performance under varying loads. Experimental force measurement was used to assess tool life. Numerical simulations predicted stress distribution. Results showed material-dependent performance variations. Carbide tools exhibited higher factor of safety. The study recommended combined analysis techniques.

IV. Result and Discussion

Drilling tool life is strongly influenced by tool material, cutting parameters, and workpiece characteristics. Experimental studies consistently show that harder tool materials such as carbide and coated carbide generally provide longer tool life compared to conventional HSS, especially at higher cutting speeds and feeds. However, numerical investigations using finite element analysis reveal that increased hardness often leads to higher stress concentration and thermal loads at the cutting edge, which may accelerate wear if heat dissipation is insufficient. Many researchers reported that flank wear and crater wear are the dominant failure modes during drilling, with temperature and thrust force being the most critical influencing factors. Comparative studies highlight good agreement between experimental results and numerical simulations in predicting deformation, stress distribution, and factor of safety. The review also shows that constant load and force-based analysis methods are effective for comparing tool performance across different materials. Overall, the combined experimental and numerical approach provides reliable insight into drilling tool life and helps in selecting suitable tool materials for improved performance and durability.

V. Conclusion

This review paper concludes that drilling tool life is a complex function of tool material properties, cutting parameters, and operating conditions. From the surveyed studies between 2017 and 2025, it is evident that advanced tool materials such as carbide and coated carbide generally outperform conventional tool steels in terms of wear resistance and tool life, particularly under high-speed drilling conditions. Experimental investigations emphasize that thrust force, torque, and temperature play a dominant role in governing flank and crater wear mechanisms. Numerical and finite element analyses have proven to be effective in predicting stress distribution, deformation, and factor of safety, showing good correlation with experimental observations. The literature also highlights that combining experimental testing with numerical modeling enhances the reliability of tool life prediction and reduces the need for extensive physical trials. Overall, the review demonstrates that an integrated experimental–numerical approach is essential for optimizing drilling tool performance and for the development of efficient and durable drilling tools.

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