



Evaluating the impact of coating type on machining performance of Cemented Carbide tool for turning Alloy Steel -A Review

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Abstract

Hard turning operations often demand cutting tools that can withstand elevated temperatures, high stress, and prolonged contact with hardened materials. In this context, the performance of Ti (C, N)-based cermet tools has been extensively explored, particularly in comparison with coated cemented carbide inserts. Prior investigations report that cermet tools tend to provide longer tool life under light cutting engagements due to their favorable thermal conductivity and reduced cutting forces. However, their brittleness limits their stability when cutting depth increases, making them more prone to chipping. Wear on cermet inserts generally initiates with the removal of the softer binder phase, which eventually leads to particle pull-out on the flank surface. Coated carbide tools, in contrast, exhibit different dominant wear modes—most notably crater formation driven by diffusion and adhesion processes at high temperatures. Both tool types show a gradual rise in surface roughness with extended machining time. Additionally, the thermal load during machining influences chip morphology; cermet tools often generate less curled and cleaner chips owing to lower cutting temperatures. This review consolidates these findings to highlight the influence of coating architecture and material selection on tool wear behavior and machining performance.

Keywords: Hard turning, Ti (C, N)-based cermet tools, Coated carbide inserts, Tool wear mechanisms, Thermal effects in machining

Introduction

Cutting tool materials and their geometric design significantly influence machining productivity, cost efficiency, and the overall integrity of machined components. Tool failure can originate from abrupt events such as chipping or plastic deformation, though gradual wear is by far the most common degradation mode during turning operations. Achieving an ideal combination of strength, toughness, thermal resistance, and wear resistance is difficult using a single material system. Coating technologies, particularly chemical vapor deposition (CVD) and physical vapor deposition (PVD), have made it possible to engineer tool surfaces that meet these diverse requirements.

Carbide substrates are typically chosen for their mechanical robustness and high thermal conductivity. When these substrates are coated with hard, stable compounds such as TiN, TiC, and Al₂O₃, their ability to resist oxidation, abrasive wear, and chemical interaction with the work material is greatly enhanced. Coatings also lower friction at the chip–tool interface, which contributes to cooler cutting and extended tool life. Even after partial wear of the coating, fractured hard particles or worn edges can continue to provide protective effects.

In dry machining, where no cutting fluids are used to control temperature or lubrication, cutting tools experience increased thermal loads. This environment accelerates wear mechanisms unless the tool material or its coating compensates through higher thermal stability and heat conduction. As a result, the development and selection of high-performance coatings have become essential for improving tool life and surface integrity under dry turning conditions.

Literature Review

A substantial amount of research has examined how coated and uncoated tools perform in turning hardened steels and similar difficult-to-cut alloys. The following sections summarize key findings relevant to tool wear behavior, coating performance, machining conditions, and optimization strategies.

hen *et al.* [1] reported that Ti (C, N)-based cermet inserts outperform coated carbide tools at shallower depths of cut, mainly because they generate lower temperatures and cutting forces. However, at larger cutting depths or higher speeds, the brittle nature of cermet materials results in premature chipping. Their study also noted that flank wear of cermets progresses through sequential removal of the binder phase followed by ceramic particle loss, whereas coated carbides degrade through progressive removal of coating layers. Severe crater wear was observed on coated carbides due to thermal–chemical interactions at the tool–chip interface, and chip curling was attributed to thermal stresses during cutting.

Das *et al.* [2] evaluated mist cooling in comparison with dry machining during the hard turning of EN-24 steel. They found that mist cooling significantly reduced surface roughness, cutting forces, and tool wear because of improved lubrication and temperature control. A similar study by Patel *et al.* [3] compared coated carbide and coated cermet tools for machining hardened AISI 4340 steel. Their statistical analysis revealed that cutting speed and feed rate were major contributors to flank wear, with coated cermet tools generally offering better thermal performance and wear reduction.

Further work by Das *et al.* [4] examined both untreated and cryogenically treated cermet inserts for dry finishing of AISI 4340 steel. Their findings showed that optimized

cutting parameters obtained through response surface methodology (RSM) can significantly reduce machining costs and extend tool life.

Boing *et al.* [5] investigated coating degradation using focus variation microscopy (FVM) and scanning electron microscopy (SEM) while turning quenched and tempered AISI 4340 steel. Their analysis indicated superior durability of PVD TiAlN coatings compared with MT-CVD multilayer coatings, with the PVD variant demonstrating markedly longer tool life.

Parmar *et al.* [6] highlighted the tangible benefits of applying AlTiN and TiSiN coatings to cermet inserts. Their results showed substantial reductions in flank wear relative to uncoated inserts at both moderate and high cutting speeds. Although the material removal rate (MRR) decreased slightly for coated tools, TiSiN exhibited better overall wear resistance and tool life at elevated cutting conditions.

Dureja *et al.* [7] studied minimum quantity lubrication (MQL) during machining of AISI 202 stainless steel using coated carbide inserts. MQL provided lower tool wear and improved surface finish compared with both wet and dry machining. Their interaction and desirability plots confirmed that MQL can effectively control temperature and friction at the tool–workpiece interface.

Noordin *et al.* [8] compared three carbide tool inserts and observed that one insert type consistently produced lower cutting forces and superior surface finish. They also discovered that tangential force dominated the cutting load and that all force components increased with feed rate. Surface roughness, in contrast to conventional theory, worsened slightly with increasing cutting speed under their experimental conditions.

Saravanakumar *et al.* [9] employed a Taguchi L27 array to optimize turning parameters for aluminum alloy machining. Their study revealed that feed rate had the greatest effect on surface finish, while higher spindle speeds generally improved the surface quality. Optimal conditions also minimized roundness error, indicating improved dimensional accuracy.

Yang *et al.* [15] and Quazi *et al.* [14] have similarly demonstrated the effectiveness of Taguchi methods in optimizing turning parameters, emphasizing that these statistical tools help reduce experimental effort while improving tool life and surface integrity.

Adinarayana *et al.* [16] conducted multi-objective optimization for turning AISI 4340 steel using CVD tools. Their work showed that surface roughness, MRR, and power consumption could be simultaneously optimized using Taguchi techniques combined with regression modeling.

Prabhu *et al.* [10] compared AlTiN and AlCrN coatings deposited through arc-PVD and noted that both coatings enhance thermal stability and reduce machining temperatures when milling EN-8 steel. AlTiN performed slightly better due to its ability to form a protective alumina layer.

Hao *et al.* [11,12] evaluated the wear behavior of TiAlN-coated ultra-fine carbide inserts during turning of AISI 420C stainless steel. Abrasion, oxidation, crater wear, and coating delamination were identified as major wear mechanisms, particularly at higher cutting speeds and feeds.

Rosa *et al.* [13] highlighted that coating failure mechanisms are strongly linked to thermal and mechanical loading during hard turning. Their findings stress the importance of

designing coatings that resist thermally activated reactions and chip–tool interaction stresses. Complementary research on DLC-based multilayer structures demonstrated that transition layers such as Cr or W-DLC significantly improve coating adhesion and reduce abrasive wear during machining of aluminum–silicon alloys.

Studies by Ali *et al.* [18] and Dabees *et al.* [19,20] further emphasize the advantages of engineered multilayer and nanocomposite coatings, particularly in demanding materials like Ti6Al4V. These coatings substantially improve tool life and surface integrity due to enhanced thermal resistance and wear protection.

References

- Chen X, Xu J, Xiao Q. Cutting performance and wear characteristics of Ti (C, N)-based cermet tool in machining hardened steel. *International Journal of Refractory Metals and Hard Materials*,2015:52:143–150.
- Parmar KV, Thakkar HR. Comparative Evaluation of flank wear of uncoated, AlTiN and TiSiN Coated Cermet Insert by Machining of D2 Tool Steel. *ADBU-Journal of Engineering Technology*,2021:143–150.
- Das A, Tirkey N, Patel SK, Das SR, Biswal BB. A Comparison of Machinability in Hard Turning of EN-24 Alloy Steel Under Mist Cooled and Dry Cutting Environments with a Coated Cermet Tool. *Journal of Failure Analysis and Prevention*,2019:19(1):115–130.
- Das A, Mukhopadhyay A, Patel SK, Biswal BB. Comparative assessment on machinability aspects of AISI 4340 alloy steel using uncoated carbide and coated cermet inserts during hard turning. *Arabian Journal for Science and Engineering*,2016:41(11):4531–4552.
- Das A, Patel SK, Biswal BB, Das SR. Machinability Investigation and Cost Estimation During Finish Dry Hard Turning of AISI 4340 Steel with Untreated and Cryo Treated Cermet Inserts. *Journal of Superhard Materials*,2019:41(4):247–264.
- Parmar KV, Thakkar HR. Comparative Evaluation of flank wear of uncoated, AlTiN and TiSiN Coated Cermet Insert by Machining of D2 Tool Steel. *ADBU-Journal of Engineering Technology*, n.d.
- Dureja JS, Singh R, Singh T, Singh P, Dogra M, Bhatti MS. Performance Evaluation of Coated Carbide Tool in Machining of Stainless Steel (AISI 202) under Minimum Quantity Lubrication (MQL). n.d.
- Noordin MY, Venkatesh VC, Chan CL, Abdullah A. Performance evaluation of cemented carbide tools in turning AISI 1010 steel. *Journal of Materials Processing Technology*,2001,116:16–21.
- Saravanakumar A, Karthikeyan SC, Dhamotharan B, Gokulkumar V. Optimization of CNC Turning Parameters on Aluminum Alloy 6063 using Taguchi Robust Design. n.d, 2018.
- Dureja JS, Singh R, Singh T, Singh P, Dogra M, Bhatti MS. Performance Evaluation of Coated Carbide Tool in Machining of Stainless Steel (AISI 202) under Minimum Quantity Lubrication (MQL). n.d, 2015.
- Prabhu S, Ambigai R, Vinayagam BK. Performance analysis of AlTiN/AlCrN coating on cemented carbide cutting tool using fuzzy logic analysis. n.d, 2018.
- Hao T, Du J, Su G, Zhang P, Sun Y, Zhang J. *et al.* Mechanical and cutting performance of cemented

- carbide tools with Cr/x/DLC composite coatings. n.d, 2020.
13. Rosa GC, Souza AJ, Possamai EV, Amorim HJ, Neis PD. Wear analysis of ultra-fine grain coated carbide tools in hard turning of AISI 420C stainless steel. n.d, 2017.
 14. Sijo MT, *et al.* Taguchi Method for Optimization of Cutting Parameters in Turning Operations. AMAE International Journal on Manufacturing and Material Science,2013;1(1):44–46.
 15. Kuljanic E, *et al.* Machinability of difficult machining materials. 14th International Research/Expert Conference ‘Trends in the Development of Machinery and Associated Technology’ TMT 2010, Mediterranean Cruise,11–18 September 1998: I-1–I-14.
 16. Kompan Chomasmutr, *et al.* Optimization Parameters of tool life Model Using the Taguchi Approach and Response Surface Methodology. International Journal of Computer Science Issues,2000;9(1):120–125.
 17. Das A, Patel SK, Biswal BB, Das SR. Machinability Investigation and Cost Estimation During Finish Dry Hard Turning of AISI 4340 Steel with Untreated and Cryo Treated Cermet Inserts. Journal of Superhard Materials,2019,41(4):247–264.
 18. Bedi SS, Behera GC, Datta S. Effects of Cutting Speed on MQL Machining Performance of AISI 304 Stainless Steel Using Uncoated Carbide Insert: Application Potential of Coconut Oil and Rice Bran Oil as Cutting Fluids. Arabian Journal for Science and Engineering, 2020.
 19. Ali A, Younas M, Khan M, Jaffery SHI, Khan Z. Machinability Performance of Single Coated and Multicoated Carbide Tools During Turning Ti6Al4V Alloy. International Journal of Precision Engineering and Manufacturing,2025;26:43–58.
 20. Dabees S, Mirzaei S, Kaspar P, Holcman V, Sobola D. Characterization and Evaluation of Engineered Coating Techniques for Different Cutting Tools—Review. Materials,2022;15(16):5633.