

## Comparative physical-tribological properties of anti-friction ion-plasma Ti-C-Mo-S coating on VT6 alloy or 20X13 and 40X steels

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**Abstract.** Results of comparative tests mechanical and tribological properties of solid antifriction Ti-C-Mo-S coating, deposited by magnetron-plasma combined sputtering method on substrates of VT6 titanium alloy, 40X and 20X13 hardened steels are provided. Coating is sputtered using the same conditions and technological regimes on substrates of different materials. However, the friction tests results showed significant difference in tribological characteristics of coating depending on type of material used for substrate, first of all by wear-resistance ability. Authors suppose that this is due to difference between physical properties such as composition and structure of substrate materials that determines hardness and coating adhesion to surface.

### 1. Introduction

At the present time it is proved by the results of experimental tests that the optimal variant of antifriction coating producing is a gradient composition construction with relatively smooth change of composition, structure and basic physical properties (hardness, thermal expansion coefficient, shear resistance) from product's basis to outer coating. Developers use different technological methods to produce such compositions. For example, in article [1] pre-hardening of steel substrate by ion nitriding prior to magnetron deposition of hard Ti-N coating and final magnetron deposition of outer antifriction MoS<sub>2</sub> layer is performed. In article [2] leveling of both structure and properties between solid sublayer TiN and outer soft antifriction layer MoS<sub>2</sub> is performed by forming intermediate combined structure of TiN+MoS<sub>2</sub>, and simultaneously by magnetron sputtering of Ti and MoS<sub>2</sub> cathodes. Combined structure layers technological method is provided in article [3]: solid anti-frictional CrN, TiN, TiCN layer is sputtered by means of magnetron sputtering outer MoST<sup>TM</sup> layer that poses as a MoS<sub>2</sub> and titanium composition. Outer layer is characterized by nanocrystal or amorphous condition depending on titanium content in it and has high hardness, wear-resistance and moisture-resistance compare to fine MoS<sub>2</sub>.



Over the last years tribological coating of combined structure with the use of different components heighten interest of developers and scientific researchers. For example, in article [4] magnetron a-C coating, doped Mo is subsidized by magnetron. It is found out that depending on Mo content the physic-tribological properties of that coating may be materially changed. Similar researches using magnetron nanocomposited nc-TiC/a-C (nc – nanocrystal phase, a – amorphous phase) coating are conducted by the authors [5]. Instant connection between physical and tribological characteristics of that coating, namely that frictional coefficient and wear-resistance both depend on the ratio between hardness and Joung's efficient module is established.

The tribological Ti-C-Mo-S solid coating of combined structure is developed by Siberian Physical-Technical Institute of National Research Tomsk State University. Magnetron-plasma synthesis method of that coating for titanium alloys with gradient-compositional structure is patented as invention [6]. It is needed to estimate the possibility of coating for sliding friction pairs to practical using. In the present paper comparative studies results of physical-tribological properties of that coating on titanium alloy and hardened steels are presented.

## **2. Materials and methods of experiment**

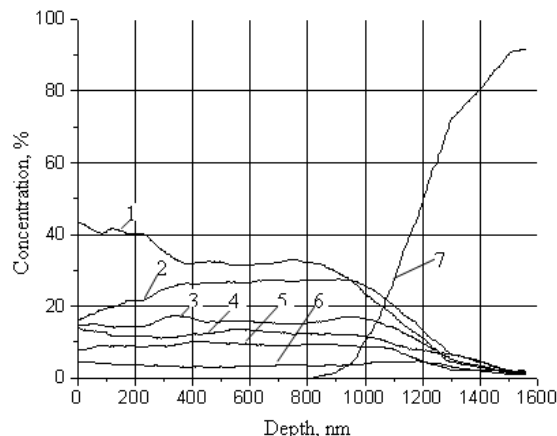
Research is carried out on titanium alloy VT6 (Ti – base, Al – 5.5-7.0%, V – 4.2-6.0%) and on industrially widely applied engineering 40X steel and corrosion-resistant 20X13 steel. These types of steels differ from each other compositionally by its chemical structure, primarily, by chrome content - approximately 1% in 40X and approximately 13% in 20X13. The hardness this of this steels are HRC40-42. VT6 alloy's hardness is about HRC36. Samples of material are produced in the shape of discs with 40-50 mm diameter and 4 mm thickness. Discs are grinded on abrasive disks with supply of quenching water and emery papers use. Then they are polished with use of diamond pastes and chrome oxide aqueous suspension. Roughness of polished samples (Ra) is controlled by profilograph model 296 and does not exceed 0.1  $\mu\text{m}$ . Ti-C-Mo-S coating deposition is performed on KOMPOSIT-3 hybrid facility simultaneously for all three types of samples (in one load) during their continues rotation in regard to sputtering cathode targets. In forming of gradient-composite coating structure ion-plasma pre-doping technique of surface layer by Ti-C-Mo-S atoms set and PINK plasma generator assisting influence are used [7]. Technological sputtering process under of two multiple-component self-propagating high-temperature synthesis (SHS) targets Ti-C-Mo-S in argon atmosphere is performed. Magnetron discharge power for each target is approximately 1.0 kW. Bias potential is 200 V, coating sputtering time – 60 minutes. Hardness of doped layer and coating measurements are made on «CSEM Nano Hardness Tester» under 100÷250 mN load. Adhesion characteristics of coating (adhesion to surface) are conducted by «CSEM Micro Scratch Tester». Doped surface layer and coating component analysis is done on «Schuna-2» using auger spectral analysis. Friction tests are done on «CSEM High-Temperature Tribometer» using the pin-on-disk scheme. In the function of indenter HRC 62-63 steel balls are used. Indenter loading for all cases is 1 N. Counter bodies sliding velocity are within 0.5-0.6 m/s. Friction coefficient value is fixed depending on number of disk turns. Coating wear rate for surfaces of different materials comparison is realized immediately after friction coefficient increasing up to 0.2 and higher. Wear volume is defined by calculation of averaged in nine measures cross-sectional scans of wear track area using a surface profilometer «Micro Measure 3D Station». Friction tracks as well as areas around Rockwell prints on coated discs are examined using optical (on IMC and METAM RV-21) and electron scanning «Tescan Vega 3» microscopes.

## **3. Experimental investigations results and their consideration**

Doped underlayer and coating hardness measurements showed that combined method of ion-plasma pre-doping and consequential Ti-C-Mo-S deposition allows relatively smooth hardness transition from surface to underlayer and then to coating for all cases. These values have insignificant difference for all three materials and are about 4-5 GPa, 6-7 GPa and 7-9 GPa. Doping elements depth dispatching comparative analysis using three types of materials showed that 40X steel has the highest one and approximately 500 nm [8] (figure 1). It is obvious that this is due to the difference between chemical

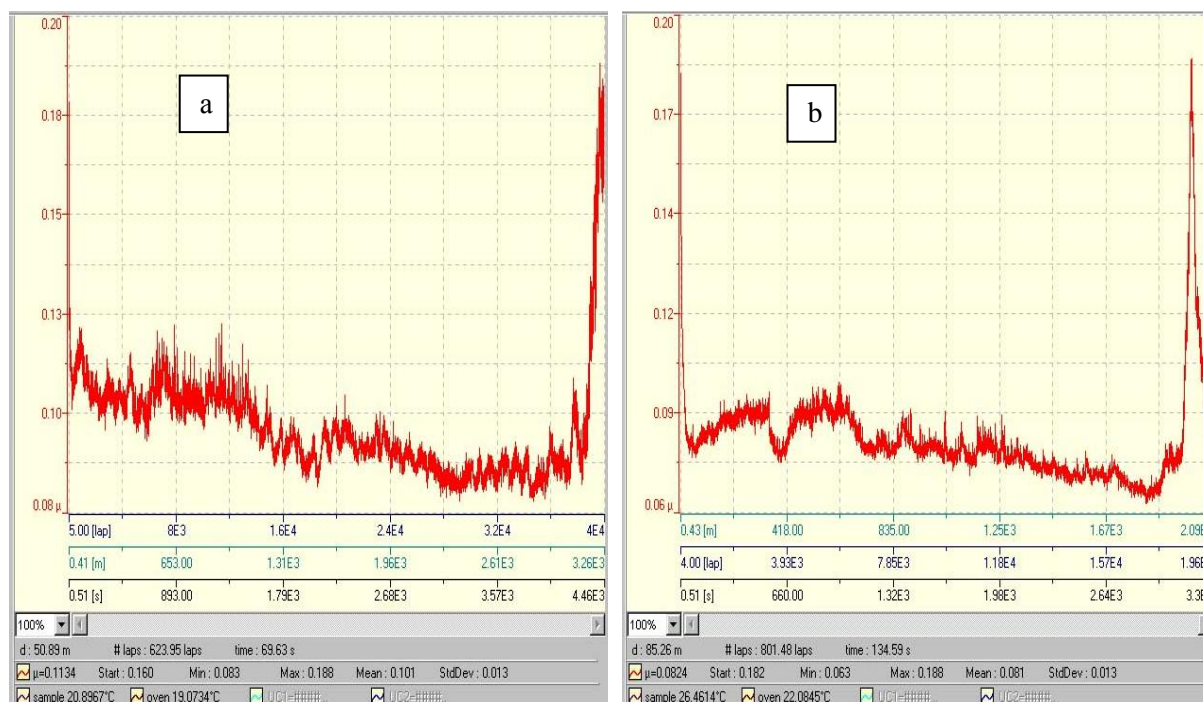
structures of surfaces. Titanium in VT6 as well as chrome in 20X13 has high reactive capacity to form chemical compounds that limits diffusion depths during doping.

Ti-C-Mo-S coating friction tests on surfaces for two types of steels showed that 40X steel has friction coefficient is approximately 0.11 from the beginning, and right after 13000-14000 disc round  $\mu$  decreased to 0.09. Friction coefficient is kept this value up to 38000 rounds (about 3000 meters of sliding path), then increased as consequence of critical coating wearout (figure 2a).

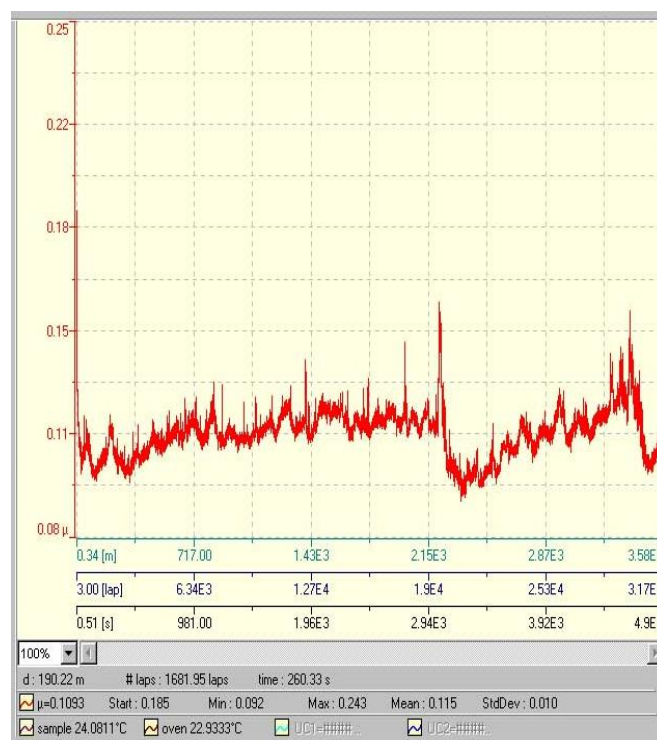


**Figure 1.** Elements allocation by depth of 40X sample after ion-plasma doping and magnetron Ti-C-Mo-S coating sputtering in argon atmosphere: 1-S; 2-Ti; 3-C; 4-Ni; 5-Mo; 6-O; 7-Fe. Accelerating voltage using doping is 1000 V; accelerating voltage using coating sputtering – 200 V.

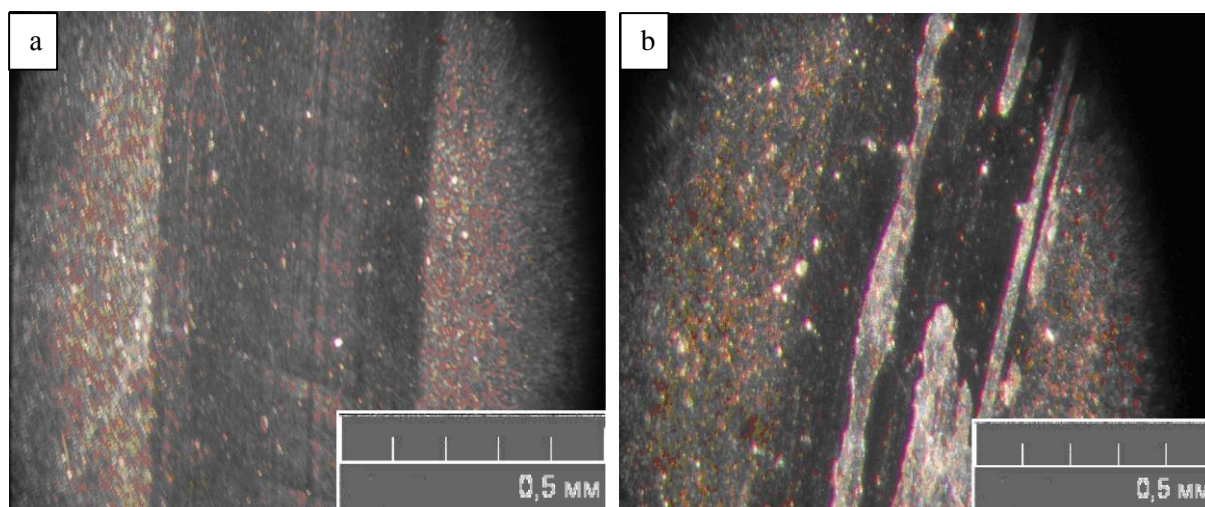
During the same frictional tests for coating on 20X13 steel, it is established that  $\mu$  is decreased from 0.09 to 0.07 and kept this value only to 18000 rounds of disc. Then  $\mu$  highly increased due to coating wear (figure 2b). VT6 coating is withstood 31500 round with average value of  $\mu$  equal to 0.115 (figure 3). Conducted optical tests of wear tracks revealed the significant difference in coating failure pattern on 40X (figure 4a) in comparison to 20X13 (figure 4b). From figure 4b it is seen on 20X13 coating damage as a result of friction contact to counter body appears as form of small flakes. Coating is scaled off by flakes prolonged to track's direction. On VT6 coating damage character is similar to the one that is also observed on 40X.



**Figure 2.** Friction coefficient value changings depending on number of sample-disc rounds with Ti-C-Mo-S coating, sputtered on 40X(a) and 20X13(b) steels.

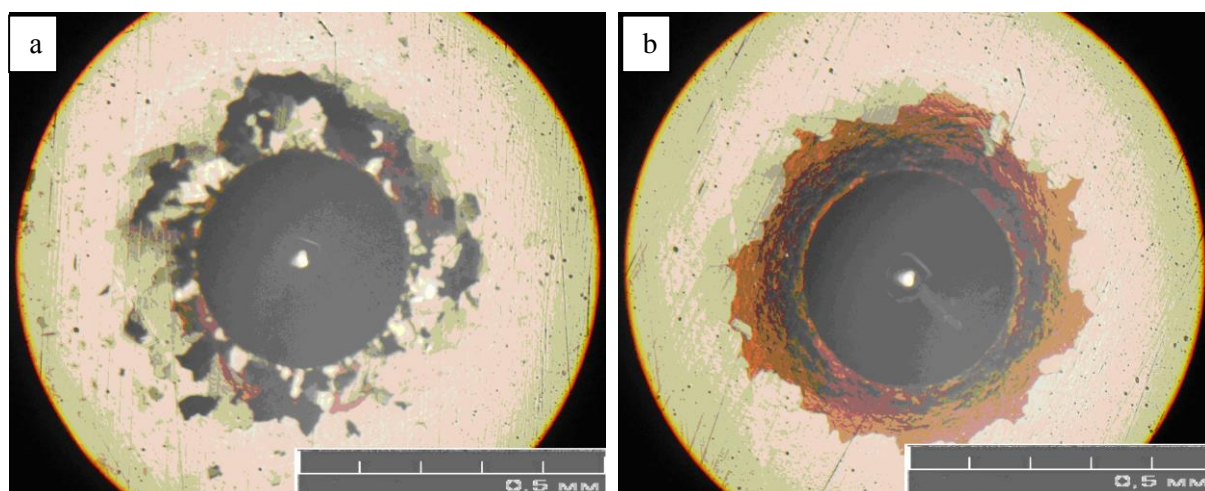


**Figure 3.** Friction coefficient value changings depending on number of sample-disc rounds with Ti-C-Mo-S coating, sputtered on titanium alloy VT6.



**Figure 4.** Ti-C-Mo-S coating damage character on wear track sputtered on layer of 40X(a) and 20X13(b) steels. Optical microscopy, IMC device.

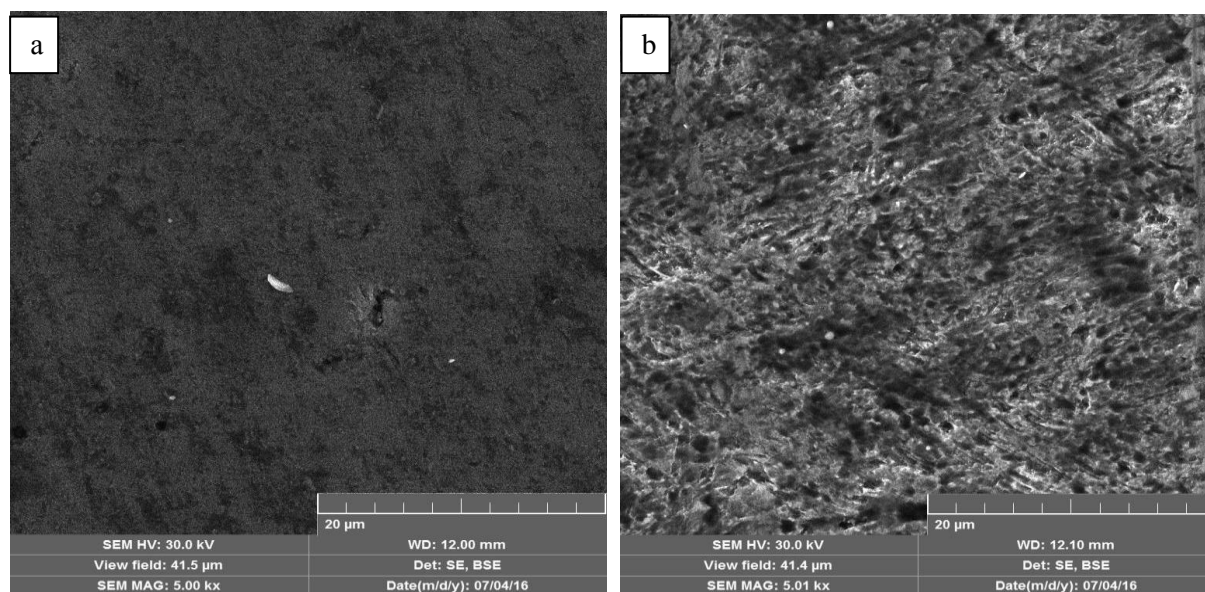
Rockwell prints optical analysis after 4% nitric acid in ethanol etching showed significant difference in etching character of area around print for 20X13 in comparison to 40X (figure 5). According to almost identical coating scaling off character for both types of steel strongly marked difference of area livery bordered to prints (without coating), may evidence of chemical composition and their doped layer significant differences.



**Figure 5.** Etched area view around Rockwell's prints for 40X(a) and 20X13(b) steels with Ti-C-Mo-S coating. Optical microscopy by METAM RV-21.

It is revealed by electronic scanning microscopy the significant difference in observed steels initial structure (figure 6).





**Figure 6.** Microscopic structure appearance of 40X(a) and 20X13(b) steels by electron scanning microscope «Tescan Vega 3».

The wear density of Ti-C-Mo-S coating comparative evaluation by averaged crosscut area of wear tracks showed that 40X has approximately  $3.3 \mu\text{m}^2$  per 1000 rounds, for VT6 this value is equal to  $7.65 \mu\text{m}^2$  and for 20X13 –  $12 \mu\text{m}^2$  per 1000 rounds.

### Conclusion

Ti-C-Mo-S coating frictional tests proved the significant difference of its wear-resistance depending on substrate material. The most significant difference among coating life value is fixed in comparison to low-alloyed 40X steel, where wear-resistance is the highest and high-alloyed 20X13 steel. Authors suggest that it is determined by difference of such physical properties as surface material chemical structure and coating adhesion to surface.

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