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SURFACE ROUGHNESS AND FRICTION COEFFICIENT AT IBAD DEPOSITED TiN HARD COATING

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Abstract: 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 load 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 data base there are 2614 papers which contain words “roughness” and “friction coefficient” as key words. Number of 160 papers per year in 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 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 $5.6 \cdot 10^{-5}$ mbar. TiN deposition was performed in a mixed Ar and N₂ atmosphere with a partial nitrogen pressure between 1.1 and $1.2 \cdot 10^{-5}$ mbar. Total operating pressure was around $7 \cdot 10^{-5}$ mbar. Growing film was bombarded by argon ion beam. Ion energy was 1 KeV, ion current density $53 \mu\text{A}/\text{cm}^2$ and ion incidence angle between 52° and 53° . 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 Al₂O₃ 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 typ. Scanning electron microscopy (SEM) was employed to investigate wear zone morphology.

3. RESULTS AND DISCUSSION

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

SEM micrographs of worn surfaces of samples 1 - 3 are shown in figures 1 - 3 respectively. It can be seen that movement direction of Al₂O₃ 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.

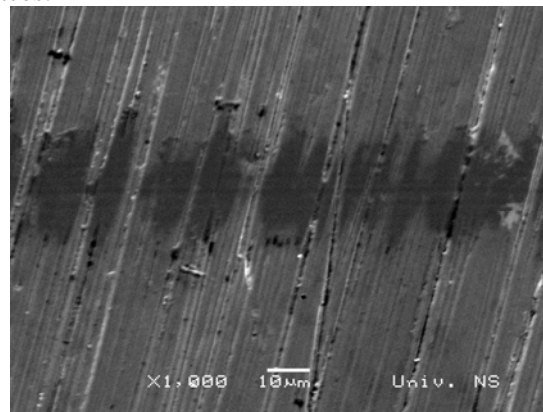


Figure 1. SEM image of fretting surface at sample 1

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

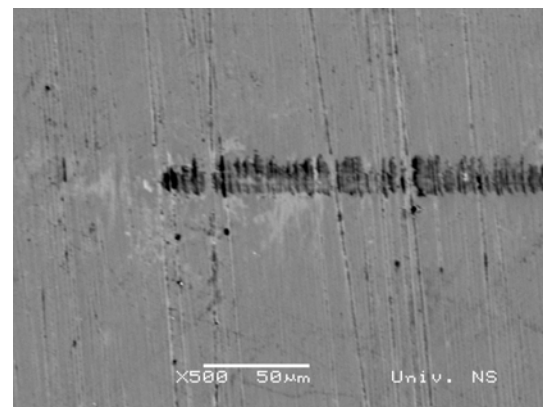


Figure 2. SEM image of fretting surface at sample 2

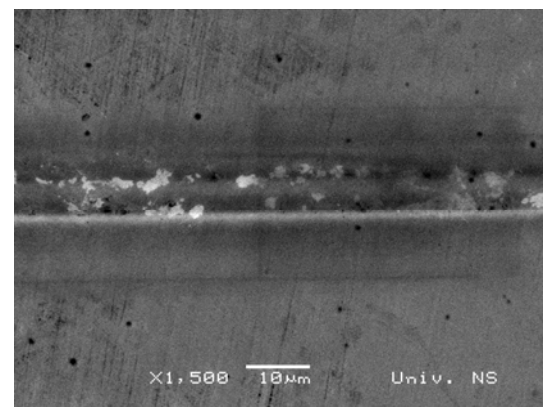
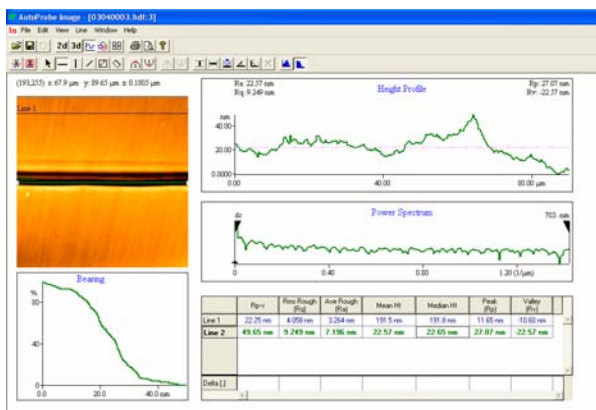


Figure 3. SEM image of fretting surface at sample 3

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 acquired parameters are shown in table 1.

Table 1. Roughness at wear zone

Sample	Bearing (nm)	Ra (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 interesting phenomenon can be seen, namely after fretting average roughness Ra in case of ground and fine ground sample decrease to 50% of starting value, while in case of polished sample increase for 100%. This can be explained by contact phenomena between TiN coating and Al₂O₃ ball and by adhesion and ploughing effects.

Ploughing effect can be easily seen at 3D AFM image (figure 5). Peaks formed during grinding were partially flattened during fretting while wear products fell into wear channel between two peaks. The Al₂O₃ ball literally jumped over the peaks, therefore several parallel traces of ball's reciprocating movement can be seen.

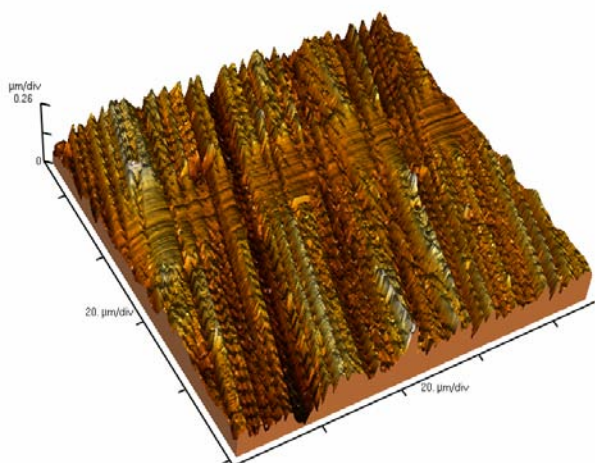


Figure 5. AFM 3D image of fretting surface at sample 1

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

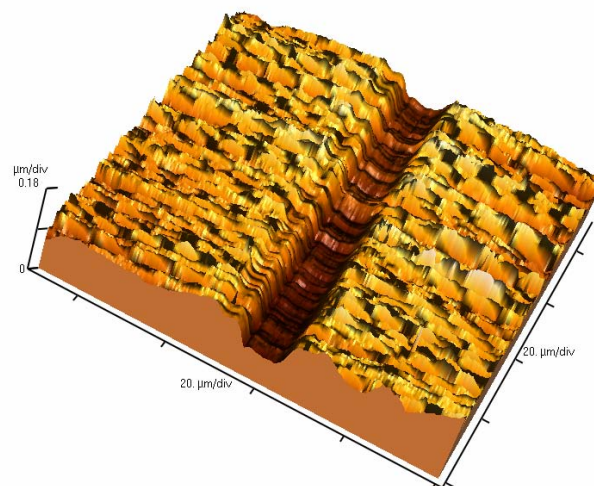


Figure 6. AFM image of fretting surface at sample 2

Relatively narrow however deep wear trace was formed at polished sample (figure 7). It should be noticed that vertical scale in figures 5-7 is not same, real peak heights are more pronounced.

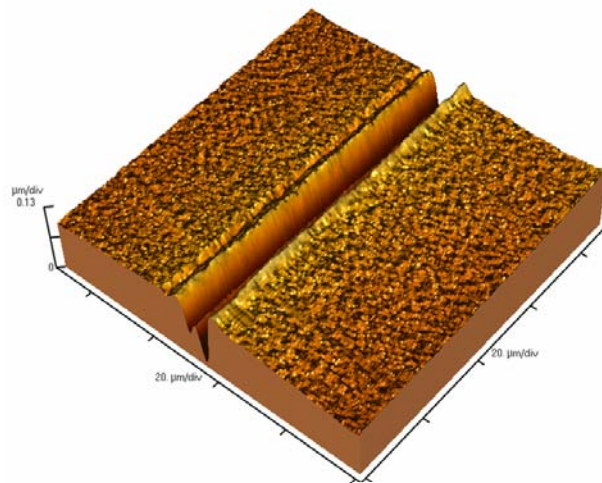


Figure 7. AFM image of fretting surface at sample 3

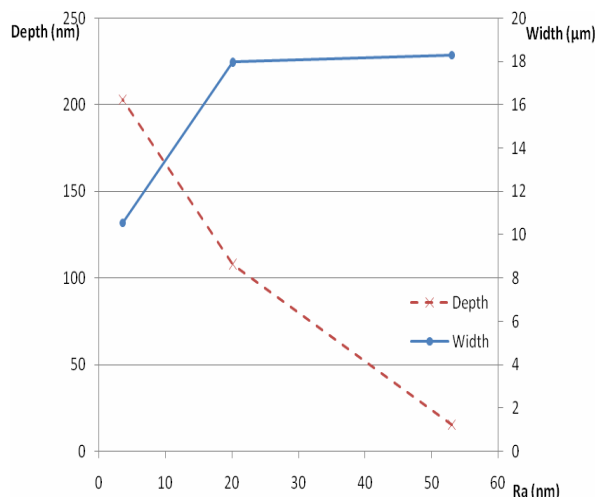


Figure 8. Depth and width of wear channel vs. surface roughness of TiN coating

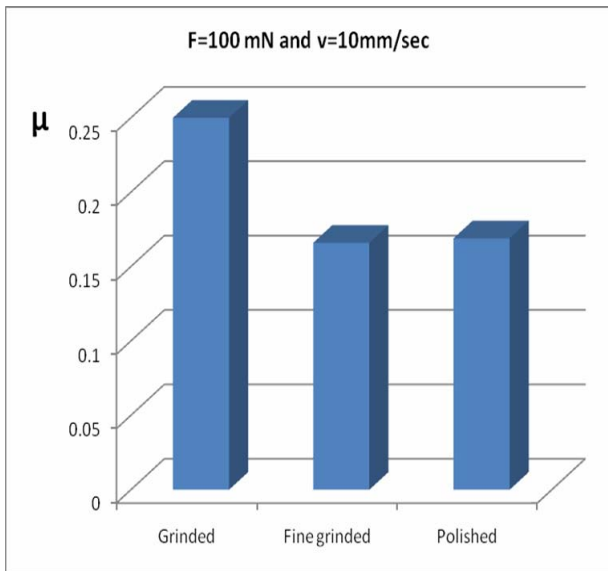


Figure 9. Friction coefficient of TiN coatings deposited at substrates with different initial roughness.

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

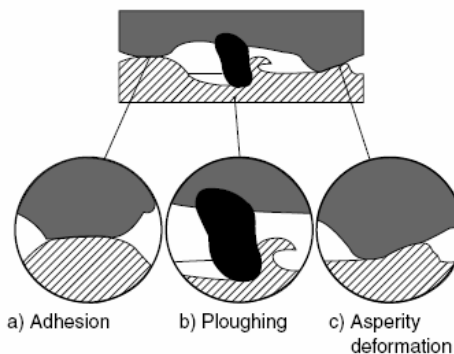


Figure 10. Sliding friction processes

4. CONCLUSION

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

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

Presented results are only the part of conducted investigation which includes varying of fretting velocity and normal force.

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