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# Surface Roughness and Friction Coefficient in IBAD Deposited Tin Hard Coating

*Influence of surface roughness of TiN coatings on friction and wear phenomena was investigated. Wear and friction properties were evaluated by using CSM nanotribometer. Relatively low loads were used during testing, therefore wear depth was less than 20 % of TiN coating thickness. Obtained results show that TiN coatings of higher hardness and lower friction coefficient can be produced by IBAD comparing to TiN coatings deposited by industrial PVD. Scanning electron and atomic force microscopy provide detailed analysis of nanochanges of wear zone morphology.*

***Keywords:*** *surface roughness, friction coefficient, TiN, AFM, nanotribology.*

## 1. INTRODUCTION

Influence of surface roughness on friction coefficient has been studied for a long time. According to Scopus database there are 2614 papers which contain words “roughness” and “friction coefficient” as key words. The number of 160 papers per year in the last three years confirms that a large interest in this subject is still present today.

The important factors that control friction are affected by: kinematics of the surfaces in contact, applied load, environmental conditions, surface texture and material properties [1]. The surface roughness parameter like $R_a$ is used in general to describe a surface. However, such a single roughness parameter, which is the universally recognized and most used international parameter of surface roughness, is not sufficient to describe a functional characteristic like friction [2]. It is possible that two surface textures have the same $R_a$, but their frictional characteristics could be different. Higher friction is observed in the case of longitudinal roughness (asperities’ ridge parallel to the sliding direction) than in the case of transverse roughness (asperities’ ridge orthogonal to the sliding direction) [3].

Both the plowing component of friction and adhesive component of friction vary with grinding angle. Stick-slip motion depends on normal load, grinding angle. During running-in, the surface profile changes significantly due to a smoothing of the asperities by plastic deformation. The solid contact between the asperities of the discs and counterbody contribute significantly to plastic deformation [4].

Very often PVD coatings are significantly harder than the counter surface material and high coating surface roughness will result in a high wear rate of the counter surface and, in general, a high friction coefficient, due to a significant contribution from the ploughing component of friction because protruding surface asperities of the harder coating will abrade the softer counter surface [5].

In this research roughness parameters and friction coefficient of TiN coatings IBAD deposited at near room temperature were evaluated. Hardness of TiN coating is similar to hardness of counter material ($Al_2O_3$) which was used during fretting tests. Complexity of characterization of wear zones was increased because very low load was used. The low load produced small wear effects in nanoscale range (from

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10 to 100 nm) smaller even than measured roughness of ground surface. The depth of wear zones was always smaller than TiN coating thickness.

## 2. MATERIALS AND EXPERIMENT

TiN coatings were deposited in an Ion Beam Assisted Deposition (IBAD) chamber with a base pressure of 1.5 · $10^{-6}$ mbar. The used apparatus consists of a 5 cm Kaufman ion source, 5 kW e-beam evaporator, residual gas analyzer, thickness monitor, and mechanical and cryo pumps. Carburizing steel (0.165 % C, 0.2 % Si, 1.2 % Mn and 1 % Cr) disks were used as substrate material. Cemented steel was used due to its high load bearing capacity. Three substrates with different surface pretreatment were used. Samples in this work are designated according to substrate pretreatment: sample 1 – TiN film on ground substrate; sample 2 – TiN film on fine-ground substrate; sample 3 – TiN film on polished substrate. Prior to deposition substrates were sputter-cleaned by argon ion beam. In order to improve adhesion between TiN layer and base material an interface was made by ion beam mixing atoms of base material and atoms of titanium (Ti) sublayer. The Ti sublayer was deposited keeping operating pressure around 5.6 · $10^{-5}$ mbar. TiN deposition was performed in a mixed Ar and $N_2$ atmosphere with a partial nitrogen pressure between 1.1 and 1.2 · $10^{-5}$ mbar. Total operating pressure was around 7 · $10^{-5}$ mbar. Growing film was bombarded by argon ion beam. Ion energy was 1 KeV, ion current density 53 μA/cm$^2$ and ion incidence angle between 52º and 53º. Titanium was evaporated using power of 720 W, producing condensation rate of 0.2 nm/s. During deposition of both, the Ti sublayer and the TiN coating temperature did not exceed 58 °C.

Friction coefficient was examined by ball-on-block tests without lubrication. The tests were conducted at CSM Nanotribometer with following parameters: counter material – 2 mm $Al_2O_3$ ball with hardness of 2700 HV, movement type – linear reciprocating movement, half amplitude 0.5 mm, total sliding distance 3000 mm, normal load 100 mN and sliding speed 10 mm/s.

Coating hardness was measured using CSM nanohardness tester. Surface roughness and morphology were evaluated by VEECO di CP II atomic force microscope. All images were required in contact mode by etched silicon probe symmetric type. Scanning electron microscopy (SEM) was employed to investigate wear zone morphology.

## 3. RESULTS AND DISCUSSION

The hardness of TiN coatings was between 2601 do 2867 HV, while the modulus of elasticity varied from 444 to 467 GPa.

SEM micrographs of worn surfaces of samples 1, 2 and 3 are shown in Figures 1, 2 and 3 respectively. It can be seen that movement direction of $Al_2O_3$ ball is almost perpendicular to grinding traces. Figure 1 shows that width of wear zone varies along zone length and depends on starting height of grinding traces.

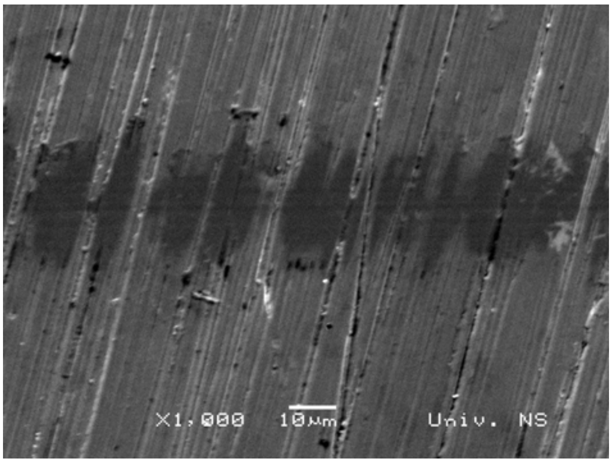


**Figure 1. SEM image of fretting surface in sample 1**

More uniform worn surfaces were developed in case of fine grinded sample (Fig. 2). The most uniform worn traces were observed at polished sample where two separated wear traces can be seen (Fig. 3). Two traces were created due to hysteresis during ball's reciprocating movement. The distance between these two traces amounts only to about 5 μm.

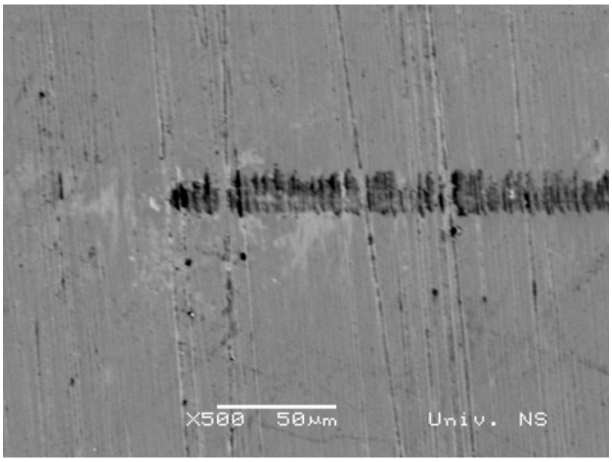


**Figure 2. SEM image of fretting surface in sample 2**

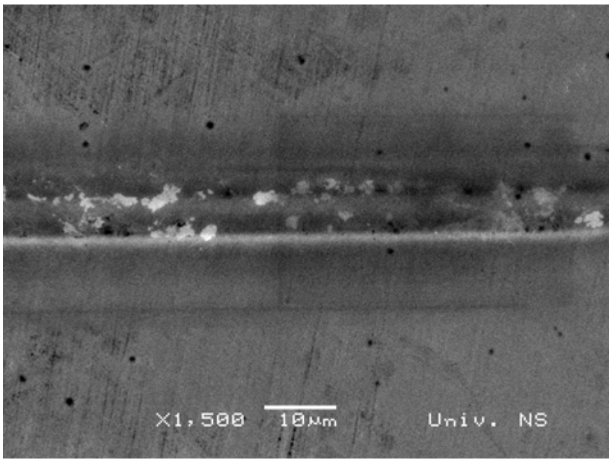


**Figure 3. SEM image of fretting surface in sample 3**

Detailed analysis of worn zones was conducted using atomic force microscopy (AFM), typical result is shown in Figure 4.

AFM gives a possibility to measure accurately width and depth of worn zones, and to acquire bearing ratio and power spectrum for each sample. Some of the acquired parameters are shown in Table 1.

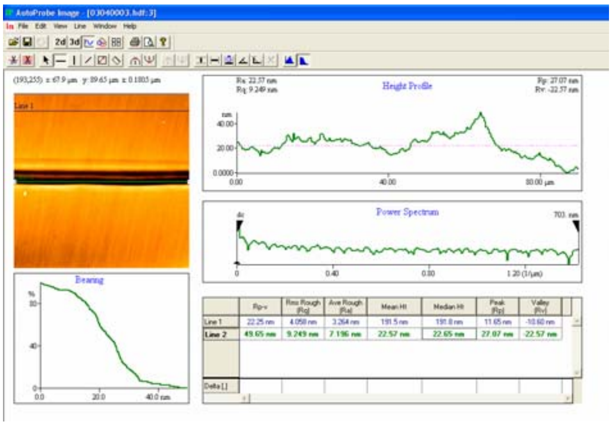


**Figure 4. Typical result of line analysis of worn zone**

**Table 1. Roughness at wear zone**

| Sample | Bearing [nm] | $R_a$ [nm] | | $R_{pv}$ [nm] | |
|---|---|---|---|---|---|
| | | Before fretting | After fretting | Before fretting | After fretting |
| 1 | 140 – 300 | 53 | 23 | 816.3 | 174.9 |
| 2 | 100 – 170 | 25 | 12.3 | 254.85 | 73.76 |
| 3 | 0 – 40 | 3.26 | 7.19 | 72.177 | 49.65 |

In this table an interesting phenomenon can be seen, namely after fretting average roughness $R_a$ in the case of ground and fine ground sample decreases to 50 % of the starting value, while in the case of polished sample it increases by 100 %. This can be explained by the contact phenomena between TiN coating and $Al_2O_3$ ball and by adhesion and ploughing effects.

The ploughing effect can be easily seen at 3D AFM image (Fig. 5). Peaks formed during grinding were partially flattened during fretting, while wear products fell into wear channel between two peaks. The $Al_2O_3$ ball literally jumped over the peaks, therefore several parallel traces of ball's reciprocating movement can be seen.

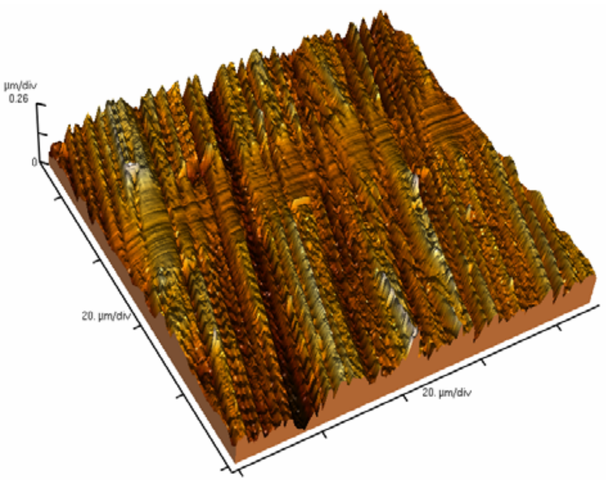


**Figure 5. AFM 3D image of fretting surface in sample 1**

For the same fretting parameters, in the case of fine ground sample a distinguished trace with the rough bottom was formed (Fig. 6).

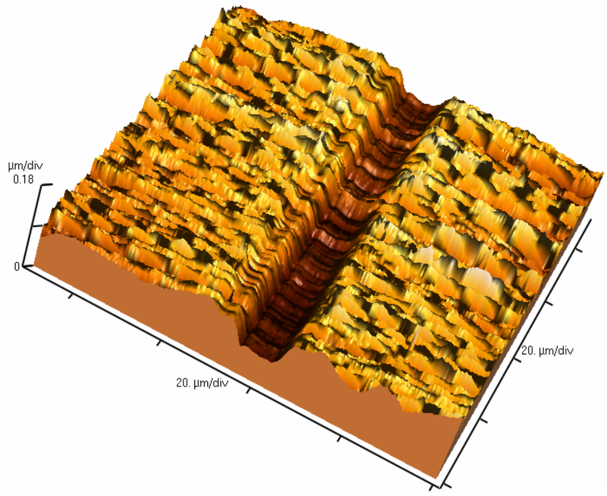


**Figure 6. AFM image of fretting surface in sample 2**

Relatively narrow but deep wear trace was formed in polished sample (Fig. 7). It should be noticed that vertical scale in Figures 5, 6 and 7 is not same, real peak heights are more pronounced.

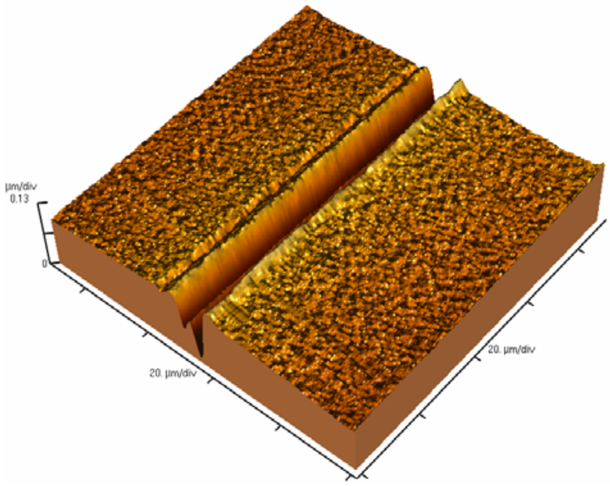


**Figure 7. AFM image of fretting surface in sample 3**

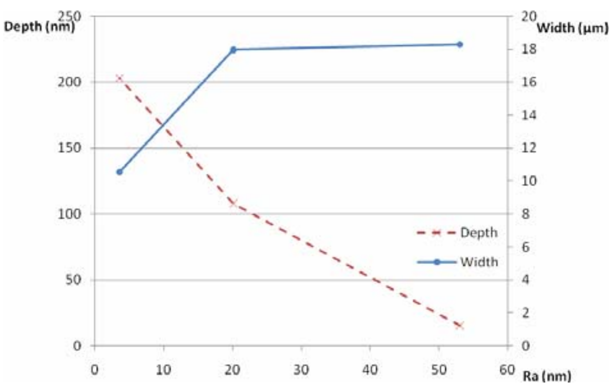


**Figure 8. Depth and width of wear channel vs. surface roughness of TiN coating**

The width of worn channels changes non-linearly with initial surface roughness (Fig. 8). Non-linear dependence on surface roughness is also visible for friction coefficient (Fig. 9). This can be explained by the presence of three processes which occur during sliding friction (Fig. 10). The ratio of three friction processes in summary friction depends on the number and dimension of present asperities.

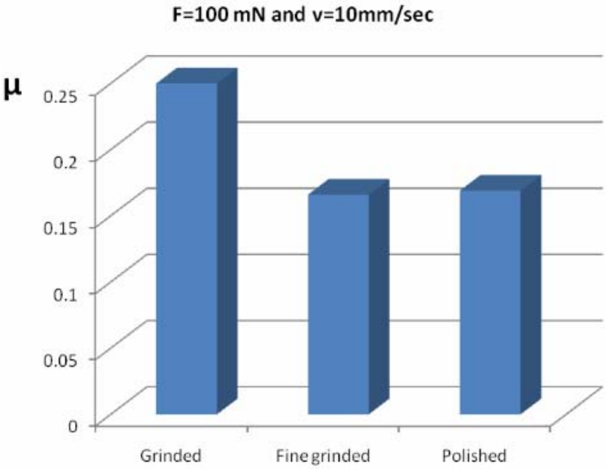


**Figure 9. Friction coefficient of TiN coatings deposited on substrates with different initial roughness**

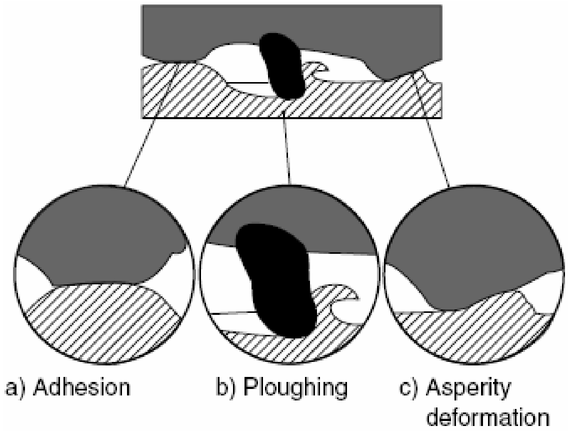


**Figure 10. Sliding friction processes**

## 4. CONCLUSION

Different surface roughness of TiN coatings deposited on ground, fine-ground and polished substrate, results in different friction coefficient during fretting test using $Al_2O_3$ ball as a counter material.

The AFM imaging helps to measure some artifacts with a high precision, as well as to present clearly all surface geometry modifications obtained during fretting tests. The SEM micrographs together with the AFM images of worn surfaces help to determine the nature and intensity of friction and wear phenomena.

The presented results are only a part of conducted investigation which includes varying of fretting velocity and normal force.

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## ХРАПАВОСТ ПОВРШИНЕ И КОЕФИЦИЈЕНТ ТРЕЊА КОД ТВРДИХ ТИТАН-НИТРИДНИХ ПРЕВЛАКА НАНЕТИХ ИБАД ПОСТУПКОМ

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Испитиван је утицај храпавости површине титан-нитридне превлаке на процесе трења и хабања. Величине трења и хабања су одређене помоћу *CSM* нанотрибометра. У испитивањима су коришћена релативно мала оптерећења, па је дубина трага хабања била мања од 20 % дебљине титан-нитридне превлаке. Резултати показују да су титан-нитридне превлаке нанете ИБАД поступком веће тврдоће и да дају мањи коефицијент трења у поређењу са превлакама од истог материјала нанетим индустријским ПВД поступком. Детаљна анализа нанопромена у морфологији зоне хабања извршена је помоћу АФМ и скенирајућег електронског микроскопа.