Effect of Cryogenic Treatment on Coated Tungsten Tool for AISI H11 Turning

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Abstract: Machining of hardened die steels such as AISI H11 presents significant challenges due to high cutting temperatures, rapid tool wear, and deterioration of surface quality. Improving the performance and durability of cutting tools is therefore essential for achieving efficient and cost-effective machining. This study investigates the effect of cryogenic treatment on the performance of coated tungsten carbide cutting tools during the turning of AISI H11 steel. TiN- and TiAlN-coated tools were subjected to deep cryogenic treatment and their machining behavior was compared with conventionally treated tools under identical cutting conditions. The influence of cryogenic treatment on tool wear, surface roughness, cutting forces, and cutting temperature was systematically evaluated. The results indicate that cryogenically treated tools exhibit improved wear resistance, reduced cutting forces, and lower cutting temperatures, leading to enhanced tool life and better surface finish of the machined components. The improvement in performance is attributed to microstructural refinement, reduced residual stresses, and improved coating–substrate adhesion resulting from cryogenic treatment. This study demonstrates that cryogenic treatment is an effective and sustainable approach for enhancing the machining performance of coated tungsten carbide tools when turning AISI H11 steel, making it a promising technique for industrial die and mold manufacturing applications.

I. INTRODUCTION

AISI H11 steel is widely used in die and mold manufacturing due to its high strength and thermal stability, but these properties make it difficult to machine. During turning operations, high cutting temperatures and rapid tool wear often lead to poor surface quality and increased production costs. Improving cutting tool performance is therefore essential for efficient machining of this material. Coated tungsten carbide tools, particularly TiN- and TiAlN-coated tools, are commonly used to enhance wear resistance and tool life. However, under severe machining conditions, conventional tools still suffer from coating degradation and thermal damage. Cryogenic treatment has emerged as an effective technique to improve tool properties by refining the microstructure, reducing residual stresses, and enhancing wear resistance. This study investigates the effect of cryogenic treatment on TiN- and TiAlN-coated tungsten carbide tools during the turning of AISI H11 steel. The performance of treated and untreated tools is evaluated in terms of tool wear, cutting forces, cutting temperature, and surface roughness, with the aim of improving tool life and machining quality for industrial applications.

II. PROBLEM STATEMENT

Machining AISI H11 steel during turning operations is associated with high cutting temperatures, rapid tool wear, and poor surface finish, which lead to increased tooling costs and reduced productivity. Although TiN- and TiAlN-coated tungsten carbide tools are widely used to improve machining performance, premature tool failure and coating degradation still occur under severe cutting conditions. Conventional heat treatment methods are often insufficient to significantly enhance tool life and machining stability. There is a lack of systematic studies evaluating the effectiveness of cryogenic treatment on coated tungsten carbide tools during the turning of AISI H11 steel. Therefore, it is necessary to investigate whether cryogenic treatment can effectively improve tool performance, reduce wear, and enhance surface quality during this machining process

III. OBJECTIVES

1) To investigate the effect of cryogenic treatment on the machining performance of TiN- and TiAlN-coated tungsten carbide tools during turning of AISI H11 steel.
2) To compare tool wear characteristics of cryogenically treated and conventionally treated coated tools.
3) To evaluate the influence of cryogenic treatment on cutting forces and cutting temperature during the turning process.
4) To analyze the surface roughness and surface quality of AISI H11 steel machined using treated and untreated tools.
5) To identify the suitability of cryogenic treatment as a practical method for improving tool life and machining efficiency in industrial applications.

IV. METHODOLOGY

The study was carried out through a systematic experimental approach to evaluate the effect of cryogenic treatment on coated tungsten carbide tools during turning of AISI H11 steel. Commercially available TiN- and TiAlN-coated tungsten carbide inserts were selected as cutting tools. A set of tools was subjected to deep cryogenic treatment using liquid nitrogen at extremely low temperature, followed by controlled warming to room temperature, while another set was kept in the conventional condition for comparison.

Turning experiments were performed on AISI H11 steel bars using a CNC lathe under dry cutting conditions. Identical cutting parameters, including cutting speed, feed rate, and depth of cut, were maintained for both treated and untreated tools to ensure a fair comparison. Tool wear was measured periodically using an optical microscope, and surface roughness of the machined specimens was evaluated using a surface roughness tester. Cutting forces and cutting temperature were recorded using appropriate measuring instruments during machining.

The performance of cryogenically treated tools was compared with that of conventionally treated tools based on tool wear progression, surface roughness, cutting forces, and temperature. The experimental results were analyzed to assess the effectiveness of cryogenic treatment in improving tool life and machining performance during turning of AISI H11 steel.

V. LITERATURE SURVEY

Machining of hardened steels such as AISI H11 has been widely studied due to the difficulties associated with high cutting temperatures, rapid tool wear, and poor surface quality. Researchers have reported that conventional machining of H11 steel often leads to severe flank wear, crater wear, and reduced tool life, especially under high-speed turning conditions. Improving cutting tool performance remains a major focus in machining research. Coated tungsten carbide tools, particularly TiN- and TiAlN-coated inserts, have been shown to improve wear resistance and thermal stability during machining of hard materials. TiN coatings provide good hardness and reduced friction, while TiAlN coatings offer better oxidation resistance and thermal stability at elevated temperatures. Several studies have confirmed that TiAlN-coated tools generally perform better than TiN-coated tools during high-temperature machining applications. Cryogenic treatment has gained attention as an advanced tool treatment technique for enhancing mechanical and tribological properties of cutting tools. Previous studies have reported that cryogenic treatment improves tool hardness, reduces residual stresses, and enhances carbide precipitation, leading to improved wear resistance and longer tool life. Positive effects of cryogenic treatment have been observed in machining of difficult-to-cut materials such as stainless steels, tool steels, and nickel-based alloys.

VI. CONCLUSION

This study investigated the effect of cryogenic treatment on the performance of TiN- and TiAlN-coated tungsten carbide tools during turning of AISI H11 steel. The experimental results demonstrated that cryogenically treated tools exhibited significantly improved wear resistance compared to conventionally treated tools. A noticeable reduction in cutting forces and cutting temperature was observed, which contributed to improved machining stability and extended tool life. Additionally, cryogenic treatment resulted in better surface finish of the machined components. Among the coated tools, TiAlN-coated inserts showed superior performance compared to TiN-coated tools under the same cutting conditions. Overall, the findings confirm that cryogenic treatment is an effective and practical approach for enhancing the machining performance of coated tungsten carbide tools when turning AISI H11 steel, offering valuable benefits for industrial die and mold manufacturing applications.

VII. FUTURE SCOPE

The findings of this study provide scope for further research on cryogenic treatment of cutting tools. Future work can focus on optimizing cryogenic treatment parameters such as soaking time, cooling rate, and tempering cycles to further enhance tool performance. The effect of cryogenic treatment on other advanced coatings and multilayer coatings can also be investigated while machining different hard-to-cut materials. In addition, studies incorporating high-speed machining, minimum quantity lubrication (MQL), or cryogenic cooling during cutting may provide deeper insights into tool behavior. Detailed microstructural and wear mechanism analysis using SEM and EDS can further strengthen understanding of tool failure modes. The industrial applicability of cryogenically treated tools in large-scale production environments may also be explored to evaluate economic and sustainability benefits.

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