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Short Communication

Tribological Tests of Modern Coatings

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During operation of machines their moving parts have rotating and translating motion. The motion between two surfaces is accompanied by wear. Hard wear-resistant coatings based on Cr have been used to increase wear resistance of these parts. Methods for determining the tribological properties of surfaces can be categorized according to the type of relative movement of the tested material and the applied bodies and the method of contact and his geometry. One of the methods most frequently used for determination of tribological properties of surfaces is the "Pin-on-Disc" method. This paper deals with analysis and comparison of tribological properties and surface of two types of Cr coatings after the tribo test. The tested Cr coatings were deposited by PVD technology (Cr_{PVD}) and by electrochemical (galvanic) method (Cr_{galv}). Results of tribological tests showed that maximum depth "h" and width "w" of the wear track was observed on the galvanic Cr coating with lower hardness.

Keywords: coating, PVD, hard chrome, tribology, Pin-on-Disc

1. INTRODUCTION

Many coating techniques have been developed in order to produce hard, wear resistance layers with high chemical and thermal stability. The PVD (Physical Vapour Deposition) and electrolytic hard chrome (EHC) plating include to those technologies [1, 2]. The properties of produced coatings are thus strongly dependent on technological parameters and process environments [3]. Lifetime and reliability of hard coating are influenced not only by the operating test parameters (contact pressure, sliding speed and counterpart materials) but also by the environmental factors including for example temperature and chemical composition of the environment [4-6].

Tribo test is a method for determining the wear of layers during sliding using a Pin-on-Disc apparatus. The friction coefficient (hereinafter called COF) depends on the thermal stability of coating which is affected by the structure [7-9]. The process of friction between two surfaces is accompanied by wear. Tribological tests are used to determine the friction coefficient and its changes during testing of the combination of two materials, the measured substrate and pin of specific characteristics and dimensions and the respective environment [10-12]. In addition to the friction coefficient, we also obtain information about the cohesion-adhesion behaviour of the tested system. The friction between two surfaces results in production of wear track. By measuring the wear track surface using a profilometer and observing it under a microscope, one can obtain important information about the process of wear and thus also about behavior of the coating–substrate system.

The methods for determining the tribological properties of surfaces can be categorized according to the type of relative movement of the tested material and the applied bodies, and the method of contact and geometry of the pin. One of the methods most frequently used to determine tribological properties of surfaces is the Pin-on-Disc method [13-16].

2. EXPERIMENTAL MATERIAL

The examined Cr coatings were deposited by two different methods: a) PVD method (reactive cathode vapour deposition method – Physical Vapour Deposition) [17]; b) electrochemical (galvanic) method [3]. Steel Böhler S600 Isorapid [18] was used as a substrate and after heat treatment the hardness of the steel reached 64 HRC. PVD process was realized in the coating center STATON Turany, Slovakia by method of cathodic arc evaporation. Using the arc have been the particles from Cr cathode accelerated towards the surface of steel substrate. Technological parameters of the PVD process are given in Table 1. The galvanic Cr coating was prepared by electrodeposition process. The nature of this process is cathode reactions:

$Cr^{6+} + 6e^{-} \rightarrow Cr^{0}$ (1)

$2H + 2e^{-} \rightarrow H_2$ (2)

$4H_2O + 4e^{-} \rightarrow 2H_2 + 4(OH)^{-}$ (3)

Electrons on the surface of the part being plated neutralize the positive charges on the metal ions (Cr^{6+}) in solution near the metal surface, with the net result that a metal (chromium) is deposited on the surface of the metal. Simultaneously, some of the electrons also neutralize positive charges on the hydrogen ions (H^{+}) and hydrogen gas is formed and liberated on the surface of the part. The reduction of H^{+} ions and/or water results in an increase of hydroxyl ions (OH^{-}) increasing pH of the cathode surface film and resulting in the formation of a chromate film on the surface of the cathode. Chemical composition of electrolyte and technological parameters of electrodeposition process are shown in Table 2.

Table 1. Technological parameters of the PVD process

Coating	**Technological parameters**				
	Substrate	*Deposition temperature (°C)*	*Cathode performance (kW)*	*Anode voltage (V)*	*Pressure (MPa)*
$Cr_{(PVD)}$	S600	200	1.5	100	0.3

Table 2. Technological conditions of the electrodeposition process

Coating	**Electrolyte (chromic acid) composition**		**Work conditions**	
	Component	*Concentration ($g.l^{-1}$)*	*Parameter*	*Value*
$Cr_{(galv)}$	CrO_3	245	pH	1.0
	H_2SO_4	2.6	Temperature	55 °C
	Additive	Company know-how	Current density	27A/dm^2
			Time	20 min

In chromium plating approximately 75-90 % of the total number of electrons is involved in liberating hydrogen. Only 10-25% of the current is utilized for the production of chromium metal. A small percentage (less than 1%) of the total current also produces trivalent chromium from hexavalent [19]. Chromate surface coating was manufactured in galvanic operation Neo Slovak, a.s. Košice, Slovakia.

By using the PVD process, we obtained Cr coating (Cr_{PVD}) of thickness 2.8 μm and by the electrochemical process Cr coating (Cr_{galv}) of thickness 20 μm.

Tribological characteristics of steel samples coated with Cr coating were evaluated using the Pin-on-Disc method on a CSM tribometer in Ball-on-Disc mode [20]. Conditions of the tribo test are shown in Table 3. In addition to the friction coefficient μ, other important evaluation parameters were obtained, such as the track depth after the action of carbide or corundum ball on the coating surface, cross section surface and width and depth of the wear track.

Table 3. The conditions of Pin-on-Disc test

Pin	Ball WC - ø 6 mm	Ball Al_2O_3 - ø 6 mm
Speed	5.00 $cm.s^{-1}$	5.00 $cm.s^{-1}$
Track length	190.00 m	250.00 m
Load	5.00 N	5.00 N
Track radius	3.01 mm	4.04 mm
Temperature	20°C	20°C

Tribological tests on the tribometer CSM [21] were conducted mainly with the aim to determine the friction coefficient and its changes during the tribo test. The character of the coating surface after wear was analysed by a confocal microscope Pluneox of company Sensofar.

3. RESULTS AND DISCUSSION

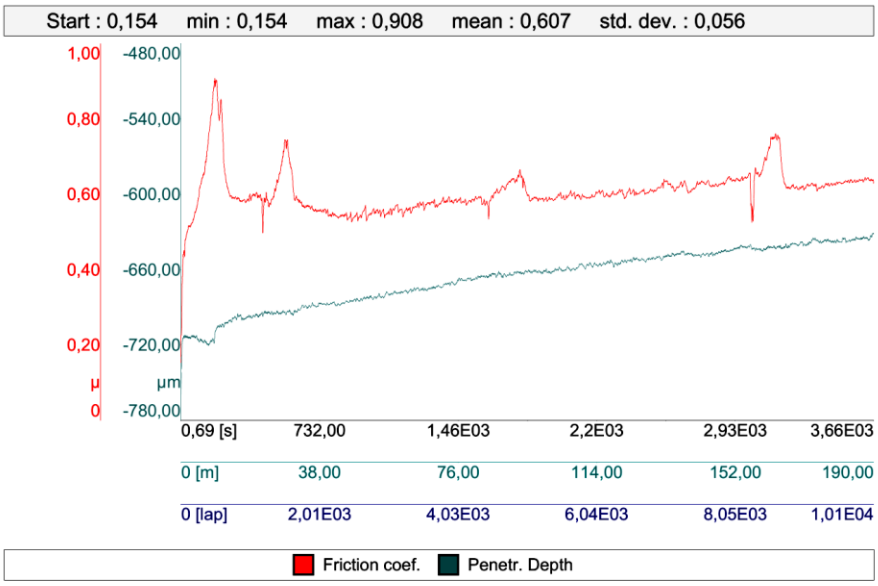

Figure 1. The friction coefficient on the surface of Cr_{PVD} coating and penetration depth of the WC ball as a function of conditions of Pin-on-Disc test

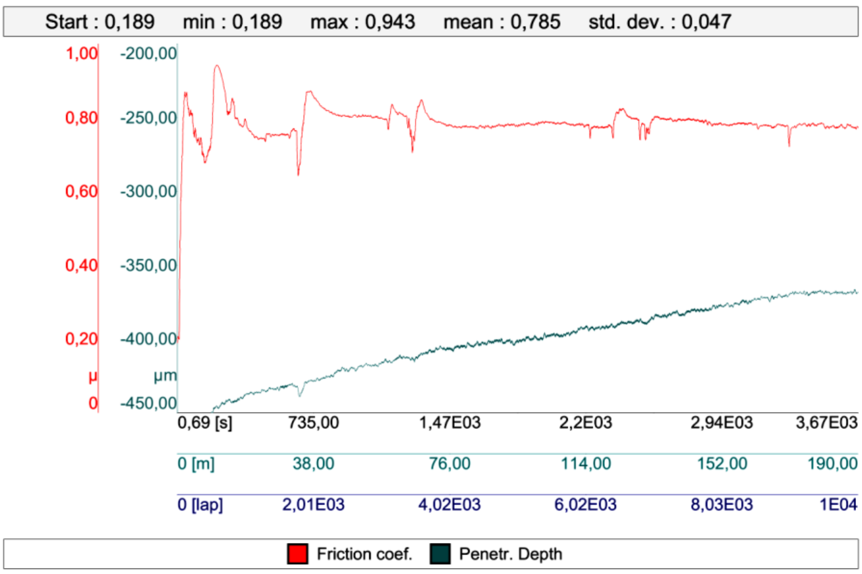

Figure 2. The friction coefficient on the surface of Cr_{galv} coating and penetration depth of WC ball as a function of conditions of Pin-on-Disc test

The function of the friction coefficient μ of the Cr_{PVD} coating and the test length (or track length) when using WC balls is shown in Fig.1. The friction coefficient changed during the test from 0.541 to 0.908. Local minima and maxima were caused by surface roughness of Cr_{PVD} coating and possibly by the wear of the ball and the separation of the coating and pin material. The depth of penetration of the WC ball continuosly increased, as documented in Fig. 1. It is well known [20] that during the contact of two materials and high rate of wear, chromium oxide layer forms on the coating surface. This oxide layer is responsible for good frictional properties of the Cr_{PVD} coating. In addition to the properties of the stressed surface the course of wear was affected also by the properties of the ball (hardness, strength, microgeometry of surface). The course of fiction coefficient of Cr_{galv} coating determined by Pin-on-Disc method using the WC ball is shown in Fig. 2.

The course of friction coefficient showed several local maxima and minima. Electrodeposited coatings exhibit higher surface roughness [3], which were also reflected in the contact of the WC ball with the Cr_{galv} coating surface. On the other hand, the friction coefficient values showed lover variations in comparison with Cr_{PVD} coating and its average value was 0.785. The depth of penetration of WC ball continuously increased, but the depth of abrading was lower than that observed for Cr_{PVD} coating. The summary results of the tribo testing are presented in Table 4.

Table 4. The summary results of the tribo testing

Coating - ball	**Friction coefficient μ**		**Tribo track width (μm)**	**Tribo track depth (μm)**	**Cross section area (μm^2)**
	Average value	*Maximum value*			
Cr_{PVD} -WC	0.607	0.908	440	5.1	371
Cr_{PVD} - Al_2O_3	0.865	0.906	320	3.0	266
Cr_{galv} - WC	0.785	0.943	920	10.0	3009
Cr_{galv} - Al_2O_3	0.793	0.947	630	8.7	2747

Fig. 3 shows the tribo track on the Cr_{PVD} surface with documented of the wear track after the action of the WC balls. The depth of the regrinding balls into coating was max. 5 μm. Because the Cr_{PVD} coating was about 2.8 μm thick the regriding of coating was uneven and the ball penetrated down to the steel substrate.

Fig. 4 shows the track depth after the action of the WC ball on the Cr_{galv} coating surface. The maximum depth of abrading by the balls was 10 μm. The thickness of Cr_{galv} coating was about 20 μm and therefore the WC ball did not reach the steel substrate. The tribo track on Cr_{galv} coating reached 920 μm and therefore was wider in comparison with 440 μm wide wear track on Cr_{PVD} coating.

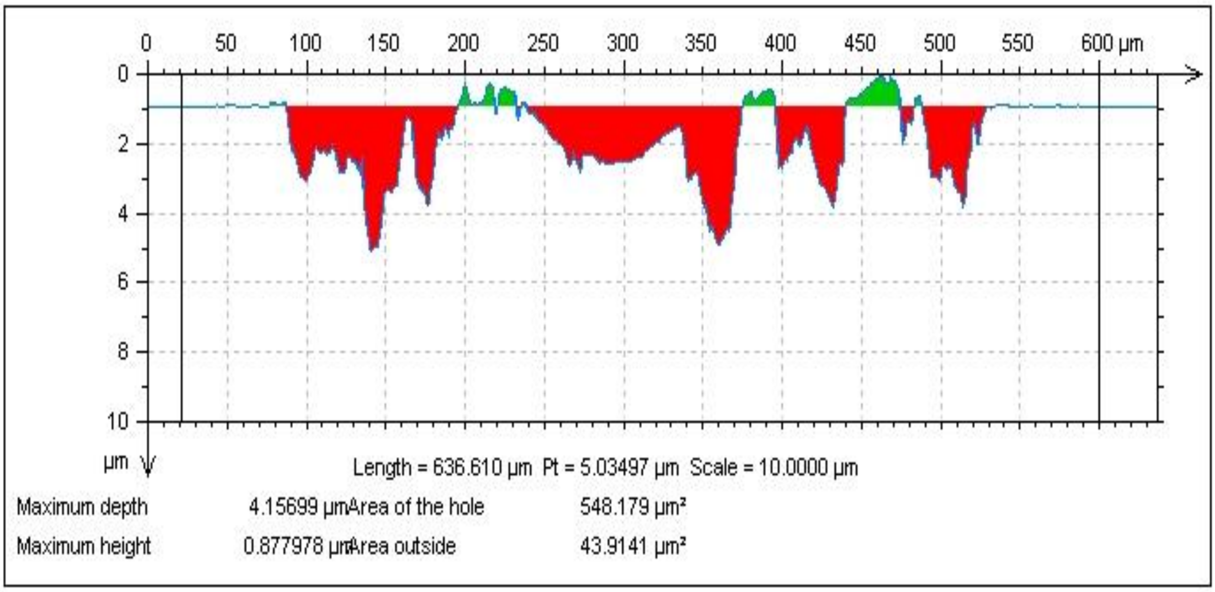

Figure 3. Depth of the wear Cr_{PVD} coating tested with the WC ball

PVD and galvanic alloy coatings belong to modern wear resistance coatings. Wear resistance these coatings are determined not only mechanical properties of the coated surface, but also properties of tribological couple. The advantage of PVD coatings consists in a great wear resistance, the high oxidation resistance for coatings thickness from 2 to 4 μm. The disadvantage of these coatings is the possibility of coating of small surface area in the expensive coated process conditions. The method of electrodeposition is the simple, most economical, reliable and reproducible technique [22]. The advantage of this process is its applicability for large surface area. The disadvantage of the coatings produced by electrodeposition process is lower wear resistance and hardness in comparison of PVD coatings. On the user is choice of coatings.

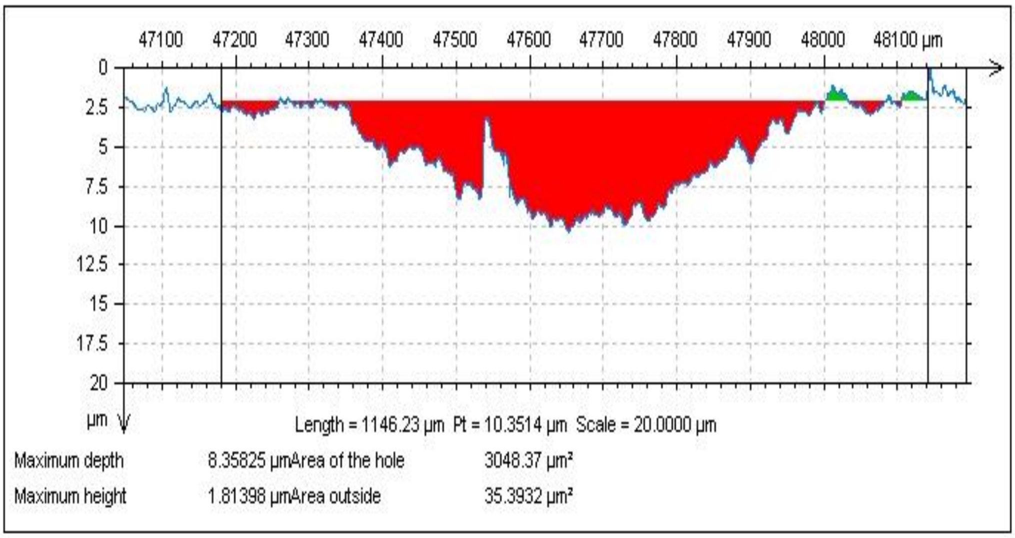

Figure 4. Depth of wear of Cr_{galv} coating tested with WC ball

4. CONCLUSION

By examining respective tribo pairs we determined and compared the character of wear of Cr_{PVD} (deposited by PVD process, namely reactive cathode vapour deposition) and Cr_{galv} (produced by electrodeposition process) coatings. The magnitude of wear was affected by hardness of coatings and hardness of test pins. While the hardness of the Cr_{PVD} coating was 1500 HV0.5, the hardness of galvanic Cr coating was 1000 HV0.5 [2]. The hardness of WC and Al_2O_3 balls was 1800 HV10 [23] and 1500 HV10 [24], respectively.

The conducted experiments, observations and analysis of results concerning the evaluation of tribological properties of tribo pairs of materials: Cr_{PVD} - WC, Cr_{PVD} - Al_2O_3, and Cr_{galv} - WC, Cr_{galv} - Al_2O_3 allowed us to draw the following conclusions:

- the best tribological properties with the lowest friction coefficient were exhibited by the pair Cr_{PVD} – WC, with the mean value of coefficient μ reaching 0.607;
- the lowest depth of regrinding, namely 3 μm, was observed on the surface of Cr_{PVD} coating when using Al_2O_3 ball; on the other hand, the greatest depth of regrinding, namely 10 μm, was recorded on Cr_{galv} surface using are WC ball;
- the smallest cross-section area of the wear track - of size 266 μm - was measured on Cr_{PVD} when using Al_2O_3 ball; considerably greater areas were measured for Cr_{galv} coating (with both types of the pins), with a maximum area of 3009 μm^2 for the tribo pair Cr_{galv} – Al_2O_3;
- the widest wear track was measured on Cr_{galv} surface when using the WC ball; the width of tribo track was about 920 μm.

The greatest depth and width of the wear track was measured on the surface of the galvanic Cr coating, i.e. on the coating with lower hardness.

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