Scuffing propagation of heavily-loaded, lubricated, coated friction joints

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1. Introduction

There is great interest in improving the wear and friction of a wide variety of machine components, e.g. gear systems, gears. In modern technology, due to the increase of the unit pressure, velocities, and hence temperatures in the tribosystems of machines, a risk of a very dangerous form of wear exists. This form is scuffing.

The most effective way of to improve the mechanical properties of various engineering components is the modification of surface properties by the deposition of PVD/CVD coatings [1].

In literature, the problem concerning whether it is the most beneficial to coat only one or both of the contacting surfaces and on when and how the coatings may improve the tribological situation in heavily loaded lubricated friction joints is not solved [2, 3]. The aim of this paper was to explore the mechanisms of scuffing propagation of heavily loaded friction pair elements coated with a low-friction WC/C coating for various material combinations.

2. Experimental

WC/C coating (also denoted as a-C:H:W or W-DLC) is one of the most recommended coating for gears applications [4]. The coating was deposited in a commercial process (Oerlikon Balzers Coating Poland Ltd.). The coating consists of an elemental Cr adhesion layer adjacent to the steel substrate, followed by an intermediate transition region consisting of alternating lamellae of Cr and WC and a hydrocarbon layer doped with W. The coating was deposited using the PVD process by reactive sputtering. DLC coatings belong to the class of solid lubricant coatings due to the presence of carbon in form of graphite. A coating with a thickness of 2 µm was deposited on DIN100Cr6 (AISI52100) chrome alloy bearing steel. The hardness of the a-C:H:W coating is 10.8 GPa.

For evaluation of scuffing resistance, a four-ball tribosystem was employed. The test balls were made of chrome alloy 100Cr6 bearing steel with a diameter of 12.7 mm (0.5 in.). Surface roughness was R_a = 0.032 µm and the hardness was 60 to 65 HRC. In this method, the investigated coating can be deposited on the upper or lower balls. The four-ball tribosystem is presented in Fig. 1.

a) b)

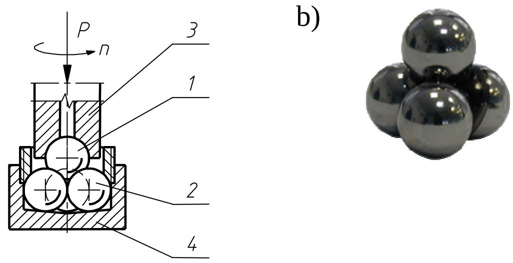

Fig. 1. Model four-ball tribosystem for testing scuffing: a) tribosystem: 1 - top ball, 2 - lower balls, 3- ball chuck, 4 - ball pot, b) photograph.

The three stationary bottom balls (2) having a diameter of 0.5 in. are fixed in the ball pot (4) and pressed against the top ball or cone (1) at the continuously increasing load P. The top ball/cone is fixed in the ball chuck (3) and rotates at the constant speed n. The tribosystem is immersed in the tested lubricant. During the run, the friction torque is observed until seizure occurs. The methods are described in detail in work [5] and patented (Polish Patent No. 179123 - B1 – G01N 33/30).

The test conditions are as follows: rotational speed: 500 rpm; speed of continuous load increase: 409 N/s; initial applied load: 0 N; maximum load: 7200 ± 100 N.

In four-ball tribosystem, the wear area of the upper ball is a track with the area larger than the wear track of all three lower balls. This means that, during the test, the wear in the contact areas of the lower balls is more intensive. This fact is critical for understanding this specific tribosystem behaviour. The tests were conducted for the following four material combinations: steel/steel tribosystem (all balls uncoated), steel/coating tribosystem (one upper ball uncoated/three lower balls WC/C coated), coating/steel tribosystem (one upper ball WC/C coated/ three lower balls uncoated), and coating/coating tribosystem (all balls WC/C coated).

To avoid any tribochemical reaction with the steel substrate, the tribosystems were lubricated with pure polyalphaolefin base oil, without any lubricating additives, denoted as PAO-8 (viscosity 7.8 mm^2/s at 100°C and viscosity index 136).

3. Results and discussions

The friction torque curves of four pairs tested are presented in Fig. 2 (darker colour is used for coated balls). The steel/steel sliding pair has shown the lowest performance level. In all cases, when a coating is applied, an increase in scuffing resistance is observed. The scuffing and seizure loads of steel/coating pair were only slightly higher. The pair that incorporate elements that are both coated has shown significantly better performance; the scuffing load is about 4 times higher than that of steel/steel or steel/coated pairs. The coating/steel pair is the best performer. The difference in tribosystem performance when one upper or lower element is coated shows the importance of the proper selection of element to coat to obtain the highest performance.

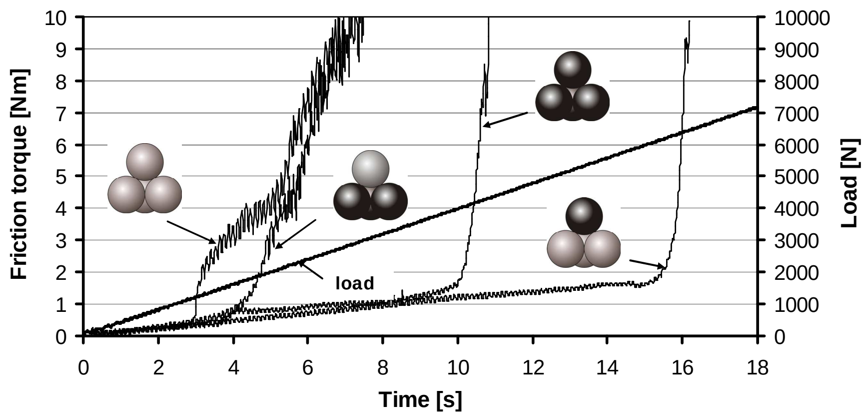

Fig. 2. Friction torque curves for various tribosystems.

The steel/coating tribosystem shows only some improvement in scuffing behaviour compared to steel/steel one. The best performance under heavily loaded lubricated conditions is achieved for the coating/steel tribosystem. The comparison of scuffing propagation for coating/coating and coating/steel tribosystems is presented below.

3.1. Coating/coating tribosystem

The schematic presentation of the main stages of coating/coating tribosystem behaviour during scuffing test is given in Fig. 3.

Initially the surfaces are separated by the lubricant film (Stage 1). Then the wear particles formed during the coating/coating micro-contacts serve as a 3rd-body abrasive and promote damage to both surfaces (Stage 2). During Stage 2, the cracks and scratches are propagated due to 3rd-body migration between balls. The surfaces become very rough. The coating is partially removed from the wear scars and the steel substrate is uncovered. However, the upper coating is only partially destroyed and can provide the transport of lubricant (oil) to the contact zone. However, at certain critical conditions, this film can be locally removed, mainly due to high local pressures and temperatures, exposing bare metal that can cause local microscopic adhesions. During the increase in load, the steel from the lower balls is transferred to the upper one and covers the valleys. As soon as the valleys, responsible for lubricant transfer stop functioning, the steel transfer accelerates and leads to scuffing (Stage 3).

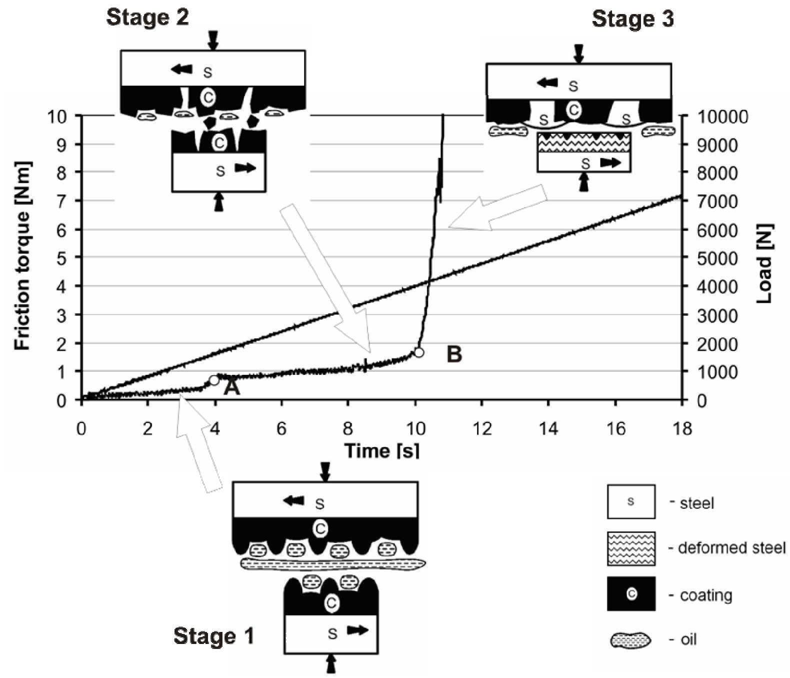

Fig. 3. The scuffing propagation in coating/coating tribosystem.

The coating/coating tribosystem exhibits only limited improvements in scuffing resistance, and the creation of a significant increase in roughness in rubbing surfaces leading to the removal of the coating material is not promising for the extension of the life of heavily loaded friction joints.

3.2. Coating/steel tribosystem

The highest scuffing resistance of the steel tribosystem was obtained when only one element, the one with a lower overlapping ratio, was coated. The schematic presentation of the main stages of coating/steel tribosystem behaviour during scuffing test is given in Fig. 4.

Stage 1 in the friction torque curve and applied load represents conditions at the beginning of the test run (low load) where the surfaces are separated by the lubricant oil corresponds to the hydrodynamic regime of lubrication. The lubricant film prevents large-scale adhesion between the sliding surfaces.

When the load increases, partial wear of the WC/C coating causes a flattening and shearing of the peaks on the coated surface. This occurs by the systematic polishing of the peaks to create a plateau that broadens as wear proceeds, until a continuous flat plateau is created. During the load increase, the contacts are on an asperity-size scale and take place during mixed lubrication regimes and cause the material transfer from coated element onto uncoated element. The lower steel balls can be deformed and can accumulate the coating particles lost by the upper ball during sliding. This enables the system to avoid the detrimental results of 3rd-body formation that were found in the case of the coating/coating pair. The enrichment of the lower steel ball by a ceramic phase lowers the friction between balls.

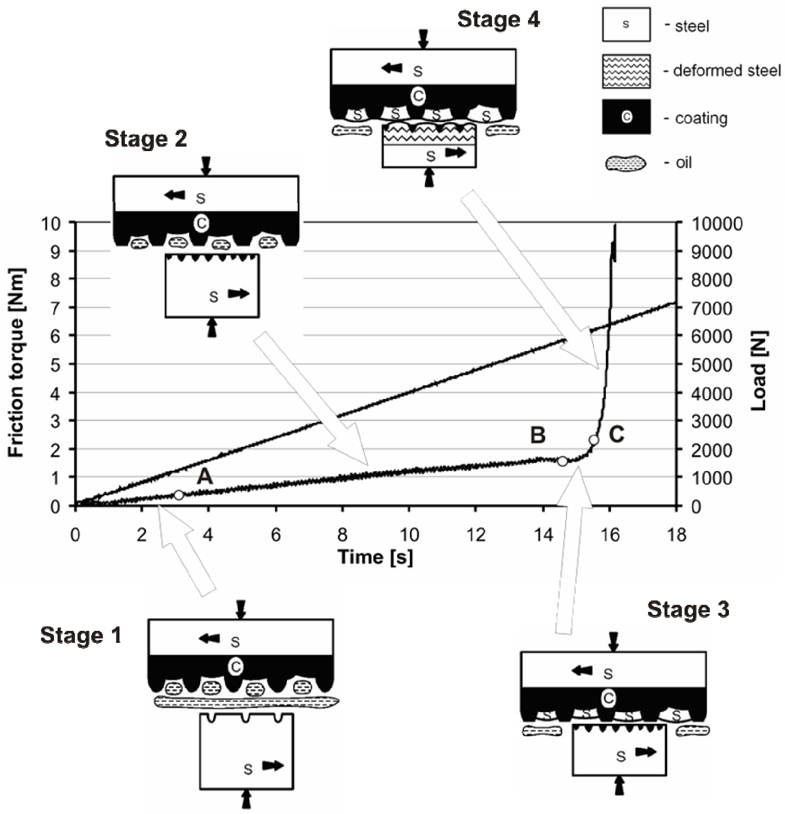

Fig. 4. The scuffing propagation in coating/steel tribosystem.

From Stage 3, the steel from the lower steel surface enriched by coating material is transferred onto coated upper ball. The transfer of steel to the upper coating starts with the filling of the valleys. The coating material is deeply included in the surface of the steel wear scar. A significant amount of graphite on the steel surface during the test of coating/steel tribosystem was detected.

4. Conclusions

The better scuffing resistance is achieved when only one specimen is coated (coating/steel tribosystem) than when all specimens are coated (coating/coating tribosystem). The description of scuffing propagation for all investigated tribosystems was done. The high scuffing resistance of coating/steel tribosystem resulted from the reducing of the adhesion between rubbing surfaces due to low chemical affinity (similarities) between the steel and the coating material and the presence of solid lubricant – graphite in the friction zone.

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