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TRIBOLOGICAL RESEARCH OF THE TRIBOLOGICAL PAIRS UNDER VACUUM CONDITIONS

1. Introduction

Development of laboratory test equipment for tribology science area is closely linked with the development of friction and wear mechanisms theories. Within the grant projects in tribological laboratory an experimental test was developed for tribometer device which allows the microscopic and submicroscopic examination of friction and wear in vacuum environments. Acquired knowledge of present research on the adhesive surfaces in high vacuum environments enables better describing and understanding of the processes going on the surfaces of components working in the specific conditions of high vacuum. In the used device samples were tested by using the principle of "Ball On Disk." Progressive nanocrystaline PVD coatings represent revolutionary solution of hard and super hard wear resistant surfaces. Tested DLC coating can be widely used for high quality machine components like: medical devices, cutting tools, aerospace components etc. Diamond-like carbon (DLC) is a metastable form of amorphous carbon containing a significant fraction of sp. bonds. It can have high mechanical hardness, chemical inertness, and optical transparency smooth surface and low friction behavior.

2. Vacuum

With increasing requirements for quality, durability, safety components, as well as whole plants, there is a need to introduce new technologies to industry, which make it possible to meet those requirements. This is also valid for the use of vacuum and vacuum technology. Today, the vacuum is not only associated with space exploration, but slowly gets into daily life, as shown in picture 1.

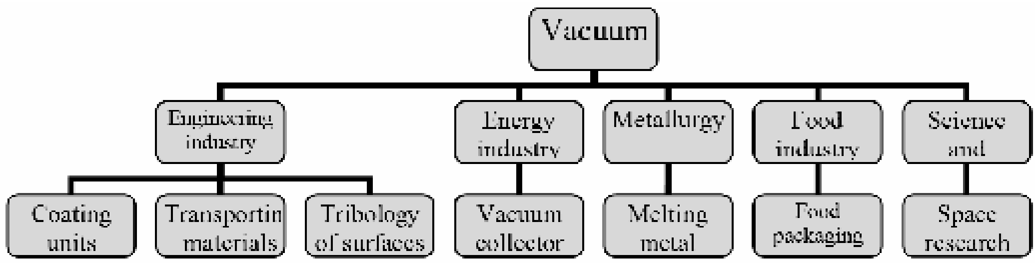


Fig. 1 – A spectrum of practical importance of vacuum in the industry [1]

3. Vacuum tribometer device

Studies of friction, wear and lubrication under vacuum can be simply classified into the two following groups:

- fundamental studies of wear mechanisms, friction and lubrication, e.g. surface film formation, often involving nascent surface;
- wear, friction and lubrication of materials for space applications [2].

A tribometer for tests under vacuum conditions consist of a vacuum chamber which contains the dynamic contact and surrounding ancillary equipment such as vacuum pumps (Turbopack) and drive system. A schematic illustration of tribometer for vacuum operation is shown in Figure 2. There is a one point contact between the rotating ball and plane sample, by using „Ball on disc" method.

Construction equipment allows examinations of friction pairs in environment of the pressure up to $p = 10^{-5}$ Pa. Operation requires keeping and maintaining a high degree of purity, not only of the environment but also the samples themselves. Figure.3. shows the detail view to chamber of equipment. From these figures the principle and the location of individual components is clearly seen followed by scheme of operation.

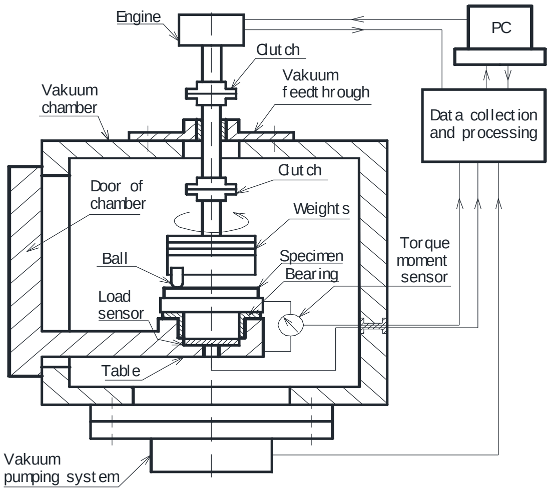


Fig. 2 – Schematic illustration of Vacuum tribometer device

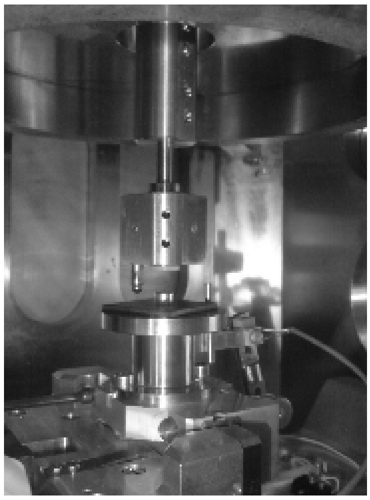


Fig. 3 – Detail view into equipment chamber

The shaft driving the dynamic contact passes through the wall of the vacuum chamber via a seal - vacuum feedthrough to the servo-motor. The servo motor is located in the atmospheric environment and the torque is transmitted through the vacuum feedthrough into the vacuum chamber.

The rotating shaft is connected with a loading head with a support of a special linear bearing. This transmits the torque and allows a vertical movement of the head along the shaft in the direction of the *z*-axis at the same time. There is a normal force F_N acting in the direction of the *z*-axis which might be regulated by the change of the weight of the loading head. A pin with a ball fixed on the end is connected with loading head. In the described construction arrangement the friction force is generated by the friction pair created by ball and tested coated disc. The rotating ball is being pushed against the stationary plane sample fixed to the holder. The value of the friction force F_T or friction moment M_T is determined by strain gage measurements applied on flat spring deformation. The values of the friction coefficient are calculated from the known F_T and F_N.

4. Samples preparation

The tested coating was applied on stainless steel of 2 mm thickness. Double coating CROMVIc$^{2®}$ with nanogradient structure was deposited by using PACVD (Plasma Assisted Chemical Vapor Deposition) and reaches thickness about 1 - 5 µm. SEM view of DLC coating is shown in Figure 4 [3].

Quality of the DLC coated surface was tested and is represented by roughness value *R*a between 0,08 - 0,12 µm, *R*z = 1,2 až 1,9 µm and hardness of about 700 HV. Sliding pair consists of bearing steel ball, SiC and WC with 3,175 mm diameter, and plane sample with 30 mm edge of square shape (Fig. 5).

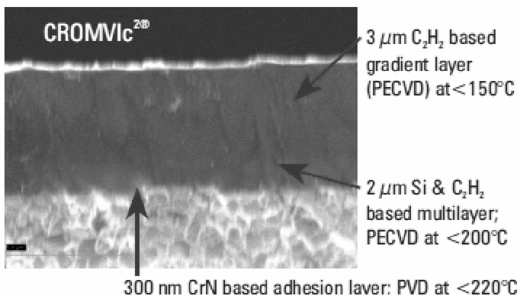


Fig. 4 – SEM view of DLC coating [3]

Fig. 5 – Examined sample coated with CROMVIc^2

5. Methodology for estimation of the tribological properties

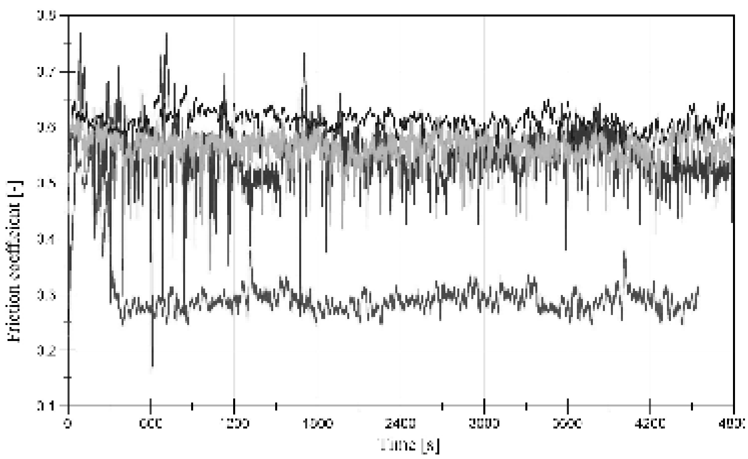
Methodology used for measurements was the same for all samples. The friction coefficient time dependence was examined under condition of low and high vacuum. For the objective comparison, coefficient of friction under normal atmospheric conditions was measured. Initial level of low vacuum was set from $1{,}0 \times 10^{-1}$ Pa to $5{,}0 \times 10^{-3}$ Pa and during the experiment value of high vacuum $5{,}6 \times 10^{-4}$ Pa was reached. The experimental time was set to 80 minutes, the applied load was F_N = 1N, and constant sliding speed v = 0,02 m.s^{-1}. The diameter of tribological track was 22 mm, sliding trajectory length of each sample was set to 100 meters.

6. Results

Experimental measurements were performed according to the methodology described above and representative values are graphically elaborated in Fig. 6 to 8.

Uncoated surface of disc and ball from bearing steel

From results analysis we can state that for each of examined pairs, differences between friction coefficient values measured under atmospheric conditions and in low vacuum, were discovered. It is clear from comparison of each sample that the friction pairs worked in high vacuum show 2 times higher friction coefficient values. Measurement also confirmed that for these types of thin coatings and under given conditions both the high friction coefficient values and the specific instability of friction process are characteristic. This instability is represented by large dispersion of measured values. At the end of experiment the average friction coefficient was 0,6. We can assume that friction coefficients tend to be more unstable in a vacuum than in open air since as soon as a protective oxide is removed by wear. The friction coefficient of most metals rises rapidly and becomes very large. From analysis of friction pair worked under atmospheric conditions, we can see stable tribological process with relatively small value of dispersion.



Where:
mi – coefficient of friction,
B – second tested sample,
1, 2, 3, – low pressure values 10^{-1} Pa, 10^{-2} Pa, 10^{-3} Pa,
ATM – atmospherical condition

Fig. 6 – The coefficient of friction as a function of time for uncoated surface of disc (17241) and ball from bearing steel (14109)

Apparently it's caused by presence of gas molecules adsorbate thin layer, and also by rapidly in few milliseconds regenerated oxide layer. Average friction coefficient value reached 0,25.

DLC coating surface of disc and SiC ball

The tendency of the friction coefficient curves for samples with double coating CROMVIc2® (5 and 6) - and also according to the level of the vacuum reached- are displayed on the Fig. 7.

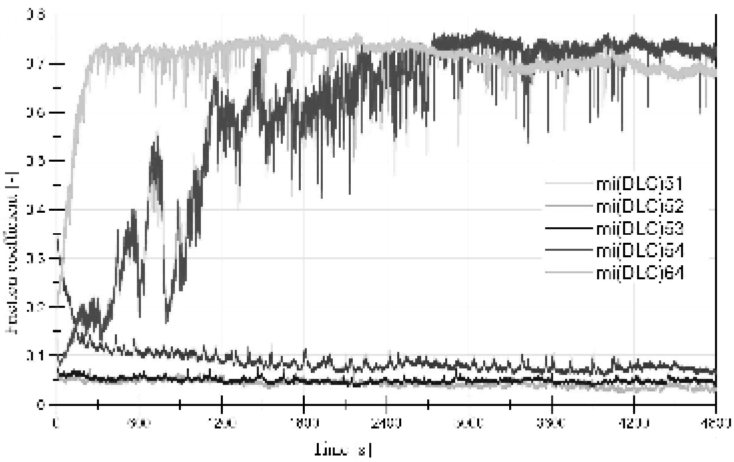


Fig. 7 – The coefficient of friction as a function of the time for DLC coated surface and SiC ball

By the 10^{-1}Pa value of pressure is possible to observe rapid decline of the friction coefficient from value of 0,35 to 0,12. This was probably caused by roughness alignment or by wear out of bounded oxides from the surface of the sample. The friction coefficient is after that phase stabilized with value of ~ 0,08. With the further decrease of the pressure to 10^{-2} Pa or 10^{-3} Pa the coefficient stabilizes around the value of ~ 0,04. Another change which is characterized by the progressive increase of the friction coefficient to the value of ~ 0,74 was caused by the achievement of a high vacuum level of 10^{-4} Pa. There is no DLC coating abrasion visible in both cases (Fig. 11).

DLC coating surface and WC ball

The coefficient of friction as a function of the time with WC ball sliding on DLC coating CROMVIc2® was examined. From results analysis (Fig. 8) we can state, that for each examined friction pair differences between friction coefficient values measured under ordinary atmospheric conditions and in vacuum were discovered. It is clear from comparison of each sample that the friction pairs worked under low vacuum show 4 times lower friction coefficient values than pairs worked under atmospheric conditions. The friction coefficient of DLC coating was in the range from 0,04 to 0,07 as shown in figure 8. The coefficient of friction was in the range of 0,14 to 0,18 for high vacuum and a higher value of 0,22 to 0,25.of friction coefficient on air was observed.

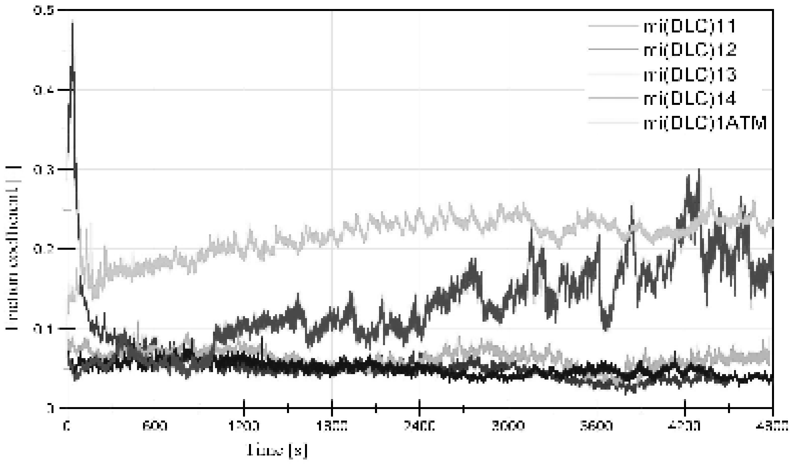


Fig. 8 – The coefficient of friction as a function of time for the friction pair DLC coated steel surface and WC ball

Evaluation of surface topography

For better understanding of tribological processes – specifically wear – it is appropriate to undertake an evaluation of a topology of coating. Wear rate evaluation through the use of friction track width was done by stereomicroscope Nikon AZ100 and AFM microscope SOLVER NEXT.

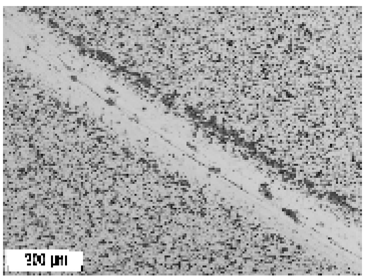


Fig. 9 – The microscopic image of worn surface for DLC coating CROMVIc2®

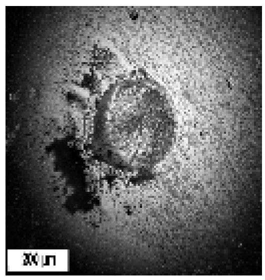


Fig. 10 – The microscopic image of worn surface for WC ball

On the Fig. 9 it is possible to observe a tribological trace created during the test with DLC coating. The wear trace is nearly 200µm wide. Because of its small size the depth of the trace could not be evaluated by the stereomicroscope. There is also no coating abrasion created during the testing. For illustration the Fig. 10 shows the coating of WC ball after completed tests. The abrasion of the ball coating is more significant as in the case of the plane sample. There was also progressive displacement of the ball´s material to the edge of the ball´s abrasion area during the testing.

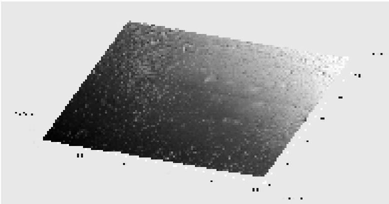


Fig. 11 – 3D image of worn surface for DLC coating CROMVIc2®

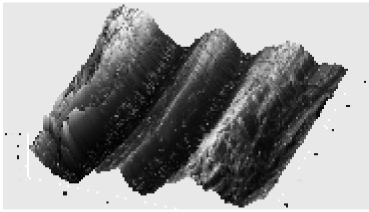


Fig. 12 – 3D image of worn surface for uncoated surface

Figure 11 shows 3D image of unworn surface for DLC coating CROMVIc2®and figure 12 shows 3D image of worn uncoated surface

7. Discussion

The friction behavior of hard coatings in vacuum can be explained by formation of low shear strength microfilms on the hard coating or on the asperity tips of the coatings and reduction in the real contact. The formation of a hydrocarbon-rich microfilm, or graphite, on the hard coating can be explanation for very low coefficient of friction reported for ceramic slider sliding on diamond-like coatings [4].

8. Conclusion

After the carried out investigations, the following conclusions can be drawn:

1. Friction pairs (DLC coating surface and WC ball) worked under low vacuum reached during the tribological tests 4 times lower friction coefficient values than pairs worked under atmospheric conditions.
2. DLC coatings represent new solution for hard and super hard wear resistant surfaces.
3. A transferred layer is often formed on steel surface when it slides over a diamond-like coating and the process of layer formation has a crucial influence on the friction and wear.

Acknowledgement

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Reference

1. Vidiečan J. and Bronček J. and Radek N.: “Design of the test system working in high vacuum”, Terotechnologia 2011, p.p. 200-205 (2011). PL ISSN 1897-2683.
2. Stachowiak G.W., and Batchelor A.W., and Stachowiak G.B.: “Experimental methods in tribology”, p.p. 36 (2004). Vol.44, ISBN 0-444-51589-5.
3. http://platit.com/coatings-structures/dlc-coating?page=0%2C2
4. Holmberg, K., and Matthews, A.: “Coatings tribology”, p.p. 119 (1998). ISBN 0 444 888 705.
5. Vidiečan J. Experimentálne hodnotenie tribologických dvojíc v podmienkach vysokého vákua“, PhD Thesis, University of Zilina, Supervised by M. Dzimko and J. Bronček, Žilina, August 2012.

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