Evaluation of tribological properties of thin coatings formed by solid lubricants

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Abstract. The article deals with the evaluation of tribological properties of thin coatings formed by solid lubricants. The aim is to obtain and compare data obtained in experiment. The monitored parameter is the coefficient of friction, which is evaluated on three types of samples. The samples are made of bearing steel with designation 100Cr6. After heat treatment, martensitic, sorbitic and bainitic structures were obtained. Thus prepared matrices were coated with WC/C based DLC coating. The experiment was carried out on a tribometer which works on the principle of "Ball on Flat". The tribological pair consisted of two members: a coated test specimen and a steel ball. All three samples were tested under the same external sub-conditions: without lubricant and under atmospheric conditions. The tensometric sensor included in the tribometer recorded and evaluated the coefficient of friction throughout the duration of the experiment. The results are clearly interpreted in the graph. The experiment showed that the coefficient of friction in all cases had a decreasing tendency. At the end of the paper, the wear on the ball is evaluated graphically.

Keywords: DLC Coating, Tribometer, Coefficient of Friction.

1 Introduction

Friction is a phenomenon that occurs wherever two rigid bodies move together. Friction is inevitable, but wear is controllable. This is the mantra, which is used in the development of any mechanical system that operates on a cycle of rotating and sliding parts. Lubrication of these systems helps to reduce the impact of shear stress on the contact surfaces. Liquid lubricants help reduce friction and wear, but their effectiveness degrades when subjected to high contact loads [**Error! Reference source not found.**-**Error! Reference source not found.**]. The use of liquid lubricants is therefore counterproductive in such applications. This fact predetermined the development of new solutions in the form of coatings that are applied directly to the contact surface. Coatings based on carbon, nanodiamond and DLC improve the reliability of sliding surfaces and they have found applications in the field of tribological research. Nanometric WC/C-based coatings are characterized by low coefficient of friction, chemical inertness, wear resistance and high hardness. Thanks to these properties, they have found applications in various industries, the automotive industry, aviation and medicine. Due to the high hardness of the DLC coating, the hardness of the base material-

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substrate on which the coating is applied must also be maintained. Ideally, the hardness of the coating and the base substrate are the same. The physical vapor deposition (PVD) method was used to create the WC/C coating [5,6]. The advantage of such deposition is that it takes place at low temperatures. Thus, there is no thermal effect on the substrate. The samples prepared in this way were tribologically tested on a tribometer using the "Ball on flat" method. This paper will deal with the evaluation of the tribological properties of WC/C based DLC coating deposited on 100Cr6 bearing steel with three different structures.

2 Experiment

The experiment took place in the tribological laboratory at the University of Žilina. The testing equipment is unique and can measure and evaluate tribological properties of materials.

2.1 Sample selection

Sample selection is an important part of conducting a successful experiment. Bearing steel with the designation 100Cr6 was chosen as the substrate. The first step was to cut the sample into the desired shape. The surface of the samples must be treated to achieve a roughness of R_a = 0.2 μm before the actual deposition of the coating. This was achieved by grinding on a BPH - 20 grinder and then hand polishing on a Struers grinder to a mirror polish using a 3 μm grit diamond paste at the same time [7,8]. A view of the sample used in the experiment is in **Chyba! Nenalezen zdroj odkazů.**.

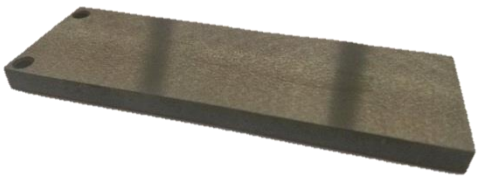

Fig. 1. Sample used in the experiment

2.2 Sample selection

The heat treatment of the substrate was carried out under three different conditions, resulting in three different structures. Martensitic, bainitic and sorbitic structures, which are shown in Fig. 2.

Fig. 2. Microstructures after heat treatment: a) martensitic, b) bainitic, c) sorbitic

The structures formed after heat treatment of the substrate are shown in Table 1

Table 1. the structure of the steel after heat treatment, indicating the hardness and heat treatment conditions

Structure	Hardness [HRC]	Heat treatment
Martensite	65	Hardening temperature: 840 ^{O}C Non tempered
Sorbite	64	Hardening temperature: 840 ^{O}C Tempered at 190 ^{O}C
Bainite	59	Austenitization temperature: 840 ^{O}C Isothermal hold: 220 ^{O}C

2.3 DLC coating based on WC/C

After heat treatment of the substrate, a nanometric DLC coating was applied to the surface in cooperation with STATON TURANY. The deposition technology was PVD by the magnetron sputtering method. This process was carried out in several steps. The sample surface was first chemically cleaned and placed in a coating chamber. This was followed by an ion cleaning process of the surface. Only after these steps were completed, the actual deposition followed [9]. In the first step, a thin Cr coating was deposited in order to increase the adhesion of the substrate surface. In the next step, a nanoscale WC/C coating was deposited [10,11]. Fig. 3 shows a cross-section of the coated sample.

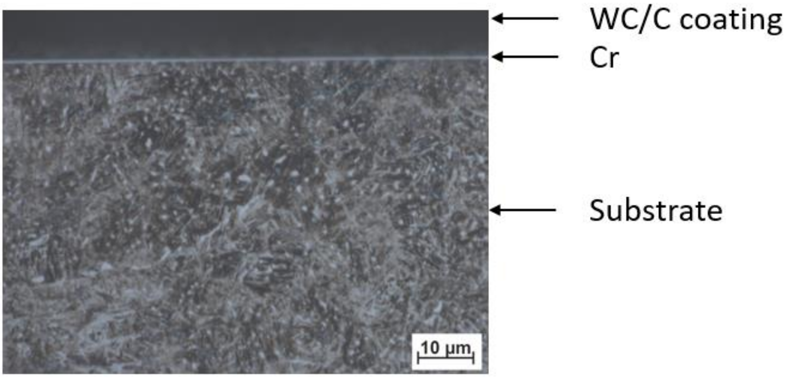

Fig. 3. Structure of 100Cr6 steel with deposited coatings

2.4 Experimental device

The experiment was carried out in the laboratory of the Department of Design and Mechanical Elements. The laboratory has several types of tribometers. For the purpose of this experiment, the linear tribometer shown in Fig. 4 was chosen.

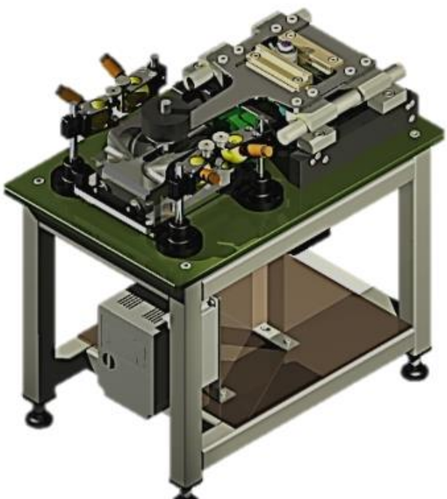

Fig. 4. Tribometer used in the experiment

This tribometer allows to measure using the "Ball on Flat" method. The principle is based on the linear movement of the tip over the sample surface, as shown in Fig. 4. The tensometric sensor is used to measure the friction force F_T and the measured values are recorded throughout the experiment. The weight that generates the normal force F_N is placed over the tip. The principle is shown in Fig. 5.

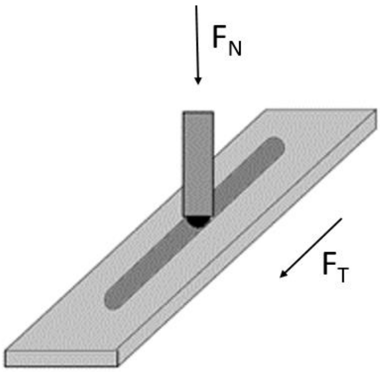

Fig. 5. Basic principle of tribometer

2.5 Tribological experiment

The tribological pair consists of two members. The first is a coated test plate. The substrate is made of 100Cr6 bearing steel with three different structures: martensitic, bainitic and sorbitic, on which the WC/C coating is applied. The second member is a ball with a diameter of d=4 mm and it is made of 100Cr6 bearing steel [12,13].

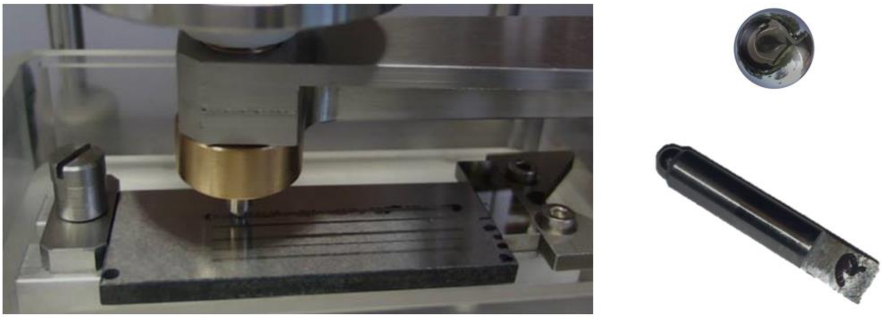

Fig. 6. Tribological pair during the test on linear tribometer (left), ball holder and steel ball (right)

To maintain comparability of results, the same external conditions must be established. The experiment is conducted under atmospheric conditions and without the presence of lubricant. The velocity waveform is sinusoidal in nature. The range of ball velocity is v = 0 to 20 mm.s^{-1}. The load was constant with a force value of F_N = 10 N. The length of the test was limited by time (t = 6000 s) and path length s = 100 m.

3 Results an discussion

The experiment was aimed at detecting the evolution of the friction coefficient values over time. The result is interpreted in graph where the horizontal axis is time and the vertical axis is the coefficient of friction. The graph shows the coefficients of friction at constant load $F_N = 10$ N. From the measurements carried out, it can be seen that the coefficient of friction μ had a decreasing character in all cases. The lowest coefficient of friction was found for the sample with sorbitic structure μ = 0.36 (-). The same value of coefficient of friction μ = 0.45 (-) was found for the samples with martensitic and bainitic structure. The experimental time was t = 6000 s. During this time, the coefficient of friction decreased for all samples at the level of μ = 0.16 (-) [14,15]. A view of the whole evolution of the friction coefficients is shown in the graph in Fig. 7

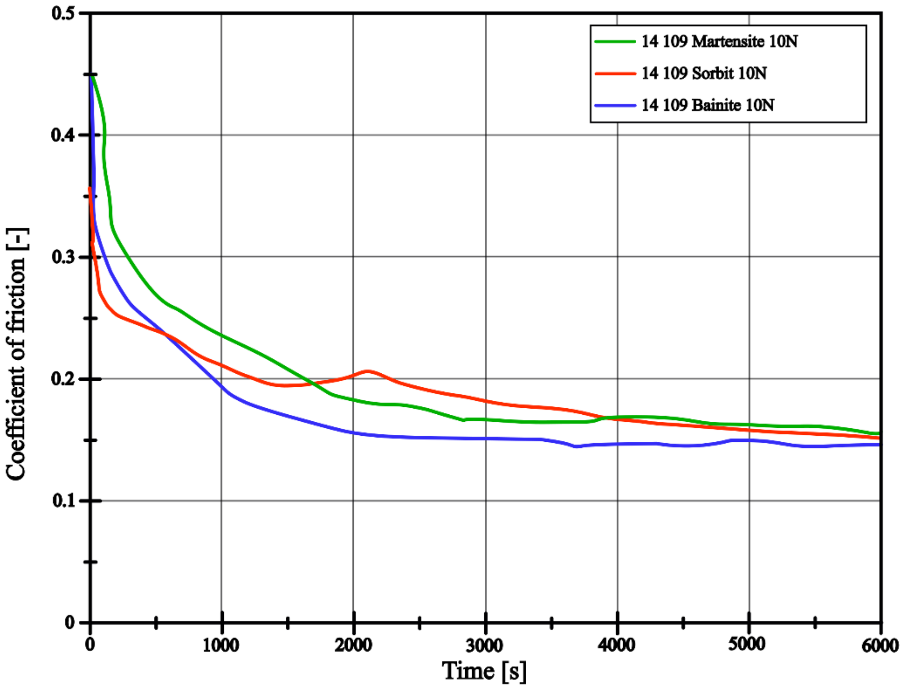

Fig. 7. Evolution of the coefficient of friction on the samples over time

After the experiment was performed, the wear of the test ball was evaluated. An optical representation is shown in Fig. 8. For each specimen and its second member, the calculated contact pressure p-values and the size of the flap on the ball resulting from the wear of its surface are shown in Table 2.

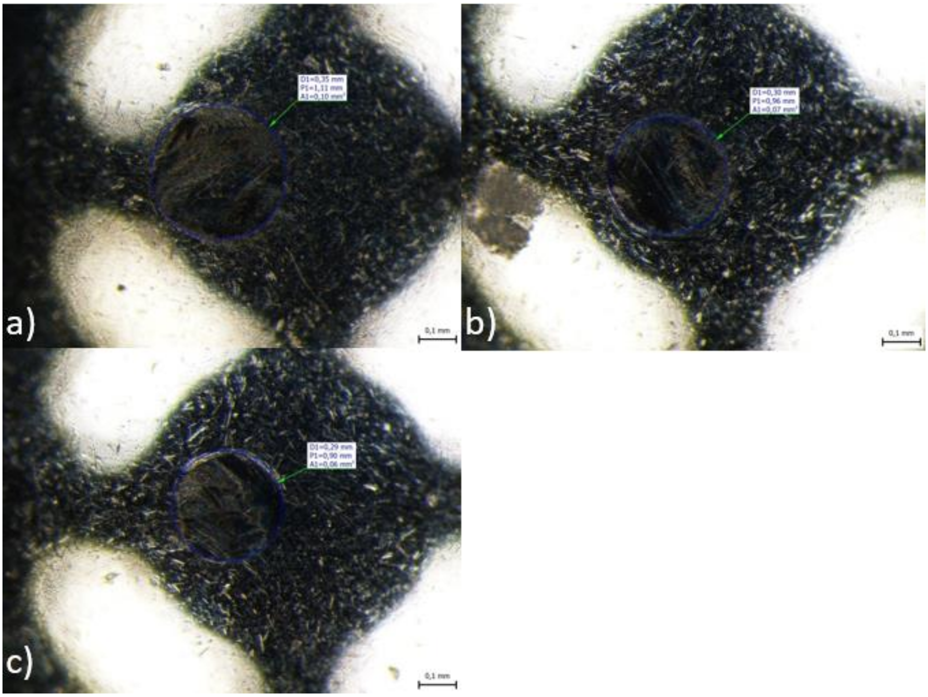

Fig. 8. Representation of the surface of the ball after testing with the corresponding sample with a substrate of : a) martensite, b) sorbitol, c) bainite

Table 2. Tribological properties

Sample	Initian coeffi-cient of friction [-]	Hertzian pressure P_{THEOR} [GPa]	Area of worn sur-face of steel ball [mm^2]	Load [N]	Number of tip
Martensite + WC/C	65	1,24	0,10	10	Tip no.20
Sorbite + WC/C	64	1,24	0,07	10	Tip no. 17
Bainite + WC/C	59	1,24	0,06	10	Tip. no. 12

4 Conclusion

The tribological properties of the coatings were evaluated by experimental measurements. The basic parameter measured was the coefficient of friction, which was determined for three samples. It can be stated that the sample with bainitic structure of the base material achieved the lowest coefficient of friction. By examining the wear of the second tribological pair: the steel ball, it can be stated that the lowest wear is found for the tribological pair with a bainite substrate.

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