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OPTIMALIZATION OF PARAMETERS FOR MEASUREMENT OF THE TRIBOLOGICAL PROPERTIES OF COATING FOR MACHINE PARTS

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ABSTRACT

When designing machines that contain dynamic components, it is necessary to consider the tribological properties of the materials used for the functional parts of these components. The movement itself during the operation of the machines has a mechanical impact on these parts, which may result in the performance of the mechanism being affected. This work is focused on the measurement of the tribological properties of coating designed for deposition on the surface of functional machine parts. The theoretical knowledge from the material area of the issue is described is reviewed. The experimental part of the paper is devoted to the measurement of tribological properties, such as wear and friction properties by the ball - on - disc method and coating adhesion by scratch test. The obtained results are summarized in the conclusion part.

Keywords: tribology, coating, measurement.

INTRODUCTION

Due to increasing industrialization, the requirements to control friction and wear processes are constantly evolving, in particular, to extend system life, increase their efficiency, save materials and energy, and also to increase safety. (Zajac et al., 2014; Gombár et al., 2019) When designing machines that contain dynamic components, it is necessary to consider the tribological properties of the materials used for the functional parts of these components. The movement itself during the operation of the machines has a mechanical impact on these parts, which may result in the performance of the mechanism being affected. The main processes include friction of the contact surfaces and the resulting material wear. (Stančeková et al., 2015; Frankovský et al., 2014)

In this study the commercial coatings applied on two types of high-speed steel made by powder metallurgy with a different chemical composition was used. The resistance of high-speed steels to decrease of hardness is up to temperatures around 550 °C. They are high-alloyed, ledeburitic steels whose carbon content is 0.7 - 2 wt.%. In addition to carbon, they also contain chromium, vanadium, molybdenum, tungsten and cobalt. Concentrations of the above elements are designed to achieve high hardness, high wear and tempering resistance and good material toughness. Total amount of alloying elements varies between 15 - 30%. Chromium, tungsten, molybdenum and vanadium form carbides with different functions in steel. Hardening of high-speed steels is usually performed at the temperatures from 1200 to 1280 °C. At tempering temperatures, carbides are partially precipitated from martensite, resulting in a slight decrease in hardness. The carbon content decreases in residual austenite at 450 to 550 °C. By further increase in the temperature austenite is transformed into martensite, resulting in a simultaneous increase in hardness due to carbide precipitation. The process of tempering at such temperatures is called secondary hardness tempering. Only a part of the austenite is transformed and the tempering is repeated. Hardness values of 60 to 66 HRC are achieved in steel by at least triple tempering. (Martinec et al., 1997).

MATERIAL AND METHODS

The coating of samples was carried out by the physical vapour deposition (PVD) method. The PVD processes were carried out in a high vacuum environment (0.1-1.0 Pa) at temperatures in the range of 150-500 °C. Basically, the PVD procedure is based on the release of metallic coating components such as titanium, aluminium, zirconium or chrome. The coating occurs as a result of the condensation of atoms or a cluster of atoms that are released from the so-called targets. This method was chosen because this coating process in comparison to chemical vapor deposition (CVD) allows deposition of very thin yet exceptionally hard and strongly adhesive coatings. Other advantages of the PVD method of coating are summarized in Table 1. (Eifeler Plasma, 2019)

Table 1 Advantages of PVD method of coating; (Eifeler Plasma, 2019)

Advantages of PVD coating	
Exceptional degree of hardness, up to 3500 HV	Visual refinement
Coating thickness: 1 – 10 μ (Standard: 2 – 4 μ)	Exceptional adhesion to the substrate
Coating temperature: 150 – 500 °C (Standard: ~ 450 °C)	No adverse effects on the environment
Variable coat structure (nano-structures, multi-layer, mono-layer)	Very good dimensional stability and contour accuracy
Wear protection	No loss of hardness
Low levels of friction	Very clean method
Smooth surfaces	

The obtained coated samples in the Figure 1 have a cylindrical shape with a diameter of 2.5 cm. Samples have a high metallic luster.



Figure 1 Samples of high-speed steel after coating deposition

Tribological properties of the coatings were tested according to standard ISO 20808:2004 (E). The standard test is designed to determine wear and friction properties by the ball - on - disc method. When testing the coatings, a test coating layer was applied to the polished sample and the sample was then placed on a turntable. A ball of defined material was pressed with a defined force onto a rotating sample with a test coating (Figure 2). The ball wear, the coefficient of friction, the layer wear, the wear profile and the like were measured. The method of measuring the frictional properties is a laboratory method and can serve to compare different types of layers and give an idea of their sliding properties. (Bartz, 1988)

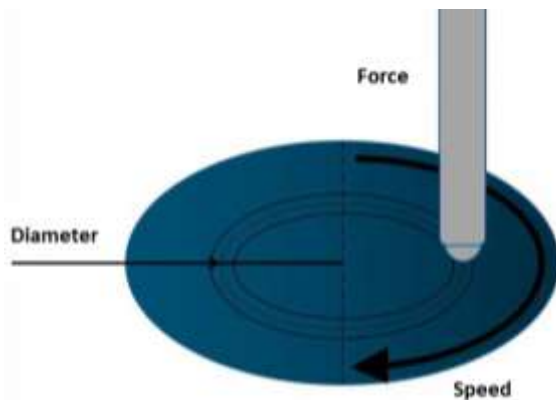


Figure 2 Schematic representation of the ball-on-disc test procedure

After the tribological test, the cross-sectional areas of the circle were measured at four points (S1 - S4) at 90 ° spacing (Figure 3), which was then used to calculate the specific wear of the material.

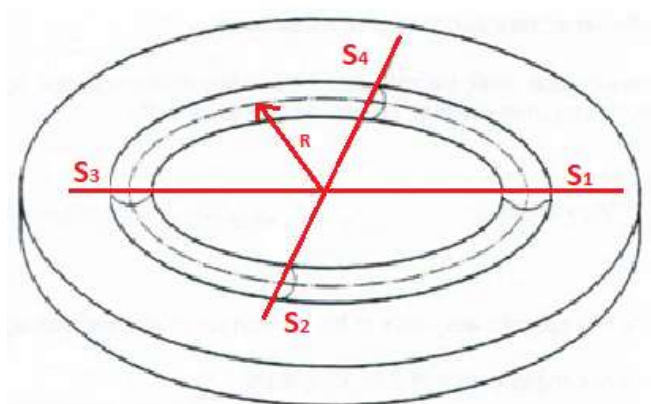


Figure 3 The scheme of measured areas S₁, S₂, S₃ and S₄

For testing the extreme conditions, in the event of lubricant failure, all the tests were carried out in the absence of lubricant. Testing was performed on the air in the room temperature. For testing were used three loads (10 N, 20 N and 40 N). Other conditions of the experiment were sliding speed 0.1 m.s⁻¹, distance travelled by the ball was 5 mm. For the first experiments, a steel ball was used, but due to the high hardness of the coating, the steel ball was during testing completely ripped and therefore the steel ball had to be replaced with ceramic one from Al₂O₃.

Tribological tests were conducted at the Institute of Materials Research of Slovak academy of sciences in Košice and were carried out on a universal tribometer UMT TriboLab from Bruker.

Coating adhesion testing was carried out by a standard method for evaluating the adhesion of coatings by the so-called scratch test. For measuring, the principle of gradually increasing loading force on a diamond Rockwell tip was used (Figure 5). While the tip has been moved along the measured layer the sample was moving horizontally at a constant rate. The indenter, which was loaded by a constant or continuously increasing force, penetrates into the sample surface and formed a groove. With respect to normal adhesion values, a loading force in the range of 20 - 120 N was used. (Bláhová et al., 2003)

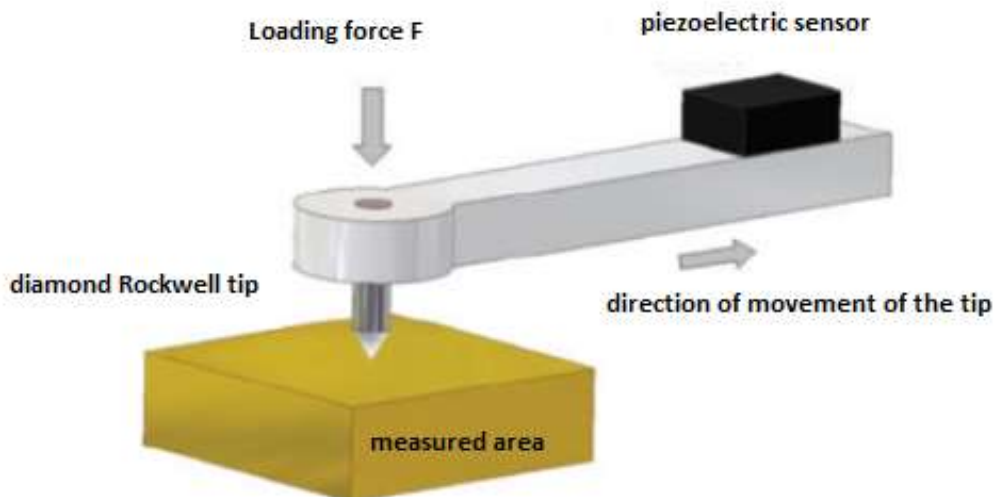


Figure 5 The scratch test principle

The value at which damage to the layer occurs is called the critical load and is used as a measure of the adhesion of the layer. The instrument records the course of the normal and tangential forces acting on the indenter, the friction coefficient values. When measuring a layer, it is possible to detect acoustic emission at the tip. By reaching the critical value of the loading force, the layer is torn off from the substrate. This is accompanied by a step increase in the acoustic emission value. (Dzimko, 1985)



Figure 6 Close up to adhesion testing of the cylindrical sample after coating deposition

CONCLUSIONS

The aim of the work was to summarize methods for testing of tribological properties of the coated samples and testing of the coatings deposited on the surface of real functional machine parts. Conditions for the tests were chosen in the wide ratio to cover even the extreme conditions, in the event of lubricant failure, so all the tests were carried out in the absence of lubricant. During the tests

on the small samples was optimized all of the processes of future testing. For example, a classic steel ball was replaced with a ceramic one from Al₂O₃, because the steel one was completely ripped during testing. Also, the forces and speeds of testing were optimized. This work serves as the starting point for further testing of different types of coatings applied by PVD method of coating. With the optimization of the parameters of the testing we could determine the suitable method for testing different types of coating applied on high speed steels for machine parts and achieve the most accurate comparability.

ACKNOWLEDGEMENTS

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