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The formation of antiwear surface layers on elements of machine parts

K e y w o r d s

Thermal spraying, electro-spark deposition, laser treatment, coating.

S ł o w a k l u c z o w e

Natryskiwanie cieplne, powłoki elektroiskrowe, obróbka laserowa.

S u m m a r y

The paper deals with selected technological and research aspects of the formation of surface layers, the aim of which is to prevent wear of machine elements. Three main problem areas will be discussed. The first is the deposition of antiwear coatings with a solid lubricant using the plasma and HVOF spraying methods. Tests were conducted to analyse the changes in the properties of NiCrBSi coatings plasma or HVOF-sprayed with an addition of ferric oxide as a solid lubricant. It has been reported that the method of coating deposition affects the behaviour of the solid lubricant phase and that the addition of ferric oxide reduces the friction resistance. The second area of interest is the electrospark deposition of transition and antiwear layers on the surfaces of sliding bearing bushes. Tests were conducted to analyse the process of the formation of antiwear silver-indium-tin layers electrospark deposited on the B83 bronze bushes. It has been found that such thin (30 μm) and soft layers are effective and suitable for the processes of lapping and the formation of low-friction surface structures. The third problem is the formation of geometrical surface textures able to reduce the friction resistance and improve the load capacity. The test results refer to the technological aspects of texture formation using the laser erosion and electroerosion techniques.

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1. Introduction

Wear prevention activities are essential at each stage of the life of a technical object. Basic assumptions concerning the object durability and reliability are made as early as at the concept stage. It is also necessary that a designer prepare the details of a security standard concerning antiwear prevention and a process engineer make sure it is met at the manufacturing stage. During the service life, antiwear prevention activities focus on the durability assurance by proper usage. A majority of wear processes begin on the product surface, and the surface properties determine the product wear resistance. Of significance are sliding velocity, pressure, surface roughness, operation temperature, hardness, heat removal capacity, moisture, type of motion, and other factors related to the environment. The application of specially formed coatings or outer layers is one of the most rational and effective methods of wear prevention. There is a tendency to combine different properties in one coating, for example, wear resistance and lubricating ability (lubricant function).

2. Thermally sprayed coatings – containing a solid lubricant

The tests were carried out for NiCrBSi coatings known to be exceptionally resistant to various wear processes, including abrasive wear. The coatings can be deposited using various thermal spray techniques, and the most important of which are plasma spraying and HVOF spraying. Various materials can be added as solid lubricants; however, it is important that their properties do not change during the spraying process. An example of such a material is one of the forms of ferric oxide. The tests [3] involved analysing the effects of the spraying process on the destruction of the solid lubricant (FeO). It was significant to determine how the high temperature of the plasma spraying process and the substantial strains occurring during the HVOF spray process influence the lubricating ability of the coating. Figures 1 and 2 show the microphotographs of the input materials and their mixtures, respectively, obtained by means of a Joel scanning microscope.

The powder mixtures were deposited using two methods: plasma and HVOF spraying. The results of the linear analysis of the content and microstructure of the resulting coating are shown in Fig. 3. The structure of the coating obtained by HVOF spray is more uniform with a clearly smaller amount of oxides and pores (dark areas in the microsections). The lamellar structure is typical of the two methods of spraying. However, the lamellas are more deformed after the HVOF process, and in some areas their boundaries are not clear [14–38].

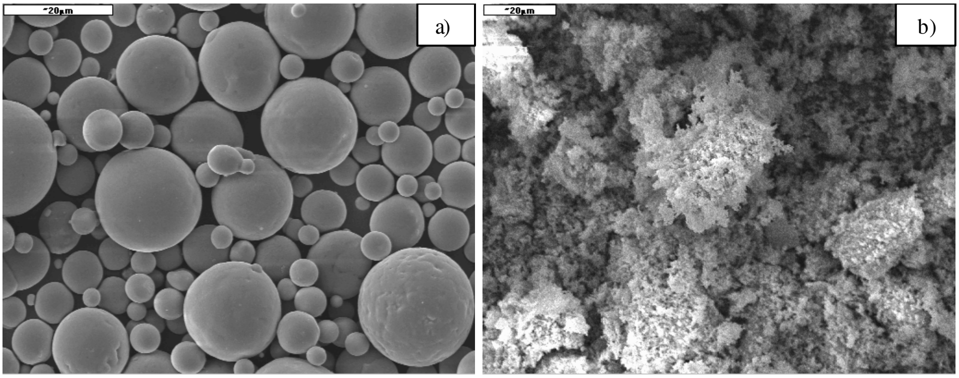

Fig. 1. Microphotographs of the input material (powders) a) NiCrBSi, b) Fe_2O_3
Rys. 1. Mikrofotografie materiałów wyjściowych (proszków) a) NiCrBSi, b) Fe_2O_3

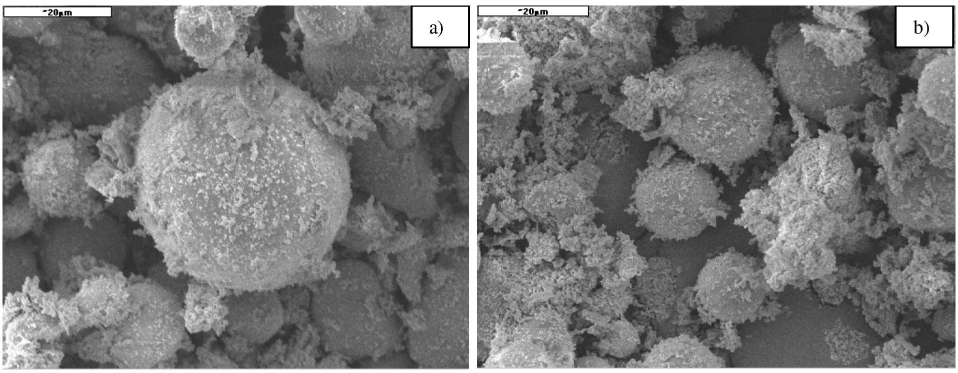

Fig. 2. Powder mixtures a) 90%NiCrBSi/10% Fe_2O_3, b) 60%NiCrBSi/40% Fe_2O_3
Rys. 2. Mieszanina proszków a) 90%NiCrBSi/10% Fe_2O_3, b) 60%NiCrBSi/40% Fe_2O_3

The plasma-sprayed coatings show microsections with iron compounds visible as dark areas. A diffractometric analysis of the phase composition shows that the ferric oxide in the form of hematite is found in the input material and in the HVOF deposited coating. The ferric oxide in the form of maghenite is reported in the plasma-sprayed coating. This confirms the occurrence of destructive transformations during the plasma spraying process.

The lubricating ability (seizure resistance) and wear resistance of the resulting coatings were analysed using a Falex test machine and a roller-block device. As can be seen from Fig. 4, an increase in the amount of ferric oxide causes an improvement in the antiseizure properties and a decline in wear resistance. An optimal content of ferric oxide is about 21% for HVOF-deposited coatings and 27% for the plasma-sprayed coatings. The results confirm the occurrence of an unfavourable transformation of the hematite form of ferric oxide into a form with no lubricating ability.

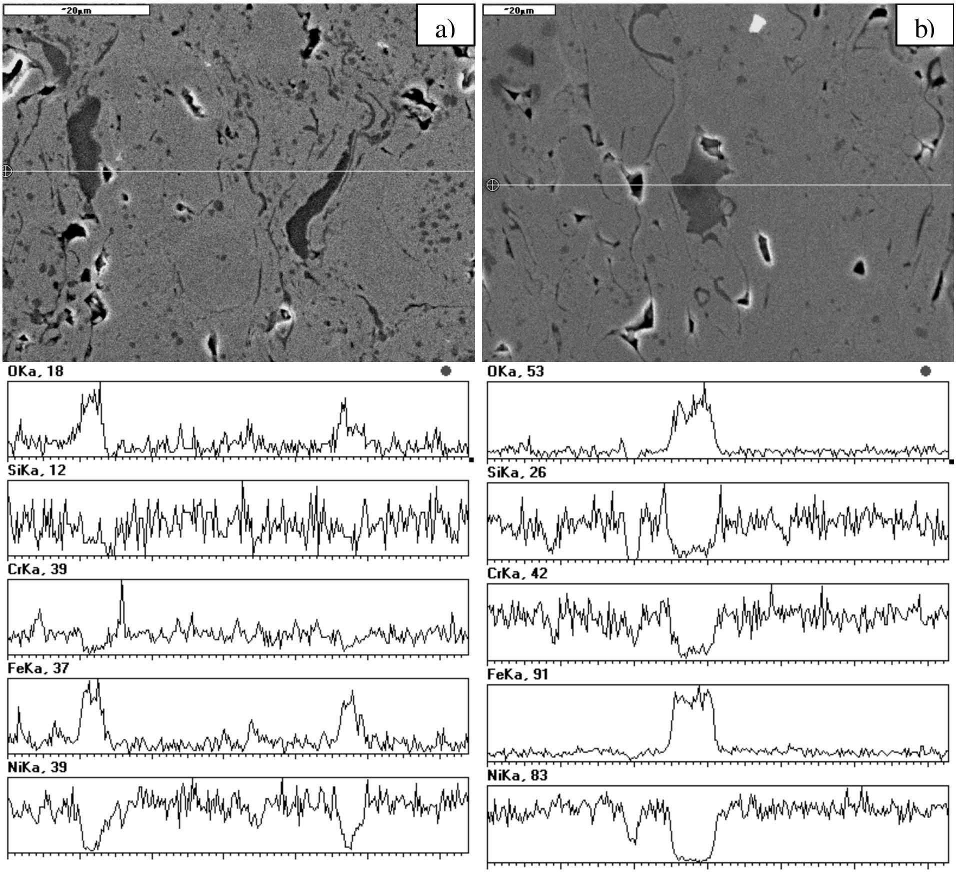

Fig. 3. Microstructure and linear analysis of the 50%NiCrBSi/50% Fe2O3 coating deposited by: a) plasma spraying, b) HVOF spraying
Rys. 3. Mikrostruktura i analiza liniowa powłok 50%NiCrBSi/50% Fe2O3 otrzymanych przez a) natrysk plazmowy, b) natrysk naddźwiękowy

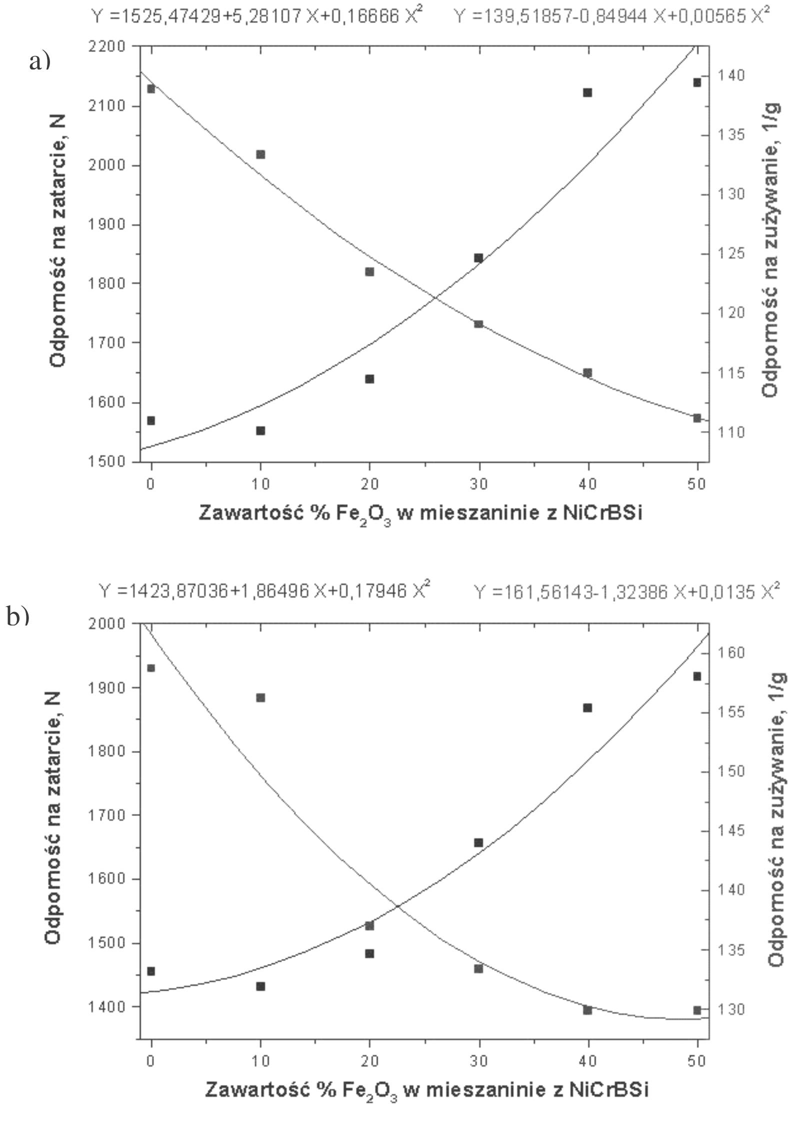

Fig. 4. Wear and seizure resistance of composite coatings with different percentage of Fe_2O_3 in the mixture with after a) plasma spraying, b) HVOF spraying
Rys. 4. Odporność na zużycie i zacieranie powłok z NiCrBSi zawierających różne udziały Fe_2O_3 natryskiwanych a) plazmowo b) naddźwiękowo

3. Antiwear layers obtained by electrodischarge machining

Among the numerous methods of outer-layer modification, the most important are those involving the deposition of metallic coatings with functional properties different from those of the substrate material. An example is the electrodischarge deposition process (EDM), which has been modified a number of times. Using this method, it is possible to apply locally thin (from several μm) or thick (up to several dozen μm) coatings of any metallic materials diffusely connected with the substrate. The tools for coating deposition are easy to use and inexpensive. The processes of coating formation on metallic elements, including the electrospark deposition, are accompanied by the transport of mass and energy as well as chemical, electrochemical, and electrothermal reactions [1–2]. Different varieties of the electrospark deposition method meet the standards of coating and surface microgeometry formation [1–4, 10–14].

Electrospark deposited coatings can be used to do the following:

- To protect new elements, and
- To regenerate worn elements.

The properties of electrospark coatings can be improved. One of the methods for coating improvement is laser treatment. A laser beam is applied to polish a surface, form the surface geometry, seal it or for uniforming the chemical composition of the resulting coatings. The electrospark technologies can be employed for the following:

- To form transition layers of copper, tin and tin bronze, the aim of which is to increase the adhesion to babbitt, tin and bronze bushes; and,
- To form silver-indium and tin layers, which are to facilitate the lapping of bronze and babbitt bushes.

As can be seen from the linear distribution of elements in Fig. 5a, the transition layer increases the adhesion of the tin coating by 35%. This is a result of a diffusive adhesion of the ESD layer with steel and the affinity of tin with the tin bronze of the transition layer. Figure 5b shows the analysis of the antiseizure indium layer electrospark deposited on babbitt bushes. The thin, easy to deform, indium layer adheres to the babbitt substrate. The results of in-service tests show that this solution is suitable for the lapping of elements and prevents the seizure of a bearing during the first hours of operation.

The tests also involved electrospark deposition of multilayer silver and brass coatings on a bronze bush. Three layers of the coating were differentiated as follows:

- The outer, softest layer (600MPa) with a height of 70–80 μm,
- the transition layer with a hardness of 1270–1400 MPa and a height of 50–60 μm,
- the matrix with a microhardness of 1050–1100 Mpa.

By electrospark alloying of a bearing alloy with indium and tin, it is possible to form an outer layer with a height of the order of 100–130 μm, containing the above elements and the substrate components. Its hardness is lower than that of the matrix. Such surface layers facilitate the lapping, because the accompanying plastic deformations are located in the thin, easy to deform, layer. It is, thus, possible to prevent seizure and, accordingly, increase the hardness and reliability of sliding bearings.

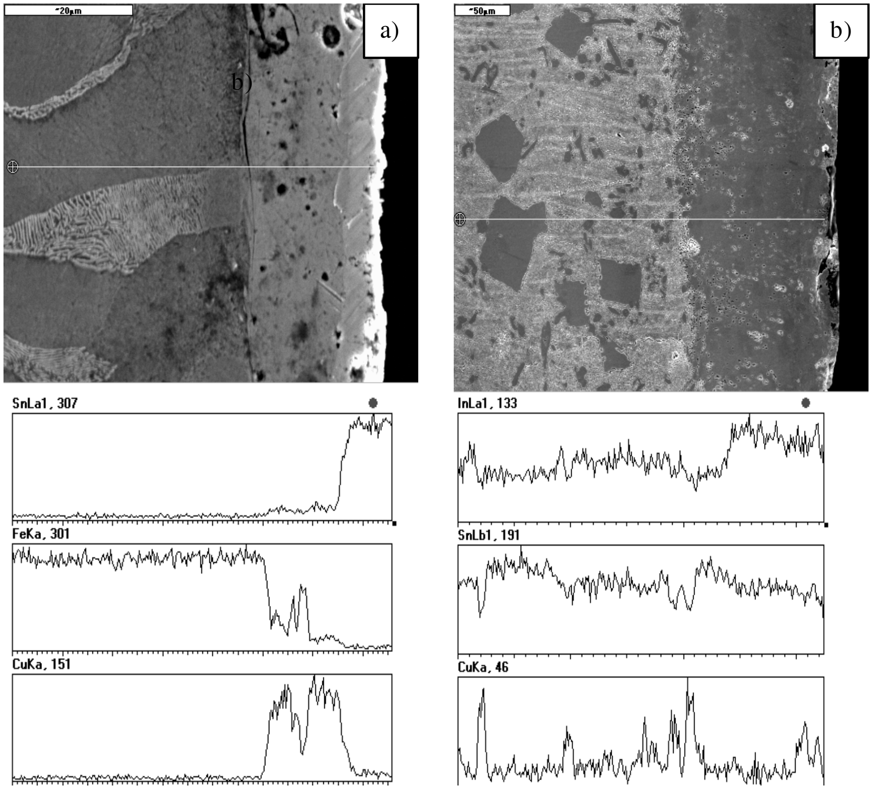

Fig. 5. Microstructure and linear composition analysis of a) a bush with a tin layer deposited on a tin bronze transition layer, b) a babbitt bush with an indium antiseizure layer deposited by EDM

Rys. 5. Mikrostruktura i liniowa analiza składu a) panewki z wylewanej cyny na warstwę przejściową z brązu cynowego, b) panewka babitowa z przeciwzatarciową warstwą indu nakładaną EEL

4. Surface texture formation

The states of the surfaces of the elements in a sliding pair have a substantial influence on the course of the friction and wear processes. In many cases, the surface state is responsible for the losses and indirectly for the general machine operation, i.e. efficiency. Additionally, in the case of combustion engines, the surface state affects the emission of toxic exhaust fume components. The formation of surface topography is becoming an increasingly important problem. Today, it is possible to form the surface micro- and macro-geometry by applying coatings of all shapes and dimensions locally and accurately. The texturing technology involving the formation of non-uniform surfaces using different methods has become very popular when the lubrication conditions of a friction pair need to be improved [5–9].

It should be noticed that the texturing processes used today mainly aim at the formation of surface geometry. The texturing processes responsible for the formation of physical properties, however, such as micro-local tempering and alloying, have not been analysed and applied sufficiently [5]. In certain applications, the texture efficiency is so high that the process can be standardised [1]. The most common technologies include the laser beam, electron, ion, as well as microelectroerosion and lithographic methods (Fig. 6).

One of the methods used for surface texturing is laser erosion, classified as a metal removal machining process usually performed at a power density of $10^6 \div 10^9$ W/cm^2. Today, it constitutes 2% of all the laser-based methods used in the world. A laser impulse causes evaporation of the material removed. It is recommended that, during the process, gas (air or neutral gas) be blown to remove the non-evaporated melted material from a gap. The gap depth is dependent mainly on the power density and the time of duration of the laser beam impulse.

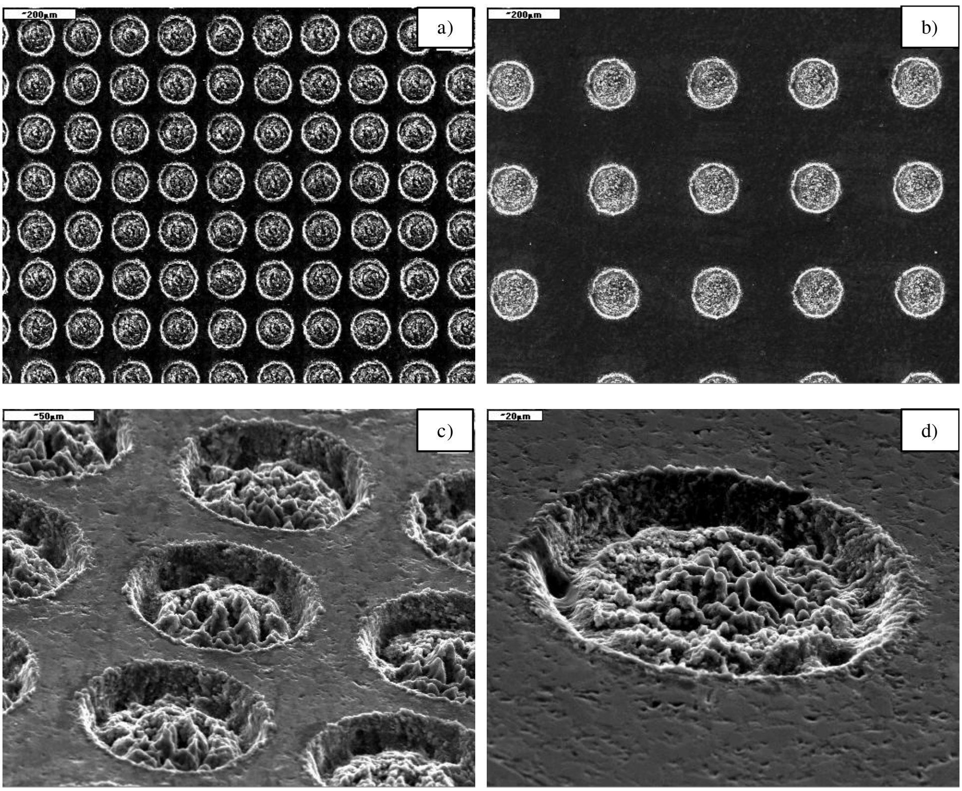

Fig. 6. View of the laser-textured surface a) degree of blackening – 51%,
b) degree of blackening – 23%, c), d) views of the cavities
Rys. 6. Widok powierzchni teksturowanej laserowo a) stopień zaczernienia 51%,
b) stopień zaczernienia 23%, c), d) widoki pojedynczych wgłębień

The tests were conducted for SiC rings with the following dimensions: outer diameter, d_o = 35.3 mm, inner diameter, d_i = 25.1 mm, height, h = 7 mm. The ring surfaces were textured with an ESI 5200 Nd:YAG laser (impulse mode). The laser operated at the third harmonic (wavelength λ = 355 nm).

The following parameters of the laser erosion process were assumed on the basis of the results: the range of laser spot diameters, d = 0.78 – 150 μm; the range of laser power, P = 0.37 – 0.4 W; the range of the beam velocity V = 15.7 – 23.56 mm/s; the distance from the focus Δf = 0 mm; and the frequency of repetition, f = 6400 Hz.

The cavities were formed in two stages (two steps). In the first stage, the laser moved along a spiral path drilling a cavity up to a specified diameter. During the second step, the remaining products of the machining process were removed from the cavity bottom with single laser impulses (strokes), their number and frequency being pre-determined.

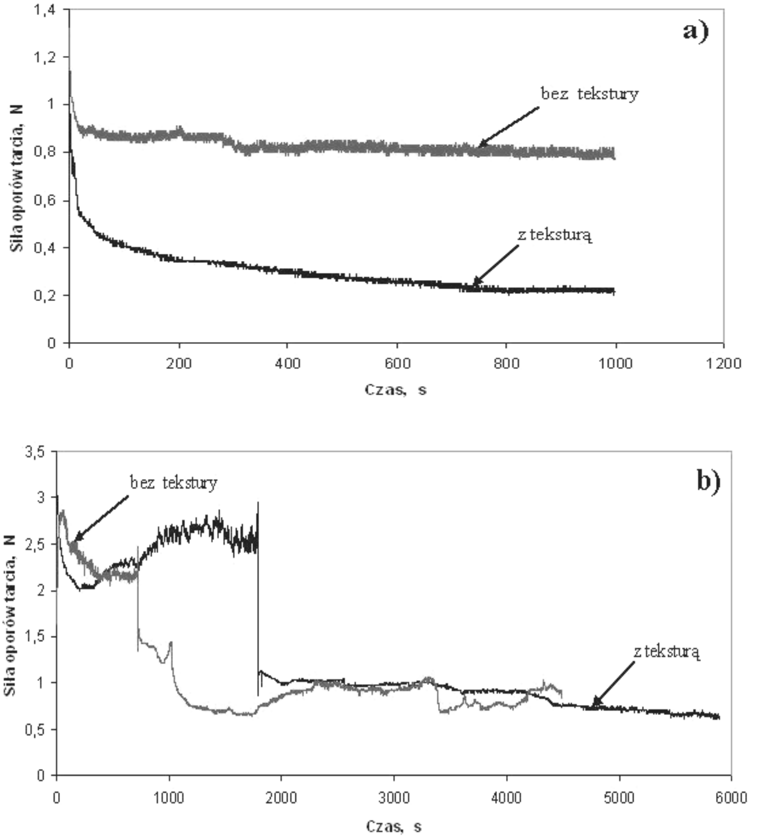

Fig. 7. Results of tribological tests obtained for specimens with and without texture: a) v = 0.6 m/s and Q = 25 N, b) v = 1 m/s and Q = 15 N

Rys. 7. Wyniki badań tribologicznych – próbka z teksturą oraz próbka bez tekstury: a) v = 0,6 m/s i Q = 25 N, b) v = 1 m/s i Q = 15 N

The tribological tests were conducted by means of a T-01M pin-on-disc device; however, the pin was replaced by a bearing ball with a diameter of 6.3 mm chamfered in such a way that the circular flat surface had a diameter of 4.5 mm. The ball was mounted in a fitting frame, which made it possible for the flat surface to be arranged parallel to the ring in contact. The extensive research described is now at the recognition stage.

Two series of tests were conducted, and the objective was to assess the suitability of the research method. The experiments involved observing the changes in the friction resistance during the comparative gears of the test machine using textured and non-textured rings.

The first series of tests performed at various rotational velocities ($v_1 = 0.3$ m/s, $v_2 = 0.6$ m/s and $v_3 = 1$ m/s) and various loads ($Q_1 = 10$ N, $Q_2 = 25$ N and $Q_3 = 40$ N) involved continuous wick lubrication with a paraffin oil (Fig. 7a). In the second series, the sliding velocity was v = 1 m/s and the load was Q = 15 N. The test gear included a dry mode followed by a wet mode. A drop of lubricant - cosmetic kerosene or paraffin oil - was applied on the ring raceway only once. It was necessary to measure the time after which the value of the friction coefficient increased (Fig. 7b).

The results show that the method used in the tests is suitable for assessing the effectiveness of the geometrical surface texture of sliding pairs under mixed friction. The texture cavities were used as micro-containers of the lubricant. Their influence on the friction process was determined.

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Kształtowanie przeciwzużyciowych warstw powierzchniowych na elementach części maszyn

S t r e s z c z e n i e

W referacie poruszone są wybrane problemy technologiczne i badawcze dotyczące kształtowania warstw powierzchniowych, ukierunkowane na ograniczenie zużycia części maszyn. W szczególności zaprezentowane zostaną trzy problemy.

I problem – natryskiwanie plazmowe i naddźwiękowe powłok przeciwzużyciowych zawierających w swojej strukturze smar stały. Wyniki prezentowanych badań dotyczą zmian własności powłok z NiCrBSi natryskiwanych plazmowo i naddźwiękowo z dodatkiem tlenku żelaza jako składnikiem stanowiącym smar stały. Wykazano wpływ sposobu natryskiwania na zachowanie się fazy stanowiącej smar stały oraz stwierdzono skuteczność dodatku tlenku żelaza jako dodatku zmniejszającego opory tarcia. II problem – wytwarzanie metodą elektroiskrową warstw przejściowych oraz przeciwciernych na powierzchniach panewek łożysk ślizgowych. Wyniki przeprowadzonych badań dotyczą wytwarzania przeciwciernych warstw ze srebra, indu i cyny nanoszonych elektroiskrowo na powierzchnie panewek wykonanych z brązu B83. Wykazano skuteczność i przydatność tych cienkich (30 µm) i miękkich warstw w procesie docierania i tworzenia niskotarciowych struktur powierzchniowych. III problem – kształtowanie geometrycznej tekstury powierzchniowej dla obniżenia oporów tarcia i zwiększenia siły nośnej. Wyniki przedstawionych badań dotyczą zagadnień technologicznych wykonania tekstury metodą erozji laserowej i elektroerozji.