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A comprehensive review on coating materials and the adhesion of coatings on cutting tool surfaces used in hard turning

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Abstract
Hard turning is a cutting process which involves the direct cutting of hard materials using a single-point cutting tool with high precision. The selection of cutting tools plays a critical role in the hard turning process, so the coating materials and the quality and adhesion of coatings on the cutting tool surface can significantly impact on the tool life and the machining performance. In this article, the main objectives are to provide an overview of the research outcomes and summarizes the key findings on coating materials and the quality and adhesion of coatings. Based on the obtained results, it can be seen that multi-layer coatings and nano-composite coatings show the better performance than TiAlN, TiCN, and Al_2O_3 coating materials. Moreover, the wear resistance of coating layer by CVD is better than that by PVD method. In addition, the CVD coating was more resistant to thermal softening than the PVD coatings, so the wear resistance and hot hardness of CVD was more excellent. Furthermore, the CVD coating exhibited smaller plastic deformation than the PVD coating.
Keywords: *Hard machining; hard turning; coating material; tool life; wear resistance*

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I. Introduction

Hard turning is a machining process that involves cutting hardened steels and other hard materials using a single-point cutting tool. It is a precision machining process that requires a high degree of accuracy and control to produce complex geometries and tight tolerances. Hard turning is often used in the manufacturing of high-performance components, such as those found in the aerospace, automotive, medical industries, and so on [1]. The selection of cutting tool materials and cutting condition plays a crucial role for successful hard turning implementation. The studies on cutting tool coatings has made the significant progress for contributing substantially to the improvement of cutting tool lifespan and performance. The main research direction on developing coatings based on alloys such as TiAlN, TiCN, and Al_2O_3 was focused to improve the wear resistance and hardness of cutting tools [2]. Kaishuo Chang. et al. (2022) [3] pointed out that the low surface roughness of the coating can effectively reduce the friction coefficient. The high wear resistance of the TiAlN coated tool was reported. Florent Uny et al. (2019) [4] made an investigation of TiAlN coatings with various Al contents deposited by CVD in order to investigate the evolution of the morphology, microstructure, hardness and oxidation resistance. The authors found that the oxidation resistance of the coatings rises continuously with an increasing Al content. Saladukhin, I.A., et al. (2017) [5] investigated ZrSiN nanocomposite and ZrN/SiNx multilayered coatings. The obtained results indicated that ZrSiN nanocomposites improved oxidation resistance with increasing Si content when compared to binary ZrN compound. However, their stability is worst among the multilayer cases surveyed. S. Ganeshkumar et al. (2023) [6] summarized the Nano-scale multi-layered-composite coatings and their influence on cutting tool performance, with particular focus on machining productivity, tool life, cutting forces and wear rate. Nano-scale multi-layered-composite coatings are a promising new solution to improve the performance of cutting tools, which could potentially lead to superior cutting performance, increased tool life, and cost-effective manufacturing processes. Vereschaka, A.A., et al. (2014) [7] studied nano-scale multilayered composite coatings for cutting tools under heavy cutting conditions. The results showed that the nano-scale grain structure and thickness of sublayers allow to achieve a balanced wear of rake and flank surfaces without micro/macro chipping of contact areas and cutting edge of the inserts. Koseki, S., et al. (2015) [8] compared TiN-coated tools using CVD and PVD techniques in continuous cutting of Ni-based superalloys. The authors showed that the CVD coating was more resistant to thermal softening than the PVD coatings. The TiN-coated material shows the high strength and thermal stability. AL-Bukhaiti, M.A., et al. (2014) [9] investigated the tribological and mechanical properties of Ti/TiAlN/TiAlCN nanoscale multilayer PVD coatings. The findings indicated that the deposited coating exhibited superior tribological and mechanical properties, and the dominant wear mechanism was abrasive wear. From the literature review, the publications in this direction are still limited, so the summary of the main results in this research direction is very important to have an overview of new points, limitations and research gaps for future studies. Therefore, the author conducted an overview of coating materials on carbide inserts used in the hard machining.

II. Main results in coating materials for carbide inserts in hard turning

Some main results on coating materials for carbide inserts applied in hard turning process are summarized in Table 1.

Table 1. Main studies and findings of coating materials for carbide inserts in hard turning

Reference and year	Coating material	Specific finding
Kaishuo Chang. et al. (2022) [3]	TiAlN	The low surface roughness of the coating can effectively reduce the friction coefficient. The high wear resistance of the TiAlN coated tool was reported.
Florent Uny et al. (2019) [4]	$Ti_{1-x}Al_xN$	The oxidation resistance of the coatings rises continuously with an increasing Al content.
Saladukhin, I.A., et al. (2017) [5]	ZrSiN nanocomposite and ZrN/SiNx multilayered coatings	ZrSiN nanocomposites improved oxidation resistance with increasing Si content when compared to binary ZrN compound. However, their stability is worst among the multilayer cases surveyed.
Vereschaka, A.A., et al. (2014) [7]	Ti-TiN-TiAlCrN compound	The nano-scale grain structure and thickness of sublayers allow to achieve a balanced wear of rake and flank surfaces without micro/macro chipping of contact areas and cutting edge of the inserts
Koseki, S., et al. (2015) [8]	TiN	The CVD coating was more resistant to thermal softening than the PVD coatings. The TiN-coated material shows the high strength and thermal stability.
AL-Bukhaiti, M.A., et al. (2014) [9]	Ti/TiAlN/TiAlCN nanoscale multilayer	The deposited coating exhibited superior tribological and mechanical properties, and the dominant wear mechanism was abrasive wear.

III. The quality and adhesion of coatings on cutting tool surfaces

In addition to the development of new coatings, the recent studies have also focused on the improvement of the coating process to enhance the quality and adhesion of coatings on cutting tool surfaces. This has led to significant improvements in the cutting performance and tool life. The coatings were deposited using physical vapor deposition (PVD) and chemical vapor deposition (CVD) techniques [10]. The CVD coating was more resistant to thermal softening than the PVD coatings [8]. Therefore, the wear resistance and hot hardness of CVD was more excellent than PVD-coated tools. Furthermore, the CVD coating exhibited smaller plastic deformation than the PVD coating. The TiN and TiCN coatings deposited by by CAE-PVD technique improve the cutting performances of the composite WC-Co cutting tools. TiCN coating is shown to be superior to TiN coating in terms of adhesion and thus represents a better alternative for coating the modified WC-Co composite matrix [11]. Based on the SEM and TEM analysis results of, $(Cr_{0.28}, Al_{0.72})N$ coating exhibits better wear resistance, approximately equal adhesion with the substrate, but lower nano-hardness compared with $(Ti_{0.55}, Al_{0.45})N$ coating [12].

IV. Conclusion

In this article, an overview has made on coating materials for carbide inserts applied in hard turning process and the importance of coating quality and adhesion on cutting tool surfaces. The results show that multi-layer coatings and nano-composite coatings show the better performance than TiAlN, TiCN, and Al_2O_3 coating materials. In addition to that, TiN coatings deposited using PVD have better quality and adhesion than TiAlN coatings deposited using CVD. The study highlights the need for careful selection of coating materials and deposition techniques to ensure optimal performance in hard turning. In addition, this study has provided valuable insights into the effectiveness and applicability of new coatings in improving the lifespan and performance of cutting tools. The findings of these studies have significant implications for the development of high-performance cutting tools and the improvement of manufacturing efficiency.

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