ISSN 1392-1207. MECHANIKA. Vol. 31, No. 2, 2025: 156–163

Tribological Characterization of AlCrN, TiAlN, TiSiN and AlTiN Coatings Against Mold Steel

Safa UNAL*, H. Abdullah TASDEMIR**

**Faculty of Mechanical Engineering, Istanbul Technical University, Inonu Street, No.65, Gumussuyu, 34437 Beyoglu, Istanbul, Turkey, E-mail: unalsa23@itu.edu.tr (Corresponding Author)*

***Faculty of Mechanical Engineering, Istanbul Technical University, Inonu Street, No.65, Gumussuyu, 34437 Beyoglu, Istanbul, Turkey, E-mail: tasdemirh@itu.edu.tr*

https://doi.org/10.5755/j02.mech.38122

1. Introduction

Certain fundamental criteria must be met for efficient material removal in machining processes. These include good surface quality and the expectation of rapid material removal [1, 2]. In this context, the selection of cutting tool materials is of great importance for the efficiency of machining processes [3]. Considering this, cutting tool materials are generally expected to possess the following characteristics: high hardness, high yield strength, high modulus of elasticity, high compressive strength, high impact resistance, high thermal conductivity, and low coefficient of linear expansion [4]. Tungsten carbide is frequently used as a cutting tool material because it largely meets these characteristics [4-6].

The service life of tungsten carbide cutting tools, which can directly affect production efficiency, can be enhanced through various coatings [7-9]. Examples of such coatings include diamond or diamond-like carbon (DLC), AlCrN, TiAlN, TiSiN, and AlTiN coatings [10-14].

Sahoo and colleagues investigated the application of single-layer TiAlN coatings of different thicknesses on micro end mills using the PVD method. Following this, approximately 1 μm thick single-layer TiN and diamond-like carbon (DLC) coatings were applied to the surfaces of uncoated WC tools. The hardness and coefficient of friction values of all coated and uncoated surfaces were subsequently evaluated. Finally, the performance of both uncoated and coated tools was assessed experimentally and analytically by analyzing dynamic machinability and stability. The study concluded that all coated tools exhibited enhanced performance by increasing stability limits, and reducing tool wear, surface roughness, cutting forces, and burr heights compared to the uncoated tools [15].

Zafar and colleagues conducted dry machining of Aluminum 2024 alloy using cemented carbide, titanium nitride, titanium aluminum nitride, and polycrystalline diamond (PCD coated) cutting inserts. The performance of these inserts was evaluated for workpiece surface roughness and tool wear. The study concluded that in evaluating tool wear and workpiece surface roughness, consideration of both the mechanical properties and adhesion strength of the inserts is crucial [16].

Marchin and colleagues investigated the effect of carbon addition on the tribological properties of multilayered TiSiN coating and compared the performance of TiSiCN and TiSiN coatings on cold forming steel dies. Tribological tests conducted during the study indicated that the coatings exhibited lower coefficients of friction compared to the steel substrate, with the lowest coefficient of friction (0.2) observed on the TiSiCN coated surface. Field tests evaluating the deep drawing operation of steel tubes revealed a tenfold increase in die lifetime with TiSiCN coating on the forming dies [17].

In the study conducted by Durmaz et al., solid carbide end mills and prismatic carbide test samples were coated with TiAlN, TiAlSiN, and AlCrN. Friction tests were performed at varying speeds, and the results indicated that the highest wear rate was observed in the TiAlSiN-coated sample, while the lowest wear rate was found in the uncoated sample. The highest wear resistance was achieved with the TiAlN coated end mill. Additionally, the lowest surface roughness value was obtained from the surface of the Impax steel workpiece machined using the TiAlN ceramic film-coated carbide end mill [18].

In this study, the tribological performance and wear behavior of cutting tools developed by Moncarb Cutting Tools were comprehensively investigated [19]. The primary objective is to provide scientific insights into the optimization of tool coatings used for machining 1.2738 plastic mold steel, with the ultimate goal of enhancing machining efficiency and extending tool life. To this end, tungsten carbide-based samples were prepared and coated using the cathodic arc physical vapor deposition (CAPVD) technique with four distinct hard coatings: aluminum chromium nitride (AlCrN), titanium aluminum nitride (TiAlN), aluminum titanium nitride (AlTiN), and titanium silicon nitride (TiSiN). The tribological performance of the coated samples was evaluated under test conditions specifically designed to simulate the actual working environment of cutting tools employed by Moncarb Cutting Tools in the machining of 1.2738 steel. Following the tribological tests, detailed analyses were conducted to assess morphological alterations and wear volumes on both the coated surfaces and their counterpart materials using optical microscopy and optical profilometry.

2. Materials and Methods

Tungsten carbide samples were obtained from the Moncarb Cutting Tools company located in Istanbul, Turkey. During production, cylindrical tungsten carbide rods with a diameter of 8 mm and a length ranging from 37 mm to 37.5 mm were used. To prepare end of the rods for tribometer testing, they were shaped into spheres using a Michael Deckel S22 grinding machine, as shown in Fig. 1.

After the grinding process, the surfaces of the samples were treated with a gas stone to achieve surface smoothness for tribometer testing. Subsequently, as shown in Fig. 2, a polishing process was carried out using abrasive paste. This polishing process aimed to prevent errors due to surface roughness and ensure that the coatings would adhere perfectly to the surface, thereby achieving a homogeneous distribution of coating quality across the entire surface of the samples.

Fig. 1 The appearance of the tungsten carbide sample in the Michael Deckel S22 grinding machine

a b

Fig. 2 Changes on the sample surface before and after the polishing process: a – unpolished tungsten carbide sample, b – polished tungsten carbide sample

The prepared tungsten carbide samples were coated with four different hard coatings: aluminum chromium nitride (AlCrN), titanium aluminum nitride (TiAlN), aluminum titanium nitride (AlTiN), and titanium silicon nitride (TiSiN). The coating process was carried out at Titanit Ultra Hard Coatings Industry and Trade Limited Company, located in Istanbul [20]. The cathodic arc physical vapor deposition (CAPVD) method was used in this process. This method involves evaporating the coating material and depositing it onto the surface of the sample, thereby achieving high-quality and durable coatings. The coatings applied can be seen in Fig. 3, and their properties are listed in Table 1. The average surface roughness values (R_a) of the test samples were determined using a Zeiss Smartproof-5 optical profilometer. The average surface roughness values for uncoated tungsten carbide, AlCrN, TiAlN, AlTiN, and TiSiN coated tungsten carbide samples are 0.1969 µm, 0.1867 µm, 0.1710 µm, 0.1548 µm, and 0.1468 µm, respectively.

1.2738 plastic mold steel with dimensions of 10x10x13 mm, as shown in Fig. 4, was used as counterpart on the tribometer testing. Produced counterpart pieces were subjected to a polishing process. The counterpart material has an average surface roughness (R_a) of 0.2322 µm, determined using a Zeiss Smartproof-5 optical profilometer. The chemical composition of the counterpart piece is given in Table 2.

Table 1

Coating properties

Coatings	Hardness, HV	Thickness, µm	Decomposition Temperature, °C
AlCrN	3600	2 ~ 2,5	1000
TiAlN	4000	2 ~ 2,5	1200
TiSiN	4200	2 ~ 2,5	1100
AlTiN	3600	2 ~ 2,5	900

a b c

d e

Fig. 3 The samples used in this study: a – tungsten carbide coated with AlCrN, b – tungsten carbide coated with AlTiN, c – tungsten carbide coated with TiAlN, d - tungsten carbide coated with TiSiN, e - uncoated tungsten carbide

Fig. 4 Counterpart

Table 2

Chemical composition of the counterpart, %

C	Si	Mn	P	S	Cr	Mo	Ni
0.35-0.45	0.20-0.40	0.20-0.40	0.03	0.03	1.80-2.10	0.15-0.25	0.90-1.20

The tribometer tests of the prepared coated and uncoated samples were carried out on a linear reciprocating tribometer at Yıldız Technical University's Automotive Laboratory [21]. The tribometer used can be seen in Fig. 5 and is equipped with a servomotor. During the test, 800 data points (values) were collected from the load cell via a data recorder. These data were directly transmitted to a monitor. It was noted that the force sensor in the load cells of the test setup was obtained from ESIT Electronics, located in Istanbul, Turkey. The SPA platform-type load cell in the test setup measures weight from a single point. The load cell, which has an internal thermal compensation feature, corrects output drifts caused by ambient temperature changes, providing a high level of accuracy. The load cell mounted at the center of the platform was manufactured with a capacity of 3 kg. Data were collected at a rate of 640 data points per second, and each stroke lasted 0.8 seconds. Thus, the average coefficient of friction (CoF) was determined.

Tribometer tests were conducted at room temperature under boundary lubrication conditions for a duration of 1810 seconds. A boron-based cutting fluid was used as the cooling liquid, with three drops (3 cc) applied to the opposing surfaces for each main sample. In the tribological tests, a normal load of 50 N was selected, with a sliding velocity of 0.018 m/s, a stroke of 11 mm, and a total distance of 33 m specified. Data collection was performed using a custom software developed in MATLAB, which filters out vibration-induced noise to calculate the average friction coefficient.

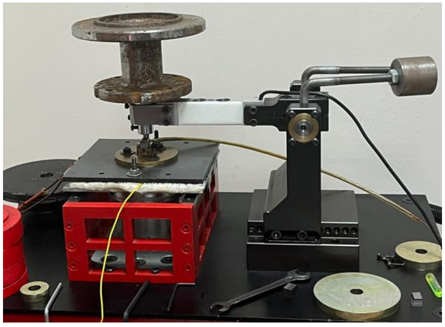
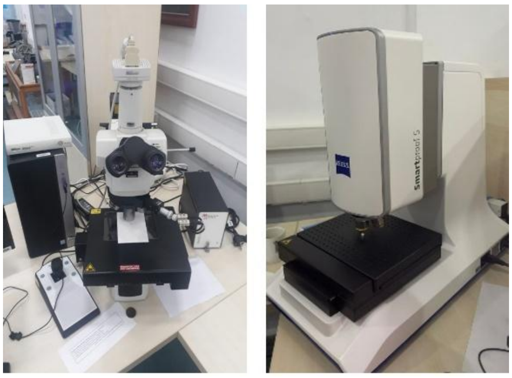


Fig. 5 Tribometer test setup

Surface analyses were conducted at the Research and Development Laboratory of the Turkish Naval Academy after the completion of tribometer tests [22, 23]. The surfaces of the tested tungsten carbide and coated samples were examined using an optical microscope (Nikon LV-150), as shown in Fig. 6. The surfaces of the counter material were scanned using an optical profilometer (Zeiss Smartproof-5) to determine wear volumes, wear tracks, and profile characteristics of the wear tracks.



a b

Fig. 6 Instruments used for surface analysis: a – optical microscope (Nikon LV-150), b – optical profilometer (Zeiss Smartproof-5)

3. Results and Discussion

The average friction coefficient of AlCrN, TiAlN, TiSiN and AlTiN coatings and uncoated tungsten carbide are depicted in Fig. 7. In the uncoated condition, the average friction coefficient was determined to be 0.2436. With TiAlN coating application, this value decreased to 0.238, while the friction coefficient was measured at 0.2272 with AlTiN coating. Using AlCrN coating reduced the friction coefficient to 0.2225, and TiSiN coating provided the lowest friction coefficient at 0.2111. These results clearly demonstrate a significant influence of different coating materials on tribological performance. It is evident that coatings have a friction-reducing effect. Particularly, TiSiN coating offers a lower friction coefficient compared to other coating types, presenting distinct advantages in various industrial applications. Findings in the literature emphasize the importance of TiSiN coatings for industrial applications due to their advantageous properties. In this context, the results obtained from the tribometer tests support previous studies [17,18,21–24].

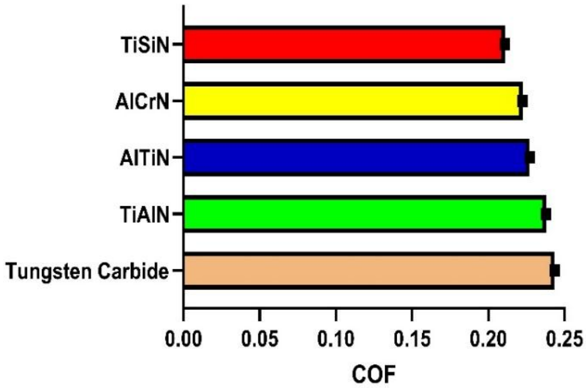
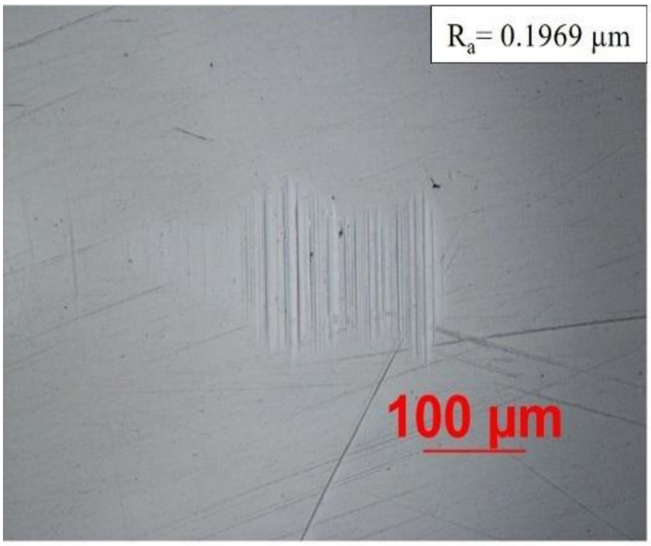


Fig. 7 Average coefficients of friction for test samples

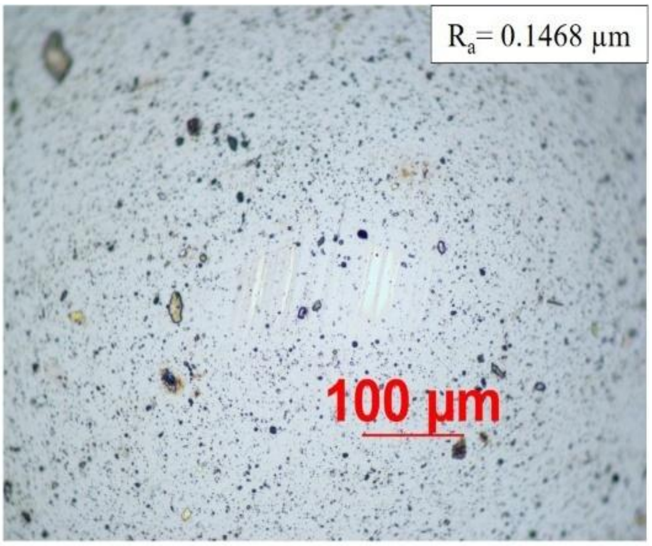
The optical microscope images of wear scars on the samples are shown in Fig. 8. Considering these images, the uncoated surface exhibits pronounced wear scars, indicating significant surface damage. This observation highlights the lower wear resistance of uncoated surfaces. While the TiAlN coating shows visible wear scars, it displays less surface damage compared to the uncoated surface, indicating improved wear resistance. The AlTiN coating exhibits visible wear scars with less surface damage, significantly enhancing wear resistance and reducing friction. Despite relatively pronounced wear scars, the AlCrN coating shows less surface damage compared to the uncoated surface and demonstrates good wear resistance, albeit with slightly higher surface roughness compared to other coatings. The TiSiN coating stands out with the least pronounced wear scars and minimal surface damage, providing the best wear resistance among the coatings tested.

Average surface roughness values (R_a), as illustrated in Fig. 8, support these findings. The uncoated surface shows a relatively high surface roughness value (R_a = 0.1969 µm), associated with high wear and friction. TiAlN coating exhibits lower surface roughness (R_a = 0.1710 µm), indicating smoother surface characteristics and increased wear resistance. AlTiN coating demonstrates lower surface roughness (R_a = 0.1548 µm), contributing to significant improvements in surface quality and wear resistance. AlCrN coating, despite its relatively high surface roughness value (R_a = 0.1867 µm), shows good wear resistance and slightly higher roughness compared to other coatings. TiSiN coating exhibits the lowest surface roughness (R_a = 0.1468 µm), providing superior surface quality and wear resistance.

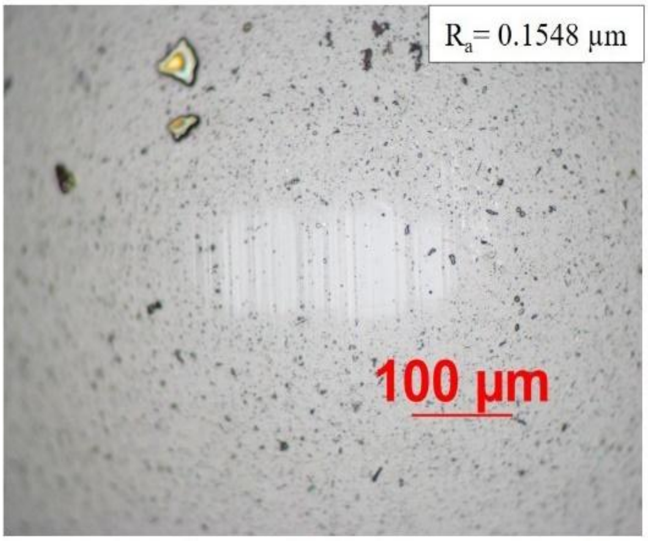
These findings underscore the significant impact of different coatings on tribological performance. The presence of coatings reduces friction coefficients and surface roughness, thereby enhancing wear resistance.



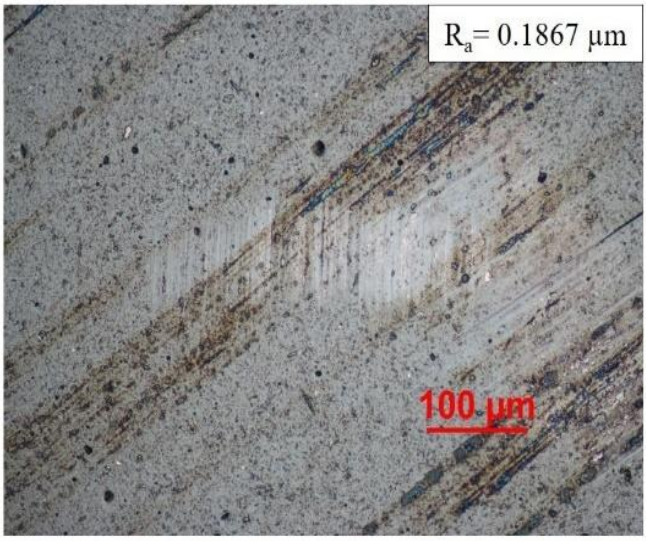
a



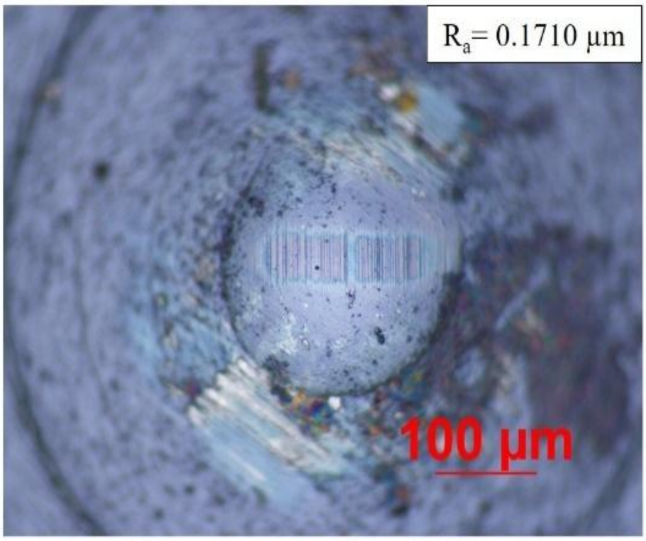
b



c

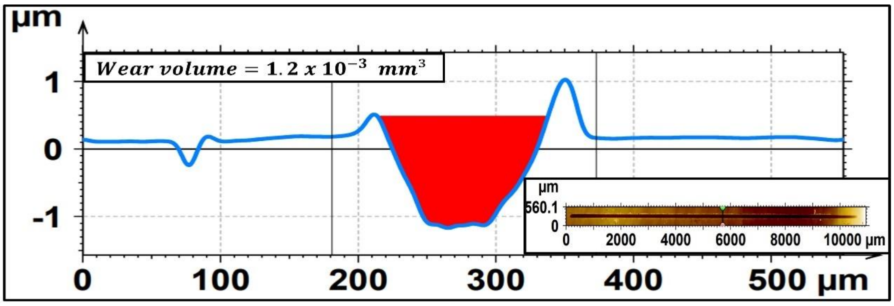


d

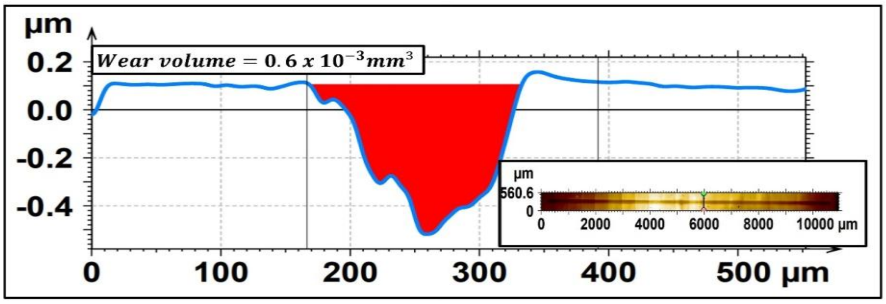


e

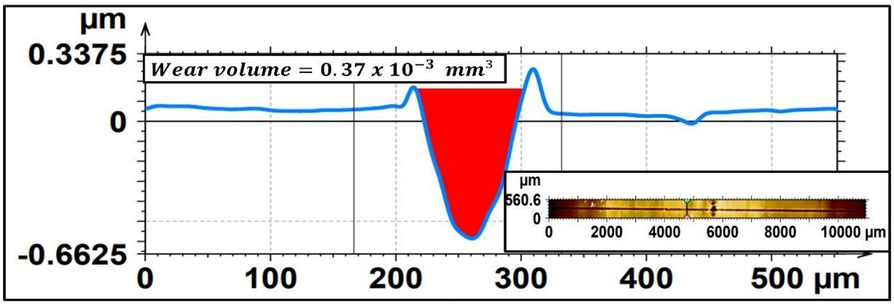
Fig. 8 Optical microscopy analysis of test samples: a – tungsten carbide, b – tungsten carbide coated with TiSiN, c – tungsten carbide coated with AlTiN, d – tungsten carbide coated with AlCrN, e – tungsten carbide coated with TiAlN



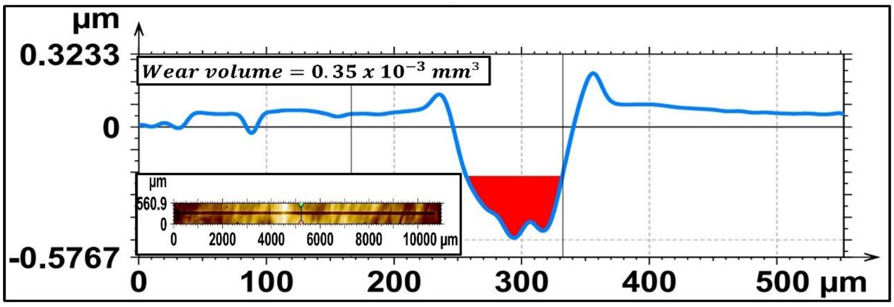
a



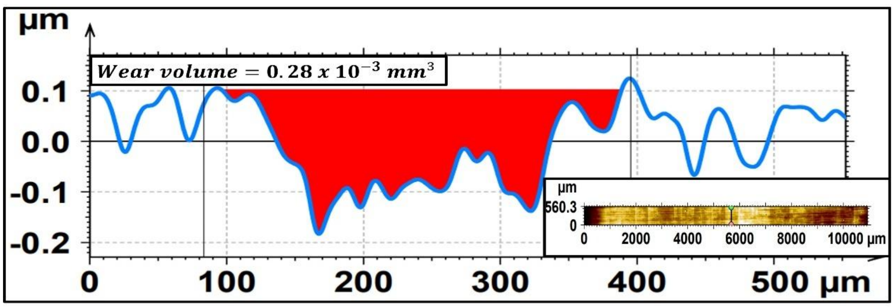
b



c



d



e

Fig. 9 Measurement of wear scars and volumes on counterparts in tribometer tests: a – TiSiN, b – AlCrN, c – AlTiN, d – TiAlN, e – tungsten carbide

TiSiN coating generally exhibits the best performance, followed by AlTiN and TiAlN coatings. AlCrN coating also performs well, although it tends to have slightly higher surface roughness compared to other coatings. Conversely, the uncoated surface shows the highest friction coefficient and the most pronounced wear scars, indicating the poorest performance in terms of wear resistance and friction reduction. These results are consistent with findings in the literature, emphasizing the significant advantages of coatings like TiSiN in industrial applications due to their superior wear resistance and reduced friction properties [24-26].

The wear profiles of the 1.2738 plastic mold steel counterparts against AlCrN, TiAlN, TiSiN and AlTiN coatings and uncoated tungsten carbide are shown in Fig. 9. Uncoated tungsten carbide caused 0.00028 mm³ wear volume on the counterpart. Wear volume of counterpart dramatically increased to 0.0012 mm³ with the TiSiN coating application. This high wear volume indicates significant wear effects of TiSiN coating on the counterpart surface. AlCrN coating also presented increased wear volume of 0.0006 mm³ compared to uncoated tungsten carbide. AlTiN coating showed a slightly higher wear volume of 0.00037 mm³ on the counterpart surface compared to uncoated tungsten carbide. Similarly, TiAlN coating exhibited a wear volume of 0.00035 mm³, resulting in minimal wear volume on the counterpart surface compared to other coatings.

Considering Fig. 7, Fig. 8, and Fig. 9, it is observed that coatings with lower friction coefficients generally exhibit less wear on their surfaces compared to others, potentially leading to higher wear volumes on the counterpart. The results presented in these figures highlight the importance of considering this phenomenon in industrial applications.

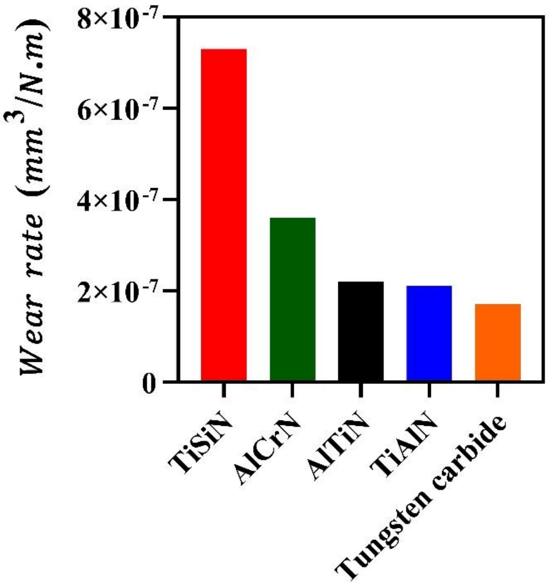


Fig. 10 Wear rates of coatings and uncoated tungsten carbide on counterpart surfaces

The wear rates (w_R) of the counterpart surfaces where coatings were applied were calculated using the Archer formula:

$$W_R = \frac{v}{L \times S} \ . \tag{1}$$

The wear volume v (mm³) was evaluated based on the applied normal load L (N) and the sliding distance S (m). According to the data presented in Fig. 10, the wear rates observed on the 1.2738 plastic mold steel counterparts for the tested coatings and the uncoated tungsten carbide were as follows: 7.3×10^{-7} for TiSiN, 3.6×10^{-7} for AlCrN, 2.2×10^{-7} for AlTiN, 2.1×10^{-7} for TiAlN, and 1.7×10^{-7} mm³/N·m for uncoated tungsten carbide. TiSiN coating demonstrated the highest wear resistance among the tested samples, attributed to its low friction coefficient despite causing the highest wear volume on the counter surface consistent with the findings reported by Kaya and Ulutan [27]. Similarly, the AlCrN coating exhibited superior performance over AlTiN and TiAlN, as reflected by its low friction and high counterface wear, aligning with the observations made by Ozkan et al. [22]. The wear behavior of AlTiN and TiAlN was quite comparable, corroborating the trends reported in the study by Durmaz and Yildiz [18]. In contrast, the uncoated tungsten carbide sample showed significantly inferior wear resistance compared to all coated specimens, which concurs with earlier findings in the literature [28, 29].

The wear rates were evaluated in conjunction with the average friction coefficients from Fig. 9, the optical microscope analyses of the coatings in Fig. 10, and the wear volume measurements of the counterpart materials in Fig. 10. It was observed that coatings significantly increase wear resistance compared to uncoated tungsten carbide. Coatings with lower friction coefficients experienced less wear but caused higher wear on the counterpart surface. This underscores the effectiveness of coatings in enhancing wear resistance and highlights the trade-off between friction reduction and increased wear on the counterpart in industrial applications.

3. Conclusions

In this study, the tribological performances of TiAlN, AlTiN, AlCrN, and TiSiN coatings were evaluated under boundary lubrication conditions, leading to the following conclusions:

1. All coating types significantly enhanced tribological performance by reducing the coefficient of friction and improving wear resistance when compared to uncoated tungsten carbide.
2. The TiSiN coating exhibited the lowest average coefficient of friction (0.2111) and the highest wear resistance, making it a promising candidate for industrial applications where both low friction and high durability are essential.
3. AlTiN and TiAlN coatings offered good wear resistance along with low surface roughness and moderate friction levels, making them suitable alternatives in scenarios where surface properties or cost constraints play a critical role.
4. AlCrN coating demonstrated notable wear resistance and induced relatively higher wear on the counterface, indicating effective engagement with the workpiece surface. This behavior highlights its potential suitability in machining or forming operations.
5. A trade-off was observed between coating wear and counterface damage: coatings such as TiSiN

and AlCrN, which displayed lower friction, experienced less wear themselves but caused greater wear on the opposing surface. This underlines the importance of system-level design considerations in industrial applications.

6. The experimental results align well with existing literature and further confirm the substantial advantages of TiSiN coatings in extending tool life and enhancing performance in tribological systems.

These findings underscore the critical role of surface engineering in optimizing material performance and support the continued development and application of hard coatings in industrial environments with high wear demands.

4. Acknowledgments

The authors gratefully acknowledge the support provided by the Scientific Research Projects Unit of Istanbul Technical University (Project No: MDK-2023-45201, congress-supported doctoral project). The authors also wish to thank Moncarb Cutting Tools for supplying test materials and Titanit Ultra Hard Coatings Industry and Trade Ltd. for their valuable assistance in the coating processes.

References

1. **Schmitz, T. L.; Davies M. A.; Medicus K.; Snyder J.** 2001. Improving high-speed machining material removal rates by rapid dynamic analysis, CIRP Annals 50(1): 263-268. https://doi.org/10.1016/S0007-8506(07)62119-2.
2. **Ekinovic, S.; Begovic, E.; Silajdzija, A.** 2007. Comparison of machined surface quality obtained by high-speed machining and conventional turning, Machining Science and Technology 11(4): 531-551. https://doi.org/10.1080/10910340701804112.
3. **Li, A.; Zhao, J.; Gong, Z.; Lin, F.** 2016. Optimal selection of cutting tool materials based on multi-criteria decision-making methods in machining Al-Si piston alloy, The International Journal of Advanced Manufacturing Technology 86: 1055-1062. https://doi.org/10.1007/s00170-015-8200-1.
4. **Maity, S. R.; Chatterjee, P.; Chakraborty, S.** 2012. Cutting tool material selection using grey complex proportional assessment method, Materials and Design 36: 372-378. https://doi.org/10.1016/j.matdes.2011.11.044.
5. **Rizzo, A.; Goel, S.; Grilli, M. L.; Iglesias, R.; Jaworska, L.; Lapkovskis, V.; Novak, P.; Postolnyi, B. O.; Valerini, D.** 2020. The Critical Raw Materials in Cutting Tools for Machining Applications: A Review, Materials 13(6): 1377. https://doi.org/10.3390/ma13061377.
6. **Jahan, M. P.; Rahman, M.; Wong, Y. S.** 2011. A review on the conventional and micro-electrodischarge machining of tungsten carbide, International Journal of Machine Tools and Manufacture 51(12): 837-858. https://doi.org/10.1016/j.ijmachtools.2011.08.016.
7. **Bag, R.; Panda, A.; Sahoo, A. K.; Kumar, R.** 2020. Cutting tools characteristics and coating depositions for hard part turning of AISI 4340 martensitic steel: A review study, Materials Today: Proceedings 26: 2073-2078. https://doi.org/10.1016/j.matpr.2020.02.448.
8. **Wang, J.; Liu, Z.; Wu, Y.; Wang, Q.; Shu, D.** 2024. Cutting Performance and Tool Wear of AlCrN- and TiAlN-Coated Carbide Tools during Milling of Tantalum–Tungsten Alloy, Machines 12(3): 170. https://doi.org/10.3390/machines12030170.
9. **Yoon, S. Y.; Yoon, S-Y.; Chung, W. S.; Kim, K. H.** 2004. Impact-wear behaviors of TiN and Ti–Al–N coatings on AISI D2 steel and WC–Co substrates, Surface and Coatings Technology 177–178: 645-650. https://doi.org/10.1016/j.surfcoat.2003.08.067.
10. **Muthuswamy, P.; Murugesan, V. G. V.** 2021. Machinability analysis in high speed turning of Ti–6Al–4V alloy and investigation of wear mechanism in AlTiN PVD coated tungsten carbide tool, Engineering Research Express 3(4): 045011. https://doi.org/10.1088/2631-8695/ac2e12.
11. **Çam, A. S.; Ergüder, T. O.; Kaya, G.; Yıldız, F.** 2022. Improvement of structural/tribological properties and milling performances of tungsten carbide cutting tools by bilayer TiAlN/TiSiN and monolayer AlCrSiN ceramic films, Ceramics International 48(18): 26342-26350. https://doi.org/10.1016/j.ceramint.2022.05.318.
12. **Rincón, C.; Zambrano, G.; Carvajal, A.; Prieto, P.; Galindo, H.; Martínez, E.; Lousa, A.; Esteve, J.** 2001. Tungsten carbide/diamond-like carbon multilayer coatings on steel for tribological applications, Surface and Coatings Technology 148(2-3): 277-283. https://doi.org/10.1016/S0257-8972(01)01360-3.
13. **Lin, Y. J.; Agrawal, A.; Fang Y.** 2008. Wear progressions and tool life enhancement with AlCrN coated inserts in high-speed dry and wet steel lathing, Wear 264(3-4): 226-234. https://doi.org/10.1016/j.wear.2007.03.007.
14. **Uddin, M. S.; Pham, B.; Sarhan, A.; Basak, A.; Pramanik, A.** 2017. Comparative study between wear of uncoated and TiAlN-coated carbide tools in milling of Ti6Al4V, Advanced in Manufacturing 5: 83-91. https://doi.org/10.1007/s40436-016-0166-1.
15. **Sahoo, P.; Patra, K.; Pimenov, D. Y.** 2022. Enhancement of micro milling performance by abrasion-resistant coated tools with optimized thin-film thickness: analytical and experimental characterization, The International Journal of Advanced Manufacturing Technology 120: 2993-3015. https://doi.org/10.1007/s00170-022-08910-0.
16. **Uddin, G. M.; Joyia, F. M.; Ghufran, M.; Khan, S. A.; Raza, M. A.; Faisal, M.; Arafat, S. M.; Zubair, S. W. H.; Jawad, M.; Zafar, M. Q.; Irfan, M.; Waseem, B.; Chaudhry, I. A.; Zeid, I.** 2021. Comparative performance analysis of cemented carbide, TiN, TiAlN, and PCD coated inserts in dry machining of Al 2024 alloy, The International Journal of Advanced Manufacturing Technology 112: 1461-1481. https://doi.org/10.1007/s00170-020-06315-5.
17. **Marchin, N.; Ashrafizadeh, F.** 2021. Effect of carbon addition on tribological performance of TiSiN coatings produced by cathodic arc physical vapour deposition, Surface and Coatings Technology 407: 126781. https://doi.org/10.1016/j.surfcoat.2020.126781.

18. **Durmaz, Y. M.; Yildiz, F.** 2019. The wear performance of carbide tools coated with TiAlSiN, AlCrN and TiAlN ceramic films in intelligent machining process, Ceramics International 45(3): 3839-3848. https://doi.org/10.1016/j.ceramint.2018.11.055.
19. Moncarb Cutting Tools. Available at: https://www.moncarb.com/ (accessed December 9, 2024).
20. Titanit PVD Coating. Available at: https://www.titanitpvd.com/ (accessed December 9, 2024).
21. **Kaleli, E. H.; Demirtaş S.** 2023. Experimental investigation of the effect of tribological performance of reduced graphene oxide additive added into engine oil on gasoline engine wear, Lubrication Science 35(2): 118-143. https://doi.org/10.1002/ls.1627.
22. **Özkan, D.; Erarslan, Y.; Sulukan, E.; Kara, L.; Yılmaz, M. A.; Yağcı, M. B.** 2018. Tribological behavior of TiAlN, AlTiN, and AlCrN coatings at boundary lubricating condition, Tribology Letters 66: 152. https://doi.org/10.1007/s11249-018-1111-1.
23. **Özkan, D.; Yılmaz, M. A.; Erdem, C.; Türküz, C.; Sulukan, E.; Yağcı, M. B.** 2022. Wear and friction behavior of CrTiN/TiCN and CrTiN/CrCN multilayer composite coatings, Ceramics International 48(10): 13732-13747. https://doi.org/10.1016/j.ceramint.2022.01.254.
24. **Yang, J.; Cao, H.; Li, Y.; Liu, F.; Tang, Y.; Zhao, N.; Qi, F.; Ouyang, X.** 2023. Microstructure, mechanical properties, and corrosion resistance of TiSiN coating prepared by FCVA technique with different N2 flow rates, Vacuum 209: 111811. https://doi.org/10.1016/j.vacuum.2023.111811.
25. **Jiang, J.; Arnell, R. D.** 2000. The effect of substrate surface roughness on the wear of DLC coatings, Wear 239(1): 1-9. https://doi.org/10.1016/S0043-1648(99)00351-8.
26. **Podchernyaeva, I. A.; Yurechko, D. V.; Panashenko, V. M.** 2013. Some trends in the development of wear-resistant functional coatings, Powder Metallurgy and Metal Ceramics 52: 176–188. https://doi.org/10.1007/s11106-013-9511-0.
27. **Kaya, E.; Ulutan, M.** 2022. Tribomechanical and microstructural properties of cathodic arc-deposited ternary nitride coatings, Ceramics International 48(15): 21305-21316. https://doi.org/10.1016/j.ceramint.2022.04.097.
28. **Akhavan Farid, A.; Sharif, S.; Idris, M. H.** 2021. Performance and wear mechanisms of uncoated, TiAlN, and AlTiN-coated carbide tools in high-speed drilling of Al-Si alloy, The International Journal of Advanced Manufacturing Technology 113: 2671-2684. https://doi.org/10.1007/s00170-021-06663-w.
29. **Warcholinski, B.; Gilewicz, A.** 2022. Surface Engineering of Woodworking Tools, a Review, Applied Sciences 12(20): 10389. https://doi.org/10.3390/app122010389.

S. Unal, H. A. Tasdemir

TRIBOLOGICAL CHARACTERIZATION OF AlCrN, TiAlN, TiSiN AND AlTiN COATINGS AGAINST MOLD STEEL

S u m m a r y

The study presents tribological evaluations of TiAlN, AlTiN, AlCrN, and TiSiN coatings under boundary lubrication conditions using a tribometer. Results show significant reductions in average friction coefficients compared to uncoated tungsten carbide (0.2436). TiSiN exhibited the lowest friction coefficient (0.2111), highlighting its superior performance. Optical microscopy and profilometry revealed that coatings like TiSiN also minimized surface roughness and wear tracks, indicating enhanced wear resistance. Coatings reduced friction but increased wear on counterparts. This study underscores the coatings pivotal role in industrial applications, balancing friction reduction with wear enhancement.

Keywords: tribological evaluations, coating performance, friction reduction, wear resistance, surface roughness, boundary lubrication.

Received July 19, 2024
Accepted April 22, 2025