**Stanisław GUZOWSKI[*], Grzegorz ZAJĄC[*],
Grzegorz KACZOR[*]**

SCUFFING WEAR OF THE TRIBOLOGICAL PAIRS UNDER OSCILLATORY MOTION

ZUŻYCIE TYPU SCUFFING W PARACH TRIBOLOGICZNYCH W RUCHU OSCYLACYJNYM

Key words:

tribological wear, scuffing wear, adhesion

Słowa kluczowe:

zużycie tribologiczne, scuffing, adhezja

Abstract

The surfaces of the friction pairs in oscillatory motion are exposed to the complex wear processes. Scuffing is a specific wear process, which comprises abrasive and adhesive wear. This paper presents the results of the preliminary scuffing tests, conducted on the T-05 test machine under oscillatory motion in the line contact. The results obtained from the tests confirmed the high probability of the scuffing occurrence under the assumed tests conditions. This is the basis for the planning of further research in this area.

[*] Cracow University of Technology, al. Jana Pawła II 37, 31-864 Kraków, Poland, e-mails: wojtek@mech.pk.edu.pl, grzegorz.zajac@mech.pk.edu.pl, gkaczor@pk.edu.pl.

INTRODUCTION

Intense and complex tribological wear processes on the surfaces of mechanical machines result from the operating conditions of these objects, which become more difficult. It is associated with the interaction of many factors, such as increasing the requirements of selected operating parameters or reducing a negative impact on the environment. Meeting these expectations requires the development of newer technologies related to the manufacture of mechanical components. These objects are often exposed to the cyclic contact stresses, which may be accompanied by, among others, a sudden rise in the friction coefficient, temperature, pressure, or the relative speed of the moving surfaces in the sliding motion. In the case of lubricated conditions, a direct contact of these surfaces may occur. Such operating conditions favour the formations of the adhesive bonds and breaking them. The consequence of the described phenomena is the thermal instability in the contact area, leading to unstable friction and seizure. Therefore, the operation of the machine is immediately stopped. One of the most important phenomena accompanying the operation the modern technical objects is scuffing. It occurs on the surfaces of the components in sliding motion (unidirectional and reciprocating). The most vulnerable components to scuffing occurrence are cylinder bore, piston ring, cams, and followers.

DESCRIPTION OF THE SCUFFING PHENOMENA

Scuffing is a type of tribological wear, and it consists of abrasive and adhesive wear. It is characterized by a sudden, unexpected deviation from the proper operation of the sliding surfaces. Although the propagation of scuffing wear has been investigated many times by the researchers, it still remains unclear. It is because scuffing is accompanied by many phenomena, such as mechanical factors, and chemical, material, and thermal reactions. Some researchers focus on macroscopic observations of the worn surfaces to identify the scuffing **[L. 1, 2, 3, 5, 6, 8, 10]**.

The problem of the scuffing behaviour arises from the fact that its consistent and unambiguous definition has not been established until now. However, there is agreement on the selected physical phenomena observed during the scuffing propagation. These include a sudden rise in friction coefficient, temperature, and sometimes an increase in the level of vibrations and noise. According to the results of the selected scientific papers, in the early stage of the scuffing propagation, it appears as a tarnishing process. It is followed by a local melting on the sliding surfaces. During the progressive wear process, scuffing generates the cavities that are visible on the macroscopic images. Small debris is also produced as the product of wear. These particles are moved within area of sliding contact. According to the authors, the most comprehensive definition of scuffing was presented by Nosal, who claims that the scuffing is a collection of phenomena occurring between the surfaces in the sliding contact, located mainly in the depth of the surface layer, resulting in increased and unstable friction, leading to seizure **[L. 11]**.

The example images of the scuffing wear on the selected mechanical components are shown in **Figures 1a** and **1b**.

a)

b)

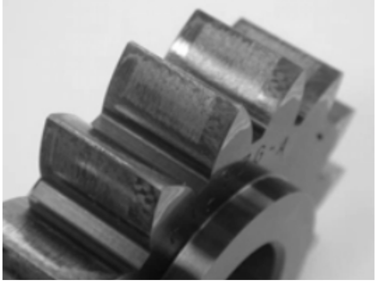

Fig. 1. Images of the scuffing wear on the surface of [L. 11, 13]: a) a piston, b) a gear teeth
Rys. 1. Obrazy zużycia typu scuffing na powierzchni **[L. 11, 13]**: a) tłoka, b) zębów koła zębateg**o**

THE CONDITIONS FOR SCUFFING PROPAGATION

There is no doubt that a necessary condition for scuffing occurrence is the lubricant film breakdown and direct metal-metal contact. Nosal claims that scuffing propagates gradually and it is a consequence of some elementary events, which include the following **[L. 12]**:

– Breaking down of the lubricant film;
– Removing of the protective oxide layers in the micro-areas of the contact;
– The formation of the adhesive bonds in the depth of the surface layer;
– Shearing the adhesive bonds, detaching and moving of the metal particles;
– The rapid development of the previously mentioned phenomena; and,
– Macroscopic scale of damage (scuffing).

A graphical interpretation of the kinetic model proposed by Nosal is shown in **Figure 2**.

Figure 2 shows that the first stage of scuffing propagation under lubricated conditions is marginal. In the second stage, the tribochemical process starts to occur and mixed conditions appear. There is a possibility to identify the adhesive wear, which is the third stage. Continuing the operation of the friction pair will result in a sudden increase in friction and the damage of the surface layer. Formation of the cavities indicates the scuffing occurrence. The last stage of the wear is seizure **[L. 12]**.

Some scientists conducted research in which they used the nano-diamond particles as the additives to the base oil. Through the analysis of the microstructure of the worn surfaces, they reveal the beneficial effects of the additives to limit the propagation of the cavities. The comparative images obtained from the surface samples are shown in **Figure 3 [L. 4]**.

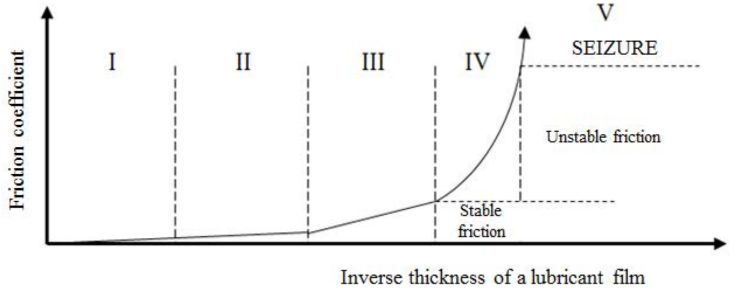

Fig. 2. Coefficient of friction during sliding against the inversed thickness of the lubricant film [L. 12]
Rys. 2. Przebieg współczynnika tarcia względem odwrotności grubości filmu smarnego w ruchu ślizgowym **[L. 12]**

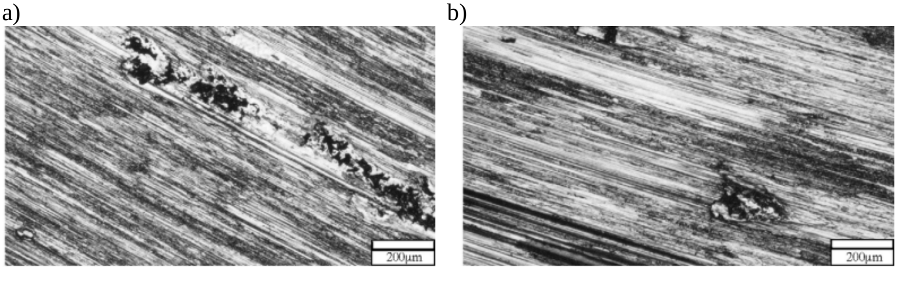

Fig. 3. Images of the worn surfaces: a) at 0% of the nano-diamond additive concentration, b) at 1% of the nano-diamond additive concentration [L. 4]
Rys. 3. Obraz zużytej powierzchni: a) przy 0% stężeniu nanocząstek diamentu w środku smarnym, b) przy stężeniu 1% nanocząstek diamentu w środku smarnym **[L. 4]**

EXPERIMENTAL DETAILS

The main aim of the conducted research was to create the conditions for the scuffing occurrence in a tribological pair operating under oscillatory motion. To conduct the research, we selected a block-on-ring test machine and established the test conditions. The block-on-ring test machine was manufactured to perform the wear tests in accordance with the following standards: ASTM D 2714, D3704, D2981, and G77. The machine allows the realisation of the following procedures **[L. 13]**:

- The calibration of the measuring system;
- Controlling the input parameters;

- The measurement of the resistance of the motion of the friction pairs, the temperature of the sliding surfaces, sliding speed or frequency of the oscillations, and time of sliding;
- Reporting the results; and,
- Archiving the results.

A schematic view of the kinematic node of the block-on-ring machine is shown in **Figure 4**. The machine consists of the specimen (block), fixed steady in the holder (4) by a hemispherical insert (3). The counter-specimen (ring) performs rotational motion according to the selected speed or oscillatory motion according to the selected frequency. The tensometric force sensor (5) measures the motion resistance of the friction pair. The temperature of the specimen and the counter-specimen is measured by the thermocouples. The block-on-ring machine allows one to conduct the tests for both the linear and surface types of contact **[L. 14]**.

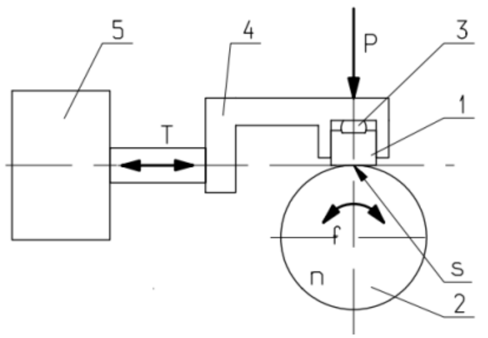

Fig. 4. Schematic view of the kinematic node in block-on-ring machine [L. 14]
Rys. 4. Schemat węzła kinematycznego w testerze T-05 **[L. 14]**

The dimensions of specimen and counter-specimen are shown in **Figures 5a** and **5b**.

a) b)

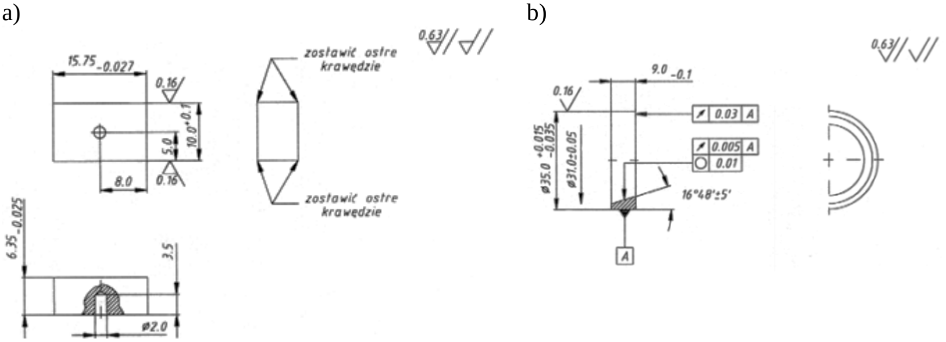

Fig. 5. The dimensions of (a) specimen, and (b) counter-specimen
Rys. 5. Wymiary: a) próbki, b) przeciwpróbki

The specimen and counter-specimen were made of the following materials: P60T steel for the rims of the rail wheelset and R350HT steel for the rails, respectively. The input parameters were as follows:

- Load P (range: 2 N – 4 N],
- The amplitude of oscillation ∝ (range: 10° – 30°), and
- The frequency of oscillation f (range: 20 Hz – 35 Hz).

The wear tests were conducted under non-lubricated conditions where: there is a direct metal-metal surface contact. They were preceded by a number of preliminary tests to establish the values of the input parameters. During the tests, the following physical quantities were recorded: friction coefficient, the temperature of specimen and counter-specimen, and the loss of the mass of the specimen and counter-specimen. The presence of scuffing phenomena during the tests will be the basis for planning further research.

RESULTS AND DISCUSSION

The results of the conducted research include the selected tribological characteristics. They relate to the friction coefficient, and the temperature of specimen and counter-specimen against the number of cycles under oscillatory motion. The example tribological characteristics are shown in **Figures 6, 7**, and **8**. During the tests, a symptom of the scuffing occurrence was observed as a sudden increase in the friction coefficient. It is a typical symptom of scuffing that is the prerequisite for the further propagation of the mentioned type of wear. It has been often referenced in scientific papers by many researchers. One of the reasons given for that is the mechanism of the adhesive bond formations and breaking them **[L. 9, 7]**.

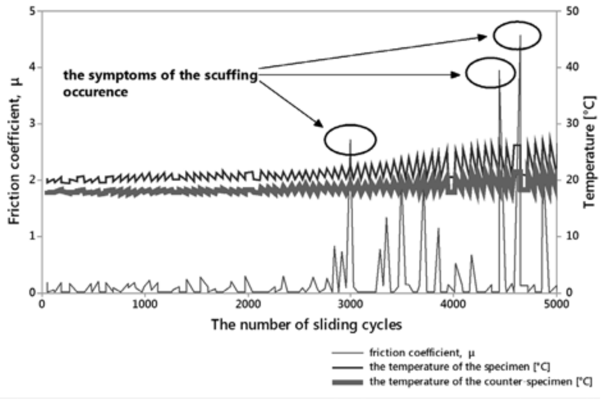

Fig. 6. The tribological characteristics obtained under the following parameters: P = 2 N, α = 30°, and f = 35 Hz

Rys. 6. Charakterystyki tribologiczne dla wartości parametrów: P = 2 N, α = 30°, f = 35 Hz

The sudden increases in friction occurred during the tests irrespective of the assumed values of the input parameters. These symptoms may recur several times during the tests, which proves that scuffing is a cyclical phenomenon and leads to the degradation of the surface layer. This regularity is consistent with the kinematic model of scuffing proposed by Nosal.

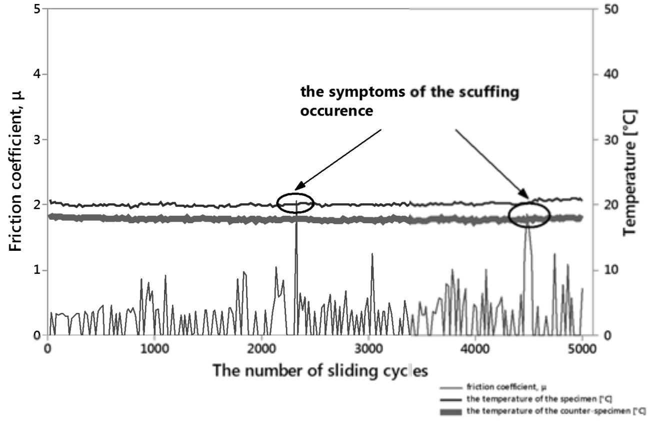

Fig. 7. The tribological characteristics obtained under the following parameters: P = 3 N, α = 10°, and f = 20 Hz

Rys. 7. Charakterystyki tribologiczne dla wartości parametrów: P = 3 N, α = 10°, f = 20 Hz

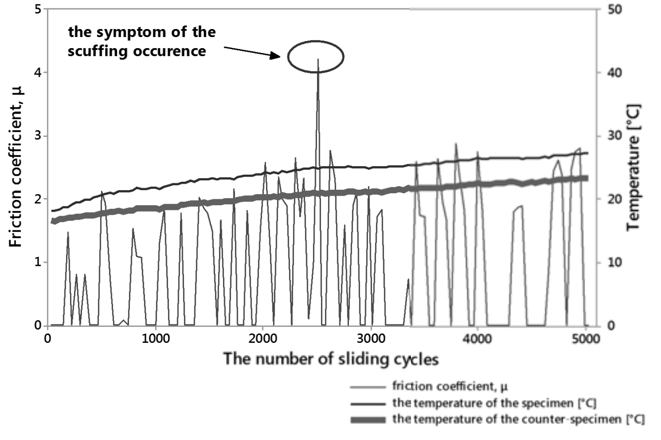

Fig. 8. The tribological characteristics obtained under the following parameters: P = 4.5 N, α = 30°, and f = 20Hz

Rys. 8. Charakterystyki tribologiczne dla wartości parametrów: P = 4,5 N, α = 30°, f = 20 Hz

The authors observed a partially matted surface of the specimen after about 1 minute of operation. Then, a sudden increase in the friction coefficient occurred followed by the appearance of clear abrasive signs on the surface.

In order to show the changes of the geometric structure of the specimen and counter specimen, the macroscopic and microscopic images of the surfaces were obtained (**Figures 9** and **10**).

a) b)

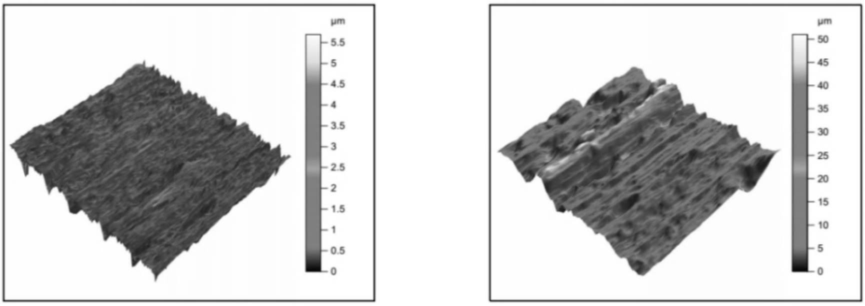

Fig. 9. Spatial roughness profile of the specimen, lc = 0.8: a) before the wear tests, b) after the wear tests

Rys. 9. Przestrzenny profil chropowatości próbki, lc = 0,8: a) przed badaniami zużyciowymi, b) po badaniach zużyciowych

a) b)

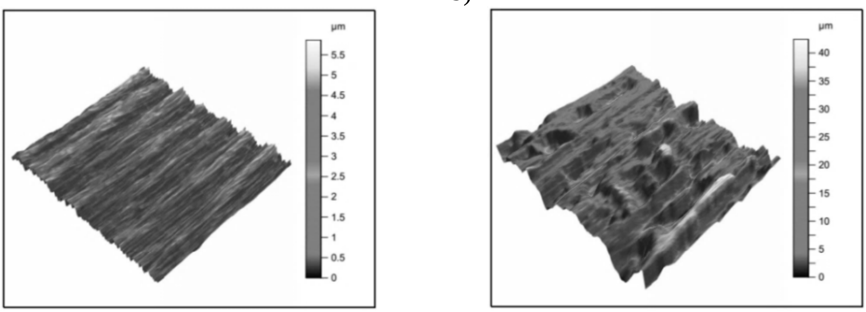

Fig. 10. Spatial roughness profile of the counter-specimen, lc = 0.8: a) before the wear tests, b) after the wear tests

Rys. 10. Przestrzenny profil chropowatości przeciwpróbki, lc = 0,8: a) przed badaniami zużyciowymi, b) po badaniach zużyciowych

In the spatial images of the worn surfaces, visible changes in the roughness profile of the specimen and counter-specimen may be observed after the tests. Created cavities may also be noticed, which confirm the occurrence of the adhesive wear. It is an additional symptom of scuffing.

Macroscopic investigation of the worn surfaces also showed the presence of the cavities (**Figures 11a** and **11b**). Around these cavities, the deposits of material are formed as a result of the adhesive forces reaction. In addition, the impact of the heat of friction leads to the plastic deformations of the surfaces.

a) b)

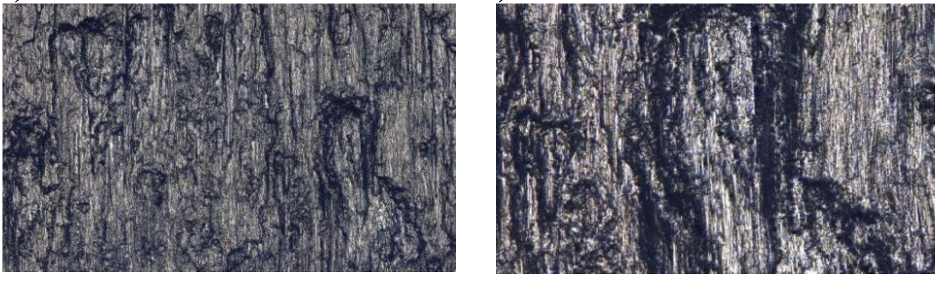

Fig. 11. Image of the worn surface of the specimen after the wear tests: a) magnified 100x, b) magnified 400x

Rys. 11. Obraz zużycia powierzchni próbki po badaniach zużyciowych: a) pow. 100x, b) pow. 400x

CONCLUSION

The obtained image of wear on the surfaces of specimen and counter-specimen confirmed the occurrence of scuffing. Therefore, it can be concluded that in the assumed model, the test conditions for the scuffing investigation were properly adopted. The range of the further research in this area includes performing a detailed documentation of the worn surfaces with the use of scanning electron microscopy as well as the investigation of the chemical composition. The obtained results are the basis for the developing a plan for further research. These will include the influence of the additional factors on the scuffing occurrence, such as the geometric structure of surface, the degree of the mechanical affinity of the friction pair, or the impact of the lubricant to reduce the scuffing.

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Streszczenie

Powierzchnie par ciernych współpracujących w ruchu oscylacyjnym narażone są na złożone procesy zużycia tribologicznego. Szczególnym przypadkiem procesu zużycia jest scuffing, które łączy elementy zużycia ściernego i adhezyjnego. W artykule przedstawiono wyniki badań wstępnych zużycia scuffing wykonanych przez autorów na testerze T-05. Badania przeprowadzono na modelu rolka–klocek o styku liniowym w ruchu oscylacyjnym. Wyniki badań zużyciowych potwierdziły, że dla przyjętych wartości parametrów istnieje duże prawdopodobieństwo rozwoju zużycia scuffing. Uzyskane wyniki są podstawą do planowania dalszych badań w tym zakresie.