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Effect of tin coating applied to new generation steel material used in elevator parts subject on tribological

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Abstract. This study investigates the effects of titanium nitride (TiN) coating deposited on Vanadis 23 and Dievar by the physical vapor deposition (PVD) method to increase the performance of elevator parts exposed to wear. In the study, hardness and wear tests were applied to steel samples before and after coating, and the influence of the coating to mechanical and tribological properties was evaluated.The results show that TiN coating significantly increases hardness and wear resistance in all two steels types. The hardness rate increased approximately 2 times in TiN coated Vanadis 23 and nearly 3 times in Dievar compared to base metal. Vanadis 23 and Dievar steels demonstrate high performance after coating, owing to their powder metallurgy-based structures. In particular, the potential of TiN coating in elevator components exposed to intense wear such as guide rails, guide shoes, rollers and gearbox was emphasized.This study presents an innovative approach for industries seeking durability and economic solutions, and demonstrates the potential of steel surfaces to which TiN coating is applied to provide longer life and reliability in elevator parts. The findings confirm that TiN coating is a strategic solution for increasing wear resistance and hardness performance.

Keywords: PVD coating; Tribology; Wear; Elevator components

1 Introductıon:

Elevators are significant elements of modern infrastructure, in which critical components need to have high reliability and safety in order to maintain smooth and safe operation (Liang & Li, 2016; Zhang et al., 2019). Traction wheels, safety clamps, brake shoes, and rope clamps in high-speed elevators and friction pads in safety gear systems are some examples that are subjected to adverse conditions of friction, high pressure, and wear (Zhang et al., 2019; Kladovasilakis et al., 2024). The harsh operating conditions are responsible for the heightened failure of key elevator parts (Liang & Li, 2016). The failure of these parts has direct effects on the accuracy, safety, and overall lifespan of the elevator system (Zhang et al., 2019), leading to potential maintenance costs and downtime (Zhang et al., 2019; Kladovasilakis et al., 2024).

To improve the poor wear resistance generally observed in mechanical components (Zhang et al., 2019; Silva et al., 2024; Xian et al., 2021), various surface modification techniques have been extensively employed. Physical Vapor Deposition (PVD) is one of the typical methods employed to deposit hard coatings ((Ichou et al., 2023; Xian et al., 2021). Titanium nitride (TiN), being a well-established hard ceramic coating (Silva et al., 2024; Xian et al., 2021), finds extensive applications in a number of industries owing to its high hardness, good chemical stability, and improved wear properties (Silva et al., 2024; Ichou et al., 2023; Hernández-Sierra et al., 2018; Murwamadala et al., 2025; Wang et al., 2022). TiN coatings have also been found to enhance wear resistance and increase the service life of the components (He et al., 2014, Zhang et al., 2019, Hernández-Sierra et al., 2018). Recent research on Al- and Zr-doped TiN coatings deposited by magnetron sputtering has found them to have increased hardness, adhesion, and wear resistance at optimized conditions (12). The substrate material is known to affect the performance of the coatings (Xian et al., 2021; Murwamadala et al., 2025, Wang et al., 2022, Komarov et al., 2016).

Although the benefits of TiN coatings developed by physical vapor deposition (PVD) are known, an in-depth study of the unique tribological and mechanical characteristics of TiN coatings on various kinds of advanced steel, especially those employed or potentially suitable for aggressive elevator applications such as guide rails, guide shoes, rollers, and gearboxes (Zhang et al., 2019), is needed. It needs a comprehension of the interaction of all steel substrates and how all the improvements by TiN coating can be optimally leveraged to gain maximum lifetime as well as efficiency in these all-important elevator components (Sert et al., 2020).

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The purpose of this work is to explore the influence of titanium nitride (TiN) coating developed by the physical vapor deposition (PVD) process on Vanadis 23 and Dievar steels. The overall aim of this study is to assess the feasibility of using this coating to improve the performance of elevator parts that are subjected to continuous wear and tear. This will be achieved by analyzing how the TiN coating affects the mechanical and tribological behavior of the different steel substrates involved.The aim of this study is to examine and compare the hardness, wear resistance, and performance potential of TiN coatings deposited on Vanadis 23, Dievar, and AISI 52100 steel substrates. The outcomes generated in this study can be a viable and cost-effective solution for the optimal design of industrial parts, particularly those applied in elevators, to enhance their life span and minimize the failure rate.

2. Material and methode

Vanadis 23 and Dievar steel were prepared as base and alternative materials with the formulation shown in Table 1 and were cut into circles with a diameter of 24-26 mm for door preparation. After cutting, they were sanded with sandpapers of 200, 400, 600, 800, 1000, 1500 and 2000 and prepared for polishing. After polishing, they were prepared for coating with the Cathodic Arc PVD technique.

Coating depositions were performed utilizing the cathodic arc evaporation process via a Platit π411 Plus device (Switzerland), modified to suit industrial purposes. The coatings were deposited with comparable conditions for all three: a cathode current of 150 ± 30 A, bias voltage of 65 ± 15 V, temperature of 450 ± 30 °C, and flow rate of nitrogen gas at 450 ± 30 scam.

To examine the substrate-coating interface, SEM examined cross-sections of steels that had been coated simultaneously and fractured in a brittle manner to avoid deformation or thermal effects. SEM also examined wear mechanisms on the coated samples and the counter bodies.

Using Al_2O_3 balls (6 mm diameter) as counter bodies to mimic abrasive wear, wear tests were carried out on a DUCOM (TR-201, India) tribometer in an ambient situation. 10 N load, 150 rpm, 8 mm wear diameter, and 5000 cycles were the test parameters. Worn surface topography was assessed through a non-contact profilometer (NANOFOCUS µscan Custom, Germany) at a resolution of 5 µm × 5 µm, and wear volumes were calculated.

An impact-sliding wear test rig was employed to evaluate the wear performance of the coatings specimens. The test was carried out under room conditions with an alumina (Al_2O_3) sphere, 10 mm in diameter, as the counterface. A fixed load of 10 N was applied, with each test consisting of 5000 cycles, each cycle comprising a sliding distance of 5 mm.

Morphological, topographical, and crystallographic examinations were carried out by scanning electron microscopy (SEM) (Zeiss EVO LS10, Germany) and X-ray diffraction (XRD) (Panalytical Empyrean, UK). XRD measurement was performed in a Bragg-Brentano configuration with a 2θ range of 5–100° and a scan rate of 3°/min with a step size of 0.05°.

For minimizing the influence of the substrate material on the measured hardness values of the coatings, in addition to microhardness tests, five nanoindentation measurements were performed. These measurements were conducted under a 0.5 g load using a Hysitron Ti 950 nanoindenter.

3. Results and discussion

3.1 Microstructural and mechanical analysis

Fig. 1 presents the SEM images of the surface morphology of TiN coating applied to Vanadis 23 and Dievar steels. Common defects of the cathodic arc evaporation method, such as white droplet-like particles and surface holes, were observed on the coatings. The droplets are mostly smaller than 1 µm. These droplets, resulting from the ejection of molten material from the cathode during arc evaporation, appear as bright, spherical features, while the holes likely originate from localized shadowing effects or insufficient film growth in certain areas. Notably, the Vanadis 23 substrate (Fig. 1- b) shows a higher density and larger size of droplets compared to the Dievar substrate (Fig. 1- a), indicating possible differences in nucleation behavior or substrate–coating interactions.

The figure 2, presents cross-sectional SEM images of TiN coatings deposited via the CAPVD method on (Fig. 2-a) Dievar and (Fig. 2-b) Vanadis 23 steel substrates. Both images clearly reveal a uniform and continuous coating layer with an approximate thickness of 5 µm. The Dievar substrate coating (Fig. 2a) is relatively dense and has a smooth microarchitecture, suggesting good compactness and adhesion. Conversely, the TiN coating on the Vanadis 23 substrate (Fig. 2b) displays a columnar and textured morphology, typical of coatings deposited by an arc process that can be disrupted by the microstructural and thermal characteristics of the substrate.

The differences in morphology can influence wear resistance and mechanical behavior of the coatings under function. These findings indicate that substrate material greatly influences resultant microstructure and deposited layer quality even at the same deposition conditions.

Table 1.EDS analys Chemical composition of substrate metals (weight %).

Elements	Fe	C	Mo	Cr	V	W	Mn	Si
Vanadis 23	80.02	1.28	5	4.2	3.1	6.4	5	---
Dievar	91.05	0.35	2.3	5	0.6	----	0.5	0.2

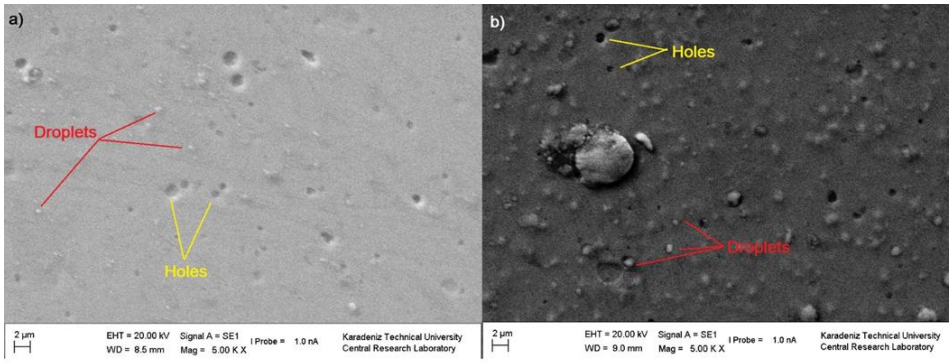


Fig. 1. The SEM images of a) Dievar-TiN, b) Vanadis23-TiN coated by CAPVD surfaces.

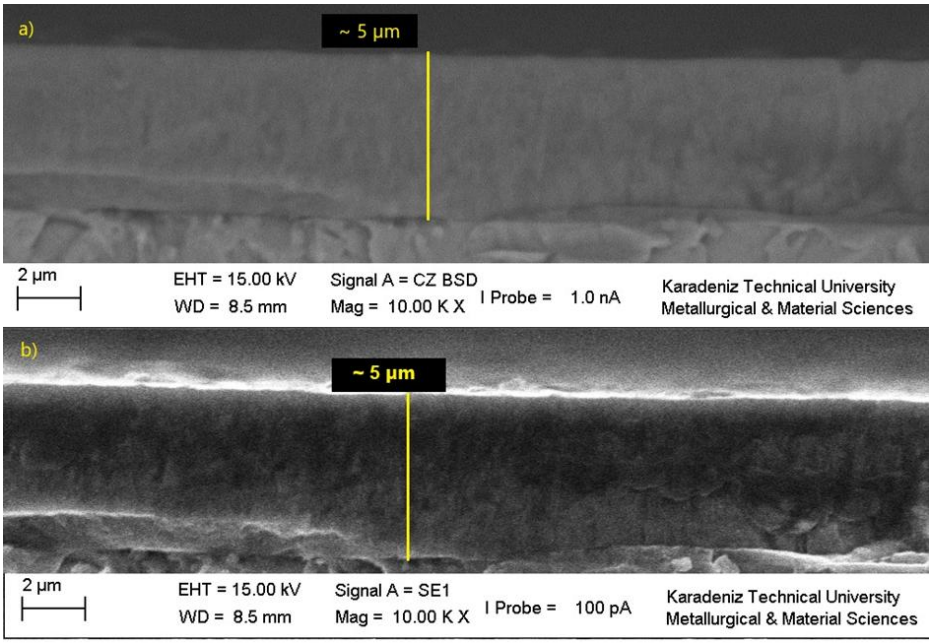


Fig. 2. The cross-section SEM image of TiN coated on a) Dievar stells and b) Vanadis 23.

XRD results of the TiN coatings are presented in Fig. 3. When the XRD patterns were analyzed, it was observed that TiN was the dominant crystal structure in the coated samples. In the TiN layers, the TiN (200) peak appeared as the main peak. The preferred growth of the (200) orientation is explained by the deposition process, which enables the adatoms to migrate over the growing surface. Besides the TiN peaks, iron peaks were also observed, particularly in the base materials. Moreover, the TiN reflections of (111), (220), and (222) were observed, but with smaller intensities. Relative to Vanadis 23, Dievar samples contained a greater amount of Fe within the TiN coating and thus a greater extent of intermixing between the coating and the substrate. Apart from this, small amounts of oxygen were also found in both the coatings, likely due to small-scale oxidation of the surface on or after deposition. Overall, the EDS analysis confirmed that TiN coatings with different extents of substrate effects were deposited successfully.

The measurements that were determined from nanoindentation (Fig. 4) confirmed that coating the base materials with a TiN coating greatly increased their hardness values. For Dievar substrate, the hardness increased from about 10 GPa to well above 30 GPa following the TiN deposition. Likewise, in Vanadis 23, the hardness

increased from around 14 GPa to about 28 GPa following the TiN coating deposition. This remarkable improvement can be attributed to the intrinsic high hardness of the TiN layer deposited by CAPVD, which contributes significantly to both base metals surface properties with very high effectiveness. Moreover, the greater relative improvement demonstrated in Dievar shows that the TiN coating affected this substrate more in comparison with Vanadis 23.

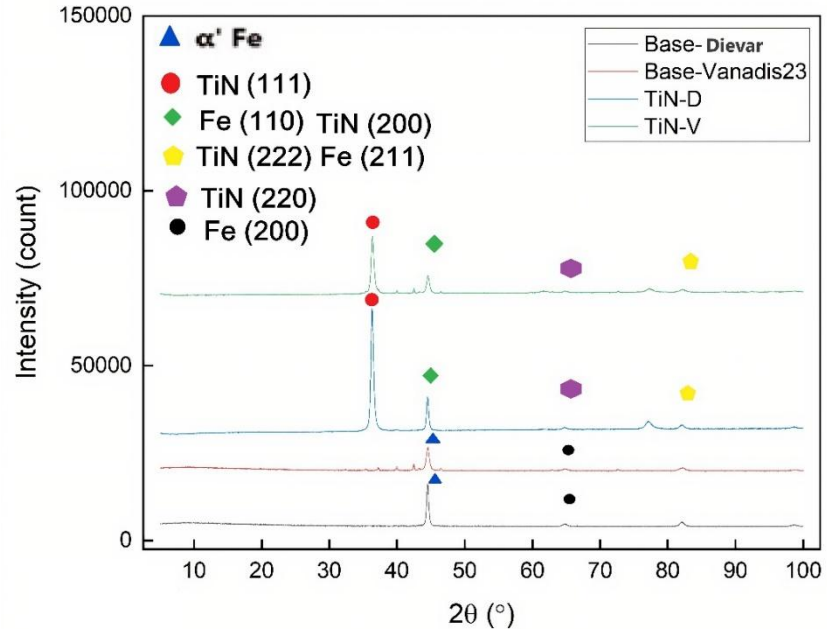


Fig. 3. The XRD patterns of the base metals and coated samples.

Table 2. EDS analyse Chemical composition of TiN coating (weight %).

Elements	Fe	Ti	N	O
Vanadis 23	7.91	57.95	33.39	0.75
Dievar	33.71	33.93	31.73	0.63

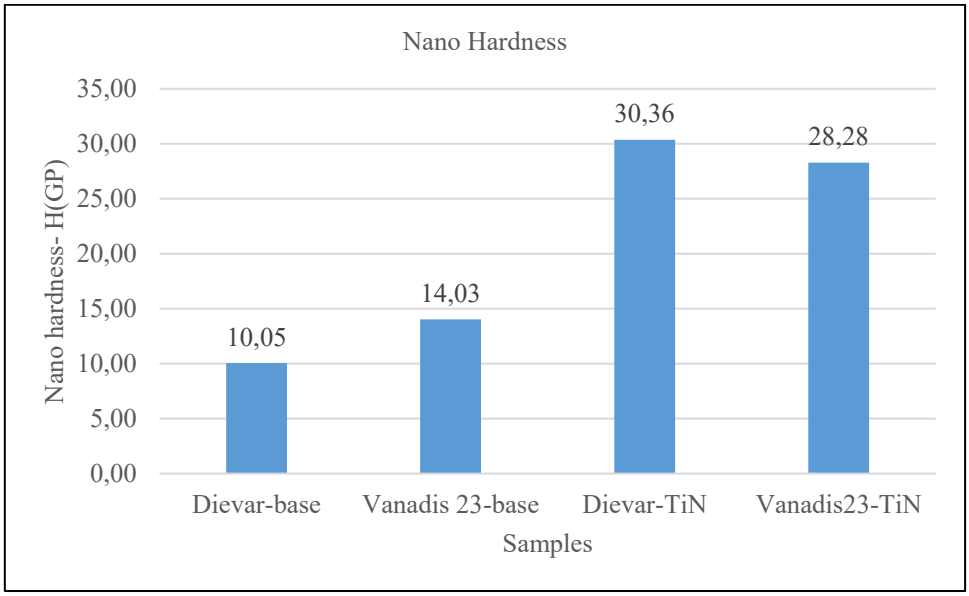


Fig. 4- The nano hardness results of base metals and coatings.

3.2 Adhesion strength analysis

Fig. 5 presents the scratch test results for the base metal samples coated with TiN, i.e., Dievar and Vanadis 23. The critical load (Lc_2), which indicates the beginning of coating failure, is considerably higher in the Vanadis 23-TiN sample (92.6 N) than that of the Dievar-TiN sample (62.2 N). This is indicative of better adhesion strength and mechanical properties of the TiN coating when deposited onto the Vanadis 23 substrate. In both samples, the scratch track images demonstrate the typical modes of failure of hard coatings, which include cohesive cracking of the coating and partial delamination. The Vanadis 23-TiN sample shows a smoother and more consistent scratch path with fewer severe defects and suggests a tougher substrate-coating bond.

3.3 Friction and wear properties

Fig. 6 illustrates the evolution of the friction coefficient as a function of time for base metals and their TiN-coated counterparts. In the initial testing stages, there is an abrupt increase in the friction coefficient in all specimens, which is typically attributed to the running-in period, where surface asperities interact and accommodate under load.

After this initial transition, the frictional behavior becomes stabilized, demonstrating marked differences between the TiN-coated and base material. Dievar's base metal (described by the red curve) presents the lowest and most stable friction coefficient throughout the experiment. In contrast, samples coated with TiN, particularly Vanadis23-TiN (blue), show steadily high friction coefficients. The observed effect is likely due to increased surface hardness and roughness provided by the TiN coating that enhances the resistance to sliding. In addition, there are minor variations in the friction coefficient curves observed in all the materials, which capture the dynamic character of surface interactions through extensive sliding.

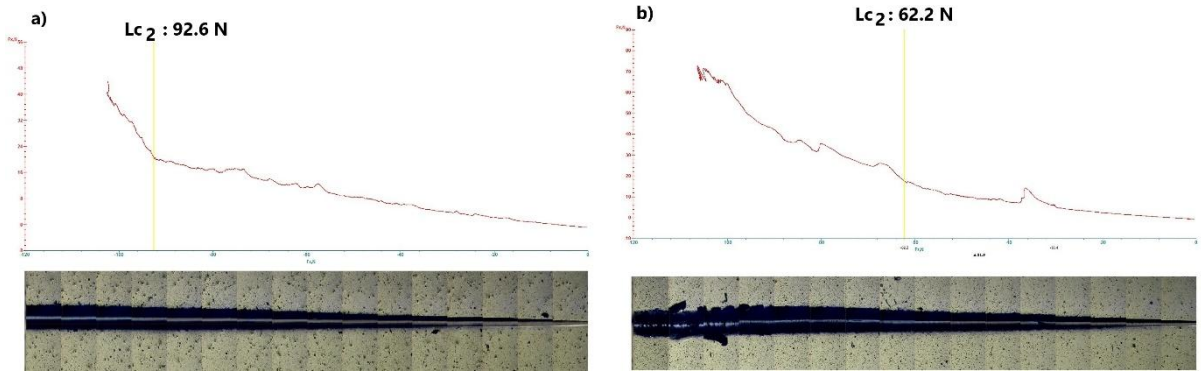


Fig. 5. The graphs of Scratch test on a) Vandis 23- TiN coating and b) Dievar- TiN coating

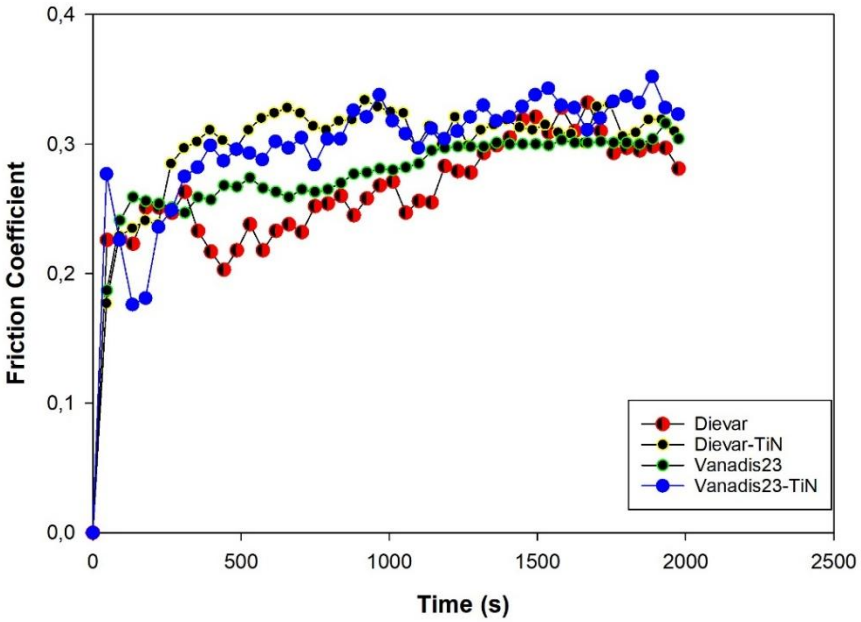


Fig. 6. The friction coefficient graphics of base metals and TiN coated materials.

Fig. 7 illustrates the Scanning Electron Microscope (SEM) micrographs of worn surfaces of Dievar and Vanadis 23 steels, tested under both uncoated and titanium nitride (TiN)-coated conditions, after an impact-sliding wear test. Every row of the figure designates a specific sample condition, while the three columns designate different positions along the wear track: (a) impact area, b) sliding area and c) final contact area.

For the Dievar-base sample (top row), the surface wear is dominated by severe plastic deformation and delamination features, particularly in the impact area, suggesting a strong initial mechanical response to cyclic loading. The wear track becomes progressively smoother towards the final contact area, but there are still recognizable grooves, which suggest continued abrasive interaction. The wear morphology of Vanadis 23-base (second row) is noticeably finer. The surface degradation is less severe than in the case of Dievar, with smaller debris particle size and less frequent microcracking events. This reflects the fact that the higher intrinsic hardness and microstructural stability of Vanadis 23 impart to it greater resistance to repeated mechanical loadings.

Moving to the coated samples, Dievar-TiN surface (third row) shows coating fracture and localized delamination, predominantly in the middle and end regions. Crack patterns spread over the coating layer, which may be attributed to lacking load-carrying capacity or interfacial strength under cyclic impact-sliding loading conditions. There is partial peeling away of the coating in some areas, revealing the substrate below.

In contrast, the Vanadis 23-TiN sample (bottom row) retains a well-intact coating over most of the wear track. Micro-cracks and ploughing scratches are apparent—particularly in the star and mid regions—however, the coating has enhanced adhesion and more regular interaction with the substrate. This enhanced performance can be attributed to the compatibility of the TiN coating with the harder Vanadis 23 matrix, which enhances the load transfer and crack deflection.

Collectively, these scanning electron microscope observations offer deep insight into wear mechanisms active and the influence of substrate nature and coating integrity on tribological performance in complex loading conditions.

Fig. 8 presents SEM images of the worn surfaces of base and TiN-coated samples. In Figure 8A, for the base material-Dievar specimen, there is pronounced abrasive wear with deep grooves and severe surface degradation. The inset, magnified further, exhibits massive plastic deformation and material removal, evidence of a vigorous sliding interaction.

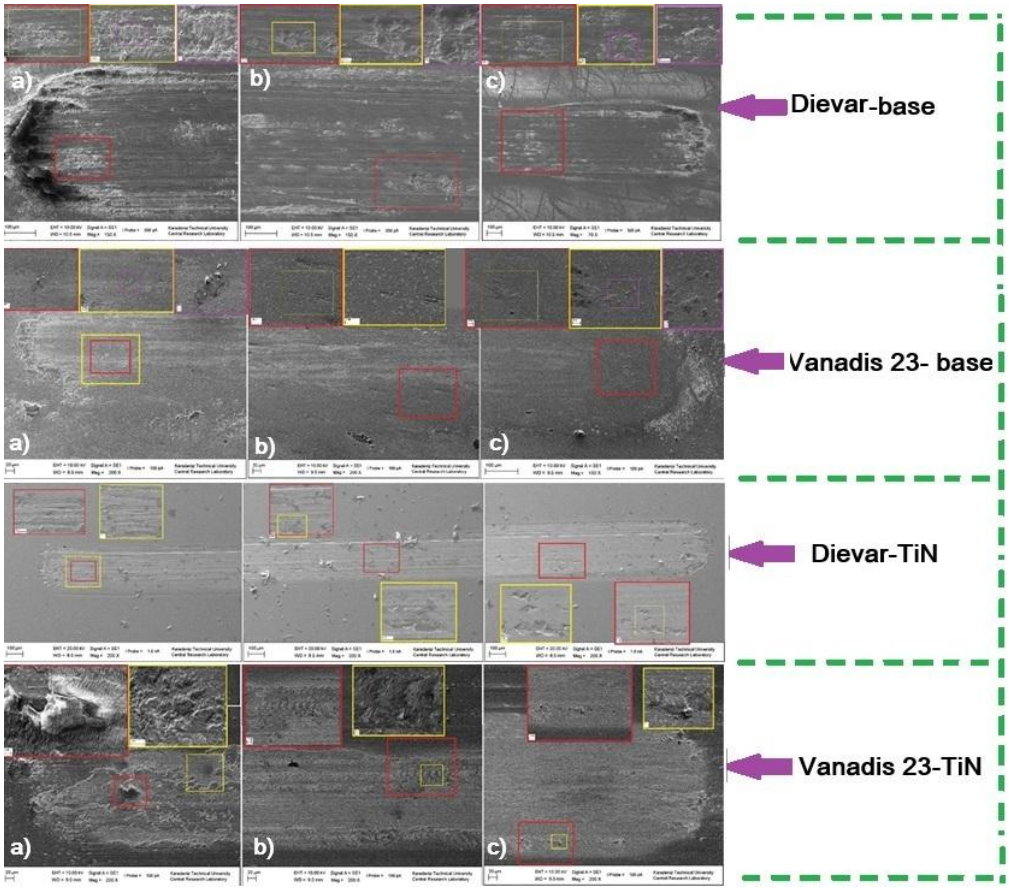


Fig. 7. The SEM images of worn surfaces by impact-sliding test. a) Impact area, b) Sliding area and c) Final contact area

Fig. 8(b) presents the worn surface of the base metal Vanadis 23 sample. In this case, the wear tracks are noticeably more pronounced than those observed in Dievar, and this is due to the greater hardness and wear resistance characteristics of the Vanadis 23 material. Accordingly, evidence of material delamination and micro-cracking is still evident in some localized areas.

Considering the coated samples, Fig. 8(c) (Dievar-TiN) reveals a more uniform wear pattern. The addition of TiN would seem to have had a profound impact on material degradation; however, small grooves can still be discerned.

Last, Fig.8(d) (Vanadis 23-TiN) manages to demonstrate the lowest amount of surface damage out of all of the samples. Wear tracks observed are relatively shallow in nature, and the coated surface seems to have maintained much of its structural integrity.

Fig. 9 illustrates the values of wear rate (mm³/N·m) for base and TiN-coated samples of Dievar and Vanadis 23 steels. As can be seen, the Dievar-base sample has the highest wear rate of all, whereas Vanadis23-base has a much smaller value. When coated with TiN, both materials are seen to significantly reduce their wear rate. The wear rate of Dievar-TiN is significantly less than that of its uncoated equivalent but remains higher than in the TiN-coated Vanadis23 sample. The Vanadis23-TiN sample has the lowest wear rate in this study. These wear behaviors are quantified very nicely by the bar chart to enable a ready comparison between all the conditions that were examined.

Fig. 10 shows the impact-sliding wear rate (mm³/N·m) of Dievar and Vanadis 23 steels in both uncoated and TiN-coated (by CAPVD) conditions. One can see a distinct difference in the wear behavior of the samples. The most pronounced wear rate among all the samples is that of the Dievar-TiN sample, showing a high sensitivity of the coated surface to the combined impact and sliding stresses.

Interestingly, though, the TiN coating affects the two substrate materials differently. On Vanadis 23, the TiN coating causes an increase in the wear rate in its coated compared to its uncoated sample; however, the increase is quite contained. In contrast, Dievar's wear rate rises substantially with TiN coating, indicating potential incompatibility or lack of adhesion performance in dynamic loading conditions for this material–coating combination.

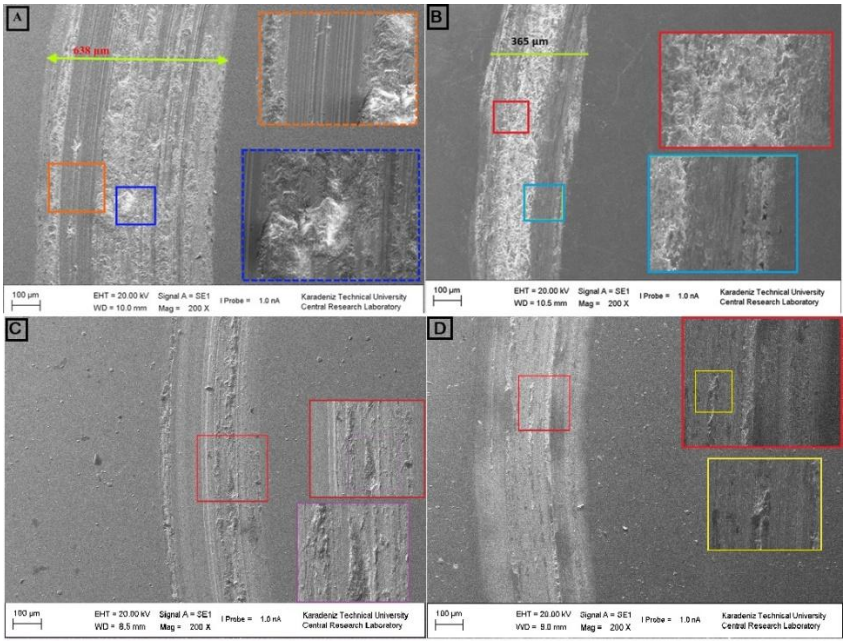


Fig. 8. The SEM images of worn surfaces a) Dievar, b) Vanadis 23, c) Dievar-TiN coating and d) Vanadis 23-TiN coating

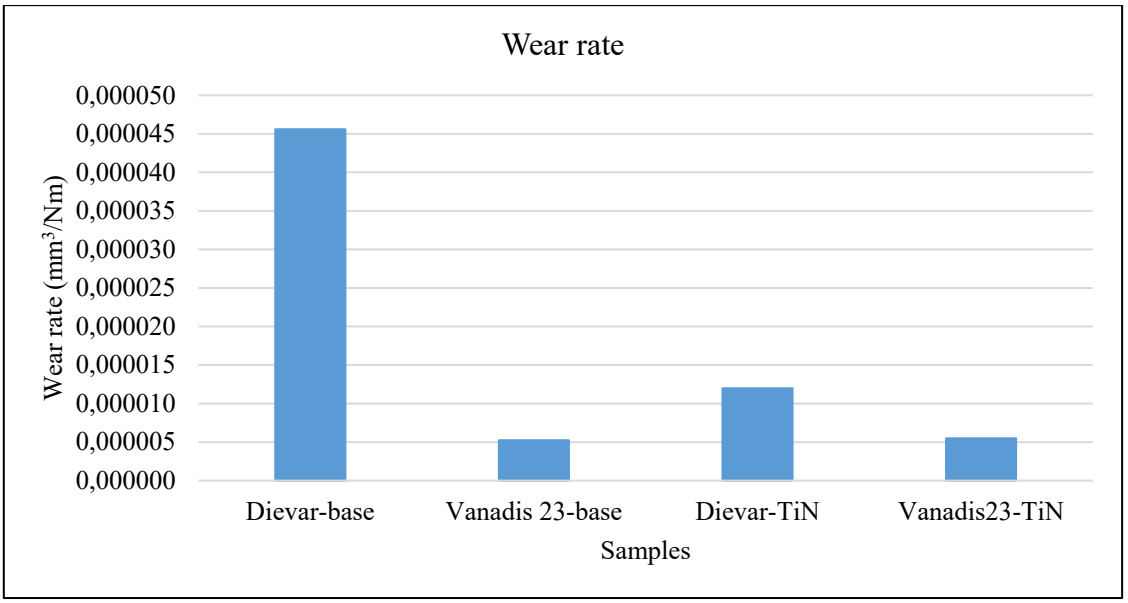


Fig. 9. The wear rate of base and coated metals that is earn by ball-on-disc wear test.

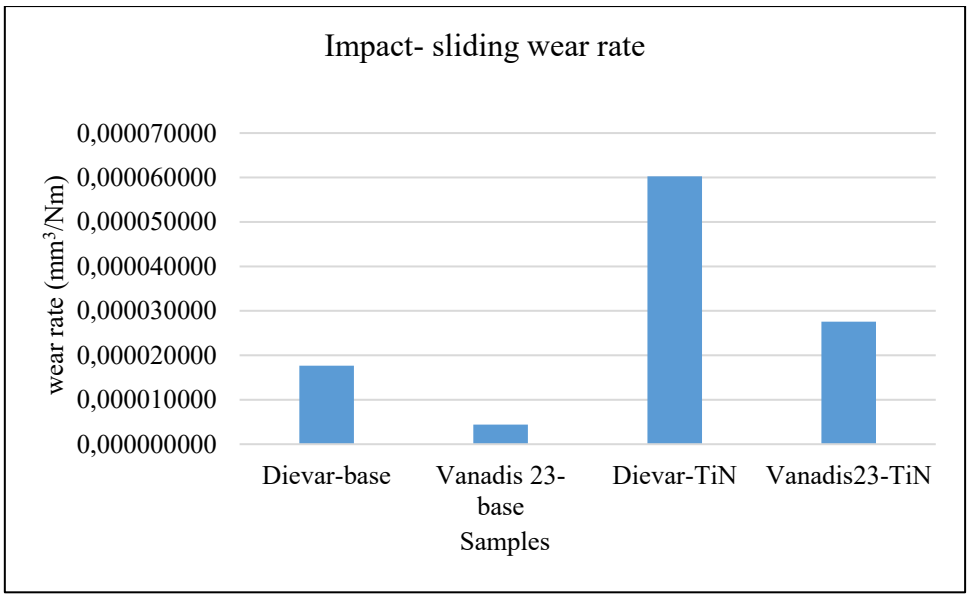


Fig. 10. The wear rate of base and coated metals that is earn by impact sliding test.

4. Conclusions

This work investigated the microstructure, mechanical, and tribological characteristics of CAPVD-deposited TiN films on Vanadis 23 and Dievar steels in a systematic manner. SEM and XRD measurements attested successful crystallite growth of the TiN(200) orientation on both substrates with substrate-dependent morphology. Whereas the Dievar coating possessed a denser and more uniform microstructural content, Vanadis 23 exhibited a more columnar structure with a greater incidence of droplet defects.

Nanoindentation experiments revealed a remarkable surface hardening in both the materials being investigated, Dievar exhibiting a very strong increase. The result suggests that it is possible for the TiN coating to enhance surface properties. However, this benefit was not always transferred to performance enhancement under all circumstances. Scratch testing and wear measurements revealed that Vanadis 23 had much better adhesion and tribological performance than Dievar. Although having a lower hardness increment, Vanadis 23-TiN exhibited high critical load values and low wear rates under sliding and impact-sliding conditions.

These findings suggest that substrate-coating interaction is an equally important determinant of the functional behavior of PVD coatings. While TiN deposition increases hardness in general, the performance under multiplex loading and especially dynamic or impact conditions is very substrate-dependent. The much poorer wear behavior

of Dievar-TiN under impact-sliding conditions is reflective of a suggested mechanical compatibility mismatch and needs further optimization of coating scheme or surface pretreatment.

In conclusion, Vanadis 23 displayed higher overall compatibility with TiN coatings in rigorous tribological environments and consequently established itself as the more durable alternative for high-wear and impact-resistant applications. The work accentuates the requirement to optimize coating-substrate systems not merely based on intrinsic material characteristics but also considering the ambient environment and complexities of loading conditions.

Acknowledgments

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