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INFLUENCE OF PROTECTIVE COATING ON THE MECHANICAL AND TRIBOLOGICAL PERFORMANCE OF CEMENTED CARBIDE TURNING INSERTS

Abstract: *This study presents a comprehensive comparative evaluation of the performance characteristics of commercial coated cemented carbide turning inserts of different grades after turning operations. The wear mechanisms of the cutting edge were investigated using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDS). In addition, the mechanical properties of the coatings, including microhardness and elastic modulus, were determined by instrumented indentation, while their adhesion strength was evaluated using the progressive scratch test. The results revealed that the coating failure was governed by a combination of abrasive and adhesive wear mechanisms, accompanied by localized edge chipping, crater formation, and material transfer from the workpiece onto the tool surface. The highest microhardness values (2258-2261 HV) were obtained for the YBC252 series inserts, which correlated with a lower degree of coating degradation after machining. Scratch test results demonstrated that coatings with higher hardness exhibited greater resistance to mechanical failure and superior adhesion strength. The comprehensive analysis established a clear relationship between the mechanical properties of the coatings, their wear mechanisms, and the service performance of commercial cemented carbide turning inserts.*

Key words: *turning insert, cemented carbide tool, coating wear, scanning electron microscopy, energy-dispersive X-ray spectroscopy, microhardness, scratch test, adhesion strength.*

Introduction

Improving the productivity of modern machining processes is closely associated with enhancing the service life of cutting tools. Among various tool materials, WC-Co cemented carbide turning inserts are widely used owing to their high hardness, excellent thermal stability, and superior wear resistance. To further improve their performance, protective coatings produced by chemical vapor deposition (CVD) and physical vapor deposition (PVD) technologies are commonly applied to the insert surface. Multilayer coating systems such as TiCN/Al_2O_3/TiN, TiAlN, TiN, and their modifications are extensively employed because they provide increased hardness, reduced friction coefficient, and enhanced tool life during the machining of various engineering materials [1, 2]. Each layer in a multilayer coating system performs a specific function. The TiCN layer provides high hardness and excellent resistance to abrasive wear, while the Al_2O_3 layer acts as an effective thermal and diffusion barrier, reducing heat transfer and diffusion wear during cutting. The outer TiN layer decreases the friction coefficient and improves the tribological interaction between the cutting tool and the workpiece. The synergistic effect of these layers significantly improves the durability of cutting tools under high cutting speeds and elevated temperatures.

In recent years, considerable attention has been devoted to investigating the wear behavior of coated cemented carbide inserts after machining. Previous studies have shown that coating degradation during turning results from the combined effects of mechanical and thermal loading, leading to abrasive, adhesive, diffusion, and oxidative wear mechanisms. Depending on the cutting conditions, these mechanisms result in crater wear, flank wear, built-up edge formation, local coating delamination, and cutting-edge chipping [3, 4]. Scanning electron microscopy (SEM) combined with energy-dispersive X-ray spectroscopy (EDS) has become one of the most effective approaches for investigating coating degradation. These techniques enable detailed characterization of wear morphology, identification of coating failure regions, and determination of material transfer from the

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workpiece to the cutting tool surface. Several studies have reported that the presence of elements such as Fe, Cr, and Cu on worn tool surfaces indicates adhesive interaction between the workpiece and the cutting tool, resulting in the formation of secondary surface layers within the tool–chip contact zone [5]. In addition to wear morphology, the mechanical properties of protective coatings play a crucial role in determining tool performance. Coating microhardness governs resistance to plastic deformation and abrasive wear, whereas adhesion strength determines the coating's ability to remain intact under progressively increasing contact loads. Instrumented indentation and progressive scratch testing are widely used to evaluate hardness, elastic modulus, critical failure loads, and coating adhesion. Numerous investigations have demonstrated that increased microhardness and improved adhesion strength significantly reduce wear intensity and extend cutting tool life [6, 7].

Despite the considerable number of studies devoted to the development of advanced protective coatings and the investigation of their wear mechanisms, comparative studies of commercial coated cemented carbide turning inserts from different manufacturers tested under identical cutting conditions remain limited. Most published research focuses on one or two coating systems, whereas comprehensive comparisons involving wear morphology, mechanical properties, and adhesion performance of commercially available inserts are rarely reported [8, 9].

Therefore, the objective of the present study is to perform a comprehensive comparative evaluation of the performance of commercial coated cemented carbide turning inserts after turning operations. The study combines SEM/EDS analysis of wear mechanisms with instrumented indentation measurements of microhardness and elastic modulus, together with progressive scratch testing to evaluate coating adhesion. Furthermore, the relationship between the mechanical properties of the coatings, their failure mechanisms, and the operational performance of the cutting inserts is established.

Materials and methods

Six commercially available coated cemented carbide turning inserts from different manufacturers were selected as the materials for this study. The investigated inserts differed in carbide grade, coating architecture, and intended machining applications. The following inserts were examined: ONGU08T508-PM JT4235, RT16.01N-1.50GM YBG201, DCMT070208-HM YBG202, CNMG120408-DM YBC252, VBMT160408-HM YBC252, and TN16ER300M T8030. All investigated inserts were manufactured from WC-Co cemented carbide substrates coated with multilayer wear-resistant coatings deposited by industrial coating technologies. According to the manufacturers' specifications, the coating systems consisted of various combinations of TiN, TiCN, and Al_2O_3 layers designed to improve wear resistance, thermal stability, and tribological performance during metal cutting. Prior to the mechanical characterization, all inserts were subjected to turning tests under identical cutting conditions. After machining, the worn inserts were used for subsequent investigations of wear morphology, mechanical properties, and coating adhesion.

The worn cutting edges were examined using a SEM3200 scanning electron microscope (SEM) to investigate the wear morphology and coating degradation after machining. The observations were performed at different locations along the cutting edge to identify wear mechanisms, coating failure regions, crater wear, edge chipping, plastic deformation, and other surface defects. The chemical composition of the wear products and the transferred workpiece material was analyzed using an XFlash Detector 730M-300 energy-dispersive X-ray spectroscopy (EDS) system (Bruker, Germany). Elemental mapping and point analyses were performed in representative wear regions to determine the distribution of coating elements and to identify the transfer of workpiece material onto the cutting tool surface.

The mechanical properties of the coatings were evaluated by instrumented indentation using a FISCHERSCOPE HM2000S tester in accordance with ISO 14577. Measurements were performed using a Vickers diamond indenter, allowing continuous recording of the load–displacement curve during loading and unloading. The maximum applied load was 2000 mN, with a holding time of 20 s at the peak load. The obtained load–displacement curves were used to determine the Vickers hardness (HV) and the instrumented elastic modulus (EIT) of the coatings. For each insert, measurements were performed at several locations on the coating surface, and the reported values represent the average of multiple indentations.

The adhesion strength of the coatings was evaluated by means of a progressive scratch test using an Anton Paar RST300 scratch tester in accordance with the recommendations of ISO 20502. A Rockwell C diamond indenter with a tip radius of 200 μm was employed. Scratch tests were performed under a linearly increasing normal load ranging from 0.5 to 200 N over a 3 mm scratch length at a constant scratching speed of 4 mm/min. During the test, the normal load, tangential force, friction coefficient, penetration depth, residual depth, and acoustic emission signal were continuously recorded. The critical loads corresponding to coating failure were determined from abrupt changes in the friction coefficient, acoustic emission signals, penetration depth, and by optical examination of the scratch tracks after testing.

Results and discussion

After the turning operation, the worn surfaces of the cutting inserts were examined by scanning electron microscopy (SEM) in combination with energy-dispersive X-ray spectroscopy (EDS). The investigations were aimed at identifying the wear mechanisms, the nature of coating failure, and determining the elemental composition of the surface after service. The SEM images of the worn surface of the ONGU08T508-PM JT4235 insert (Fig. 1) indicate significant damage to the cutting part of the tool. Intensive crater wear accompanied by local coating failure was observed on the rake face. Chipping and local edge spalling were detected in the cutting-edge region, indicating the development of fatigue-induced coating failure under high contact stresses. The EDS analysis revealed the presence of iron (Fe) in the wear zone, indicating the transfer of workpiece material onto the tool surface as a result of adhesive interaction. During the friction between two metals, adhesion of the contacting surfaces may occur, resulting in the transfer of the machined material onto the surface of the cutting tool. A built-up edge forms on the rake face along the cutting edge and consists of highly deformed particles of the workpiece material. It should be noted that the built-up edge forms most intensively during the machining of ductile metals, such as steel, aluminum, and ductile brass. The banded structure of the built-up edge indicates its continuous growth due to retarded layers of the chip adhering to its surface (Fig. 1). In addition, coating constituents and cemented carbide substrate elements (W and Al) were identified in the damaged region, indicating local disruption of the integrity of the protective coating and partial exposure of the substrate. The obtained results suggest that the dominant wear mechanisms of this insert are crater wear, adhesive wear, and localized cutting-edge chipping.

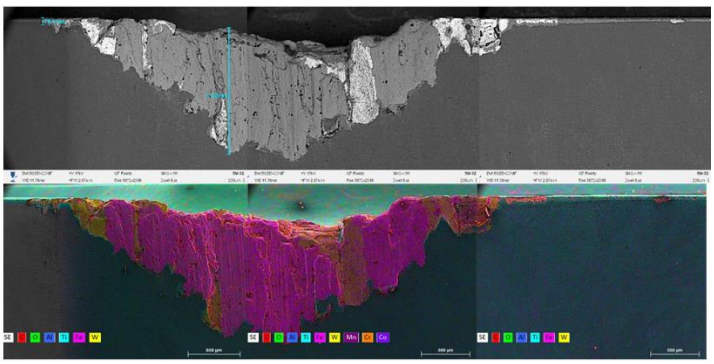


Figure 1 – SEM micrographs of the worn surface and EDS elemental maps of the ONGU08T508-PM JT4235 turning insert after turning

The SEM analysis of the YBC252 CNMG120408-DM insert (Fig. 2) showed that the coating failure was predominantly localized in the cutting-edge region. The elemental distribution maps indicate a non-uniform distribution of aluminum, which is associated with the local degradation of the upper Al_2O_3 layer. In certain areas, partial preservation of the underlying Ti(C,N) layer was observed, confirming the multilayer structure of the coating. The EDS analysis revealed the presence of iron (Fe) in the wear region, which is associated with the transfer of workpiece material and the formation of secondary surface layers in the tool–chip contact zone. Despite the local degradation of the upper coating layer, a significant part of the protective coating system retained its integrity, indicating sufficiently high resistance of the coating to service loading.

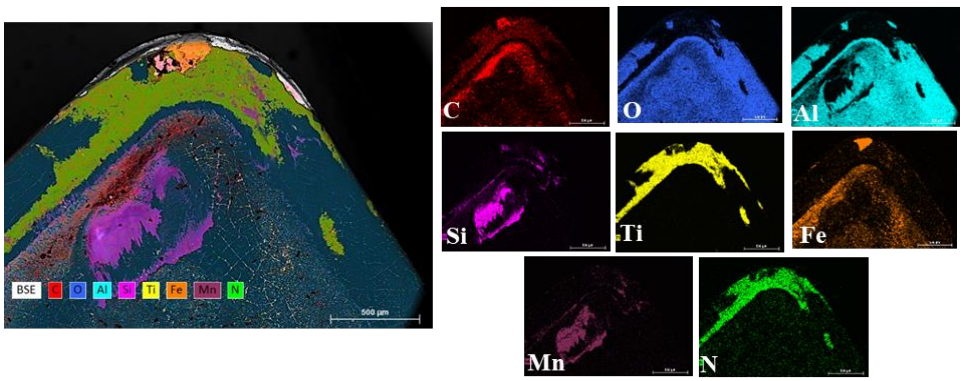


Figure 2 – SEM micrographs of the worn surface and EDS elemental distribution maps of the YBC252 CNMG120408-DM cemented carbide turning insert after turning

Local chipping and minor edge spalling were observed on the surface of the YBG202 DCMT070208-HM insert (Fig. 3). Compared with the previous samples, the coating degradation was less pronounced, and no evidence of severe crater wear was observed. Elemental analysis revealed the presence of copper (Cu) on the worn surface, indicating the transfer of workpiece material during the cutting process and the development of adhesive interaction between the tool and the workpiece. At the same time, coating elements (Ti, Al, N, and O) remained on the surface, confirming that a significant portion of the protective coating was preserved after service. The analysis of the surface morphology indicates that adhesive and abrasive wear are the predominant wear mechanisms for this sample, while the coating degradation is localized in nature.

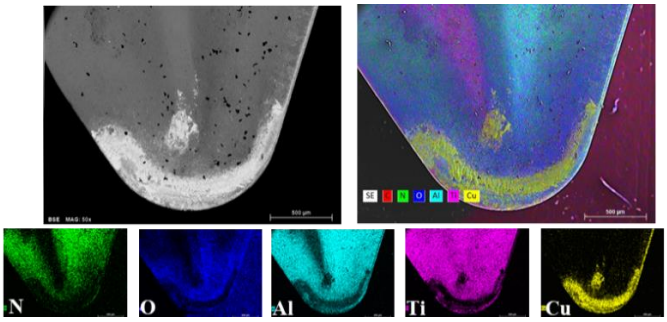


Figure 3 – SEM micrographs of the worn surface and EDS elemental distribution maps of the YBG202 DCMT070208-HM cemented carbide turning insert after turning

The comparison of the SEM/EDS results showed that the failure behavior of the investigated coatings strongly depends on their composition and structure. The most severe coating degradation was observed for the ONGU08T508-PM JT4235 insert, which was characterized by pronounced crater wear, cutting-edge chipping, and transfer of workpiece material onto the tool surface. The YBC252 CNMG120408-DM coating exhibited local degradation of the upper Al_2O_3 layer while preserving the underlying Ti(C,N) layer, indicating the high effectiveness of the multilayer coating architecture. The YBG202 DCMT070208-HM insert exhibited the lowest degree of coating degradation, where adhesive interaction and abrasive wear were the dominant wear mechanisms without significant disruption of the coating integrity.

To evaluate the mechanical properties of the investigated coatings, instrumented indentation tests were performed. The obtained values of microhardness and elastic modulus, as well as the representative load-penetration depth curves, are presented in Fig. 4. The test results showed that the investigated commercial coatings exhibited different mechanical properties. The microhardness values ranged from 1792 to 2261 HV, whereas the elastic modulus varied from 410 to 571 GPa. The lowest microhardness was obtained for the DNMG 150608E-FM insert and amounted to 1792 ± 170 HV, with an elastic modulus of 297.9 ± 160.6 GPa. The highest microhardness was observed for the YBC252 series inserts. The VBMT160408-HM YBC252 insert exhibited a microhardness of 2261 ± 390 HV, while the CNMG120408-DM YBC252 insert showed a value of 2259 ± 365 HV. At the same time, these coatings exhibited high elastic modulus values (413-516 GPa), indicating their high resistance to plastic deformation under contact loading.

Sample	HV	E, GPa
ONGU08T508-PM JT4235	1850.7±175.9	310.0±108.8
DNMG 150608E-FM	1792.0±169.6	297.9±160.6
TN 16ER300M Grade T8030	1937.8±241.6	570.7± 74.3
YBC252 VBMT160408-HM	2261.4± 389.7	515.5±110.5
YBC252 CNMG120408-DM	2258.7±365.1	413.0± 85.8

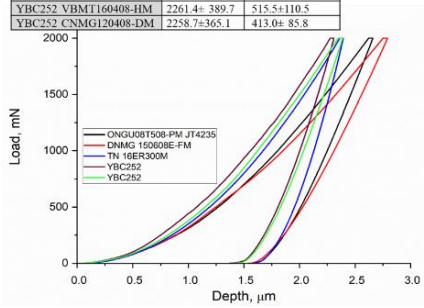


Figure 4 – Dependence of indentation depth on the applied load

The adhesion strength of the coatings was evaluated by means of a progressive scratch test. The obtained curves of the friction coefficient, tangential force, indenter penetration depth, residual depth, and acoustic emission are presented in Fig. 5. For all investigated samples, a gradual increase in the friction coefficient and indenter penetration depth was observed with increasing normal load. Coating failure was accompanied by characteristic spikes in the acoustic emission signal and changes in the penetration depth profile, indicating the local initiation of cracks and partial coating failure. It should be noted that the investigated coatings exhibited different behavior under scratch loading. For the YBC252 series inserts, the recorded parameters changed more gradually, without abrupt fluctuations during the initial stages of the test, indicating high coating adhesion strength and its ability to withstand increasing loads without premature failure. In contrast, for the ONGU08T508-PM JT4235, RT16.01N-1.50GM YBG201, and TN16ER300M Grade T8030 inserts, signs of local coating failure appeared at lower loads. This was accompanied by an increase in the acoustic emission signal and a more pronounced increase in the indenter penetration depth, indicating lower resistance of these coatings to contact mechanical loading. The scratch test results are consistent with the instrumented indentation and SEM analyses. Coatings with higher microhardness exhibited superior adhesion strength and a lower degree of degradation after turning. In contrast, coatings with lower hardness showed earlier failure under mechanical loading and more intensive wear of the cutting edge.

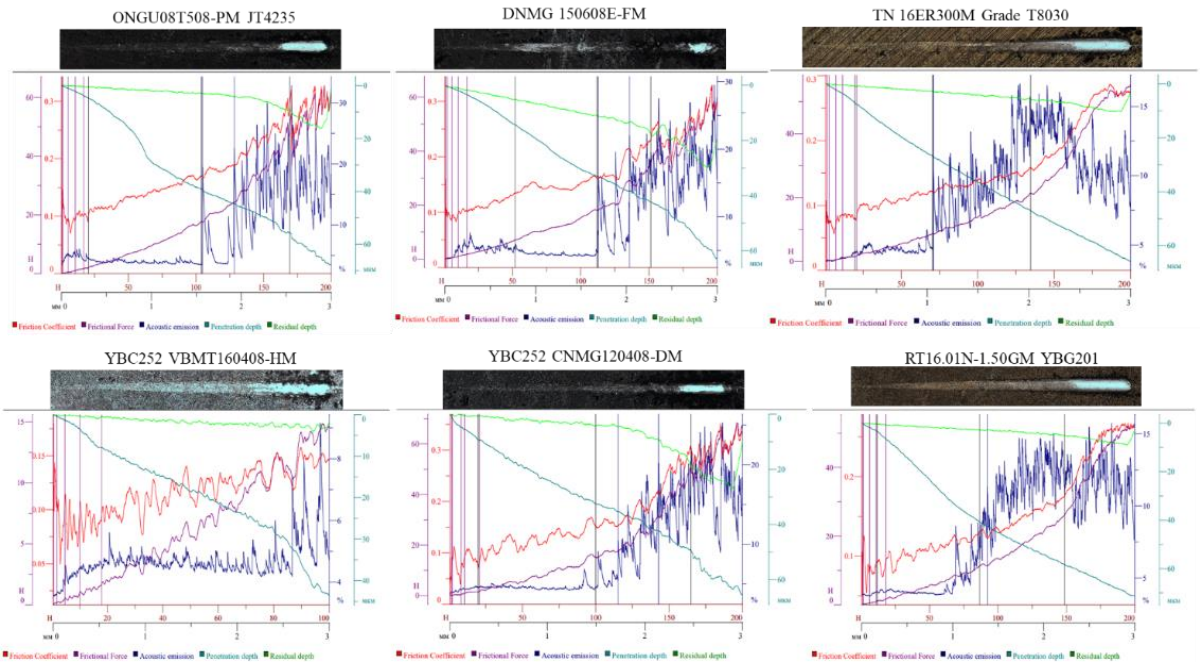


Figure 5 – Scratch test results of the investigated turning inserts: scratch tracks and variations in the friction coefficient, tangential force, acoustic emission, penetration depth, and residual depth as a function of normal load

Conclusion

1. A comprehensive comparative analysis of commercial cemented carbide turning inserts of different grades after turning operations was carried out using SEM/EDS, instrumented indentation, and scratch testing.

2. The SEM investigation revealed that the dominant coating degradation mechanisms were abrasive and adhesive wear, accompanied by localized crater wear, chipping, cutting-edge spalling, and partial failure of the protective layers. The EDS analysis confirmed the transfer of workpiece material onto the tool surface, as evidenced by the presence of Fe and Cu in the wear regions.

3. Instrumented indentation showed that the microhardness of the investigated coatings ranged from 1792 to 2261 HV, while the elastic modulus varied from 297.9 to 570.7 GPa.

4. The scratch test results demonstrated different levels of resistance of the investigated coatings to mechanical failure. Coatings with higher microhardness exhibited more stable behavior under progressively increasing loading and superior adhesion strength compared with coatings possessing lower hardness.

5. The combined analysis of the SEM/EDS, instrumented indentation, and scratch test results demonstrated that increasing the microhardness and adhesion strength of the coatings contributes to reducing the intensity of service wear and improving the durability of cutting tools. Among the investigated samples, the YBC252 series inserts exhibited the most favorable combination of mechanical properties and resistance to service-induced degradation, making them the most promising candidates for turning applications under the investigated cutting conditions.

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ҚОРҒАНЫШ ЖАБЫНДАРЫНЫҢ ҚАТТЫ ҚОРЫТПАЛЫ ТОКАРЛЫҚ ПЛАСТИНАЛАРДЫҢ МЕХАНИКАЛЫҚ ЖӘНЕ ТРИБОЛОГИЯЛЫҚ ҚАСИЕТТЕРІНЕ ӘСЕРІ

Жұмыста токарлық өңдеуден кейінгі әртүрлі маркалы коммерциялық қатты қорытпалы токарлық пластиналардың пайдалану қасиеттеріне кешенді салыстырмалы бағалау жүргізілді. Кескіш жиектің тозу механизмдері растрлық электрондық микроскопия (SEM) және энергия-дисперсиялық рентгендік спектрлік талдау (EDS) әдістерімен зерттелді. Сонымен қатар, аспаптық индентирлеу әдісі арқылы жабындардың микрқаттылығы мен серпімділік модулі анықталды, ал прогрессивті скретч-сынақ әдісімен олардың адгезиялық беріктігі бағаланды. Зерттеу нәтижелері жабындардың бұзылу сипаты абразивтік және адгезиялық тозу механизмдерінің бірлескен әсерімен анықталатынын көрсетті. Бұл құбылыстар кескіш жиектің жергілікті мүжілуімен, кратерлік тозудың түзілуімен және өңделетін материалдың аспап бетіне тасымалдануымен қатар жүреді. Ең жоғары микрқаттылық мәндері (2258-2261 HV) YBC252 сериялы пластиналарда анықталды, бұл олардың пайдалану барысында жабынның аз дәрежеде бұзылуымен сәйкес келеді. Скретч-сынақ нәтижелері жоғары қаттылыққа ие жабындардың механикалық бұзылуға төзімділігі мен адгезиялық беріктігінің жоғары екенін көрсетті. Алынған нәтижелерді кешенді талдау жабындардың механикалық қасиеттері, олардың бұзылу механизмдері және коммерциялық қатты қорытпалы токарлық пластиналардың пайдалану төзімділігі арасында өзара байланыс бар екенін анықтауға мүмкіндік берді.

Түйін сөздер: *токарлық пластина, қатты қорытпалы құрал, жабынның тозуы, SEM, EDS, микрқаттылық, скретч-сынақ, адгезиялық беріктік.*

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ВЛИЯНИЕ ЗАЩИТНЫХ ПОКРЫТИЙ НА МЕХАНИЧЕСКИЕ И ТРИБОЛОГИЧЕСКИЕ ХАРАКТЕРИСТИКИ ТВЕРДОСПЛАВНЫХ ТОКАРНЫХ ПЛАСТИН

В работе проведена комплексная сравнительная оценка эксплуатационных свойств коммерческих твердосплавных токарных пластин различных марок после токарной обработки. Исследованы механизмы изнашивания режущей кромки с использованием растровой электронной микроскопии (SEM) и энергодисперсионного рентгеноспектрального анализа (EDS). Дополнительно методом инструментального индентирования определены микротвердость и модуль упругости покрытий, а методом прогрессивного скретч-тестирования исследована их адгезионная прочность. Установлено, что характер разрушения покрытий определяется сочетанием абразивного и адгезионного механизмов изнашивания, сопровождающихся локальным выкрашиванием режущей кромки, кратерообразованием и переносом материала обрабатываемой детали на поверхность инструмента. Наибольшие значения микротвердости (2258-2261 HV) получены для пластин серии YBC252, что коррелирует с меньшей степенью разрушения покрытия после эксплуатации. Результаты скретч-тестирования показали, что покрытия с более высокой твердостью характеризуются большей устойчивостью к механическому разрушению и лучшей адгезионной прочностью. Комплексный анализ результатов позволил установить взаимосвязь между механическими характеристиками покрытий, механизмами их разрушения и эксплуатационной стойкостью коммерческих токарных пластин.

Ключевые слова: *токарная пластина, твердосплавный инструмент, износ покрытия, SEM, EDS, микротвердость, скретч-тестирование, адгезионная прочность.*

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