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DIFFUSION LAYERS FORMED ON STEEL AND THEIR WEAR BEHAVIOUR

WARSTWY DYFUZYJNE WYTWORZONE NA STALI I ICH WŁAŚCIWOŚCI TRIBOLOGICZNE

Key words:

structural and tool steels, boriding, carburizing, nitriding, chromizing, “3 cylinder-cone” method

Słowa kluczowe:

stale konstrukcyjne i narzędziowe, borowanie, nawęglanie, azotowanie, chromowanie, metoda: „3 wałeczki – stożek”

Abstract

The article presents the results of investigations of wear resistance by friction, employing the “3 cylinder-cone” method, of selected structural and tool steels, subjected to given thermo-chemical treatment, i.e. boriding, carburizing, nitriding and chromizing. It was observed that a proportionality exists between their wear resistance and the value of surface unit loading. Moreover, the friction-wear properties of these layers exhibited certain differences, dependent on their microstructure and chemistry.

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INTRODUCTION

Among the many methods of generating a surface layer from the point of view of its advantageous tribological properties, a significant place is occupied by the formation of diffusion layers by, e.g., thermo-chemical treatment. Such treatment constitutes one of the most effective methods of the shaping of the surfaces mating during friction, which helps to minimize tribological wear. Of the technological processes of forming diffusion layers with just such properties, the majority has been developed by the Institute of Precision Mechanics **[L. 1, 2, 9]**.

Such diffusion layers are diversified from the point of view of their structure and physicochemical properties. Within the extent of their existence, occurs changes in chemical compositions, microstructures and often phase compositions, which cause a diversification of properties in their particular zones. Additionally, it is not always that the generated layer is totally utilized during service of machine components. This is connected, on the one hand, with allowable wear. On the other hand, this is often due to the necessity of the removal of the superficial portion of the layer to correct the shape and size or in order to achieve a specified grade of surface roughness.

Numerous works have been devoted to the effect of determining friction-wear properties of materials, but relatively only a few pertain to diffusion layers **[L. 3, 10]**. The small number of research works devoted to the problems of the co-dependence of friction-wear properties and the determination of types of diffusion layers formed in different technological processes has inspired investigations undertaken at the Institute of Precision Mechanics. Their topics encompassed the following types of layers: carburized, nitrided, borided, and chromized. The standardized "3 cylinder- cone" test was selected as the method of evaluation of their tribological properties **[L. 4]**.

DESCRIPTION OF INVESTIGATIONS OF DIFFUSION LAYERS CARRIED OUT

Selected grades of steel (types of diffusion layers)

For the thermo-chemical processes, enabling the formation of the appropriate diffusion layers, corresponding structural, or tool steels were selected which were especially useful for the formation of the types of layers to be investigated. A list of these steel grades and heat treatments conducted before or after the thermo-chemical treatment is given in **Table 1**.

Conditions of generating the layers, as well as those of heat treatment before or after the thermo-chemical treatment are also given in **Table 1**.

The process of diffusion boriding was carried out by the powder pack method. Proportions of powder constituents were selected to ensure the obtaining of single phase layers made up of Fe_2B type borides. After boriding, the samples were subjected to additional heat treatment that enabled the hardening of the underlying substrate, as well as a reduction in brittleness and residual stresses in the layer **[L. 5, 11]**.

Table 1. Conditions of formation of diffusion layers and corresponding thermal treatment
Tabela 1. Warunki wytwarzania warstw dyfuzyjnych i obróbki cieplnej

No.	Type of thermo-chemical treatment	Steel grade	Process parameters			Heat treatment
			Temperature T [°C]	Time τ [h]	Environment	
1	Boriding	C45 (1045)	950	5	Boron carbide, borax, ferro-boron, potassium fluoroboron	Normalizing at 900°C, quenching from 850°C, tempering at 200°C, 2h
2	Carburizing	18HGT	930	6	Controlled atmosphere with carbon potential = 0.85%	Quenching directly from carburizing temperature, tempering 180°C, for 2h
3	Nitriding		530	6	NH_3 – N_2 type controlled atmosphere	Quenching from 860°C and tempering 600°C, for 3h prior to nitriding
4	Chromizing	C85W1	950	4	Chromizing powder pack	Quenching from 840°C, tempering 200°C, for 2h after chromizing

The nitriding and carburizing processes were carried out in controlled atmospheres, enabling the formation of a layer with a predetermined surface concentration of nitrogen and of carbon **[L. 6, 12]**. Nitriding was preceded by quenching and tempering, usually applied before this process in order to enhance the strength properties of the core. Carburizing was carried out with quenching directly from the carburizing temperature, which enabled the shortening of the joint time of the process of formation and hardening of the case, as well as diminishing of deformation.

The chromizing process was carried out in a powder pack in which the chemical composition of the powder constituents was selected to obtain a layer with a microstructure of $(Cr,Fe)_7C_3$ chrome-iron carbides, which is beneficial from the point of view of minimization of wear by friction **[L. 7**, **13]**.

Metallurgical characteristic of the investigated diffusion layers

The layers prepared for the investigations corresponded to the thicknesses and hardnesses of those usually recommended in industrial practice, from the point of view of microstructure, and the characteristics are given in **Table 2**. The thickest – carburized case with a martensitic microstructure – featured the lowest surface hardness, and the thinnest were the chromized layers obtained on tool steels.

Table 2. Metallurgical characteristic of obtained layers
Tabela 2. Charakterystyka metaloznawcza warstw dyfuzyjnych

No.	Type of layer	Steel grade	Process parameters T[°C]/t[h]	Description of microstructure	Thickness of layer g [mm]	HV 0.5 Hardness of Surface/core
1	Boriding	C45	950/5	Fe_2B ferroboride	0.20	1420 / 510
2	Carburizing	18HGT	930/6	Martensite with a subsurface zone of retained austenite	0.95	745 / 460
3	Nitriding		530/6	Subsurface zone of $\varepsilon + \gamma'$ carbonitrides and nitrides and a solid solution zone ($Fe_\alpha[N]$)	0.16	826 / 268
4	Chromizing	C85W1	950/4	$(Cr, Fe)_7 C_3$ Ferro-chrome carbide	0.015	1900 / 710

Tribological properties of diffusion layers

In the investigations of tribological properties of diffusion layers, the standardized 3 cylinder-cone method was adopted **[L. 4]**, and this method was used to determine the linear wear of borided, carburized, nitrided, and chromized layers. Friction tests were conducted while maintaining an approximately constant unit loading at a preselected level. The mating material was C45 (Equiv. 1045 AISI) steel in each case, which were quenched and tempered to ca. 30 HRC, from which the conical counter-specimens were made. The joint duration of the test was 100 min. Wear was measured during interruptions of the test every 10 min, followed by raising the unit loading appropriately to the growing wear surface.

Sliding wear tests were carried out with lubrication by Lux-10 oil, metered into the mating pair. Linear wear was characterized by total wear obtained during the entire test and denoted z_l [μm], and also by the intensity or rate of wear – I_l [μm/m]. Tribological properties of the diffusion layers were portrayed by 3D plots that characterized the wear processes as a function of sliding friction time and surface unit loading. This type of investigation, as applied to different materials and diverse thermo-chemical treatments, as well as differing experimental methods, have been carried out at the Institute of Precision Mechanics for many years **[L. 8]**. In this work, the tests were carried out on borided, carburized, nitrided, and chromized layers. Their results are portrayed accordingly by **Figs. 1 – 4**. **Figure 1** shows the effect of surface forces in the range of 50 – 600 MPa on the wear and wear intensity of borided 1045 grade steel. In the case of this steel, one does not observe the effects of accelerated wear or seizure until the unit loading reaches the level of 200 MPa. Above this value of unit loading, such effects do occur.

Wear of carburized 18HGT grade steel is shown in **Fig. 2**, as determined under unit loading within the range of 50 – 600 MPa. For this case, a rise of unit loading above 200 MPa causes clearly noticeable acceleration of linear wear, conducive to seizure under a unit loading of ≥ 400 MPa.

Figure 3 shows the effect of unit loading within the range of 50 – 600 MPA on the wear of a nitrided layer on 18HGT grade steel. A clear intensification of wear vs. unit loading is characteristic of the behaviour of this layer, but no accelerated wear is observed up to 200 MPa. However, such acceleration is present under 400 MPa, and even more so under 600 MPa, where seizure phenomena were observed.

Characteristics of linear wear of a chromized layer on a plain carbon tool steel of the C85W1 grade vs. the length of the friction path and surface unit loading applied within the range of 100 – 400 MPa are shown in **Fig. 4**. No signs of accelerated wear or seizure were observed within this range.

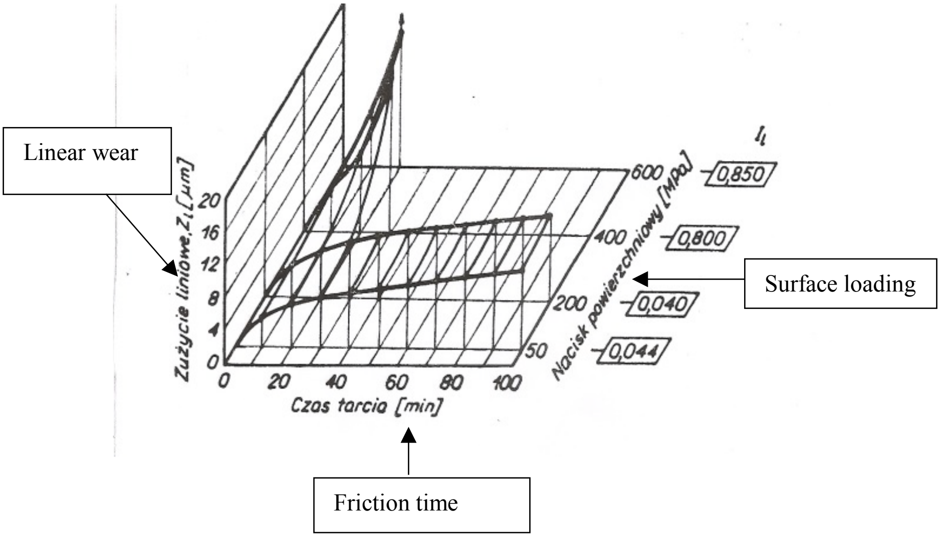

Fig. 1. **Linear wear of borided layer vs. friction time and surface loading. Numerical values next to plot – wear intensity – I_l [µm/m]**

Rys. 1. Zużycie liniowe warstwy borowanej w zależności od czasu tarcia i nacisków powierzchniowych. Wartości liczbowe obok wykresu – intensywność zużywania – I_l [µm/m]

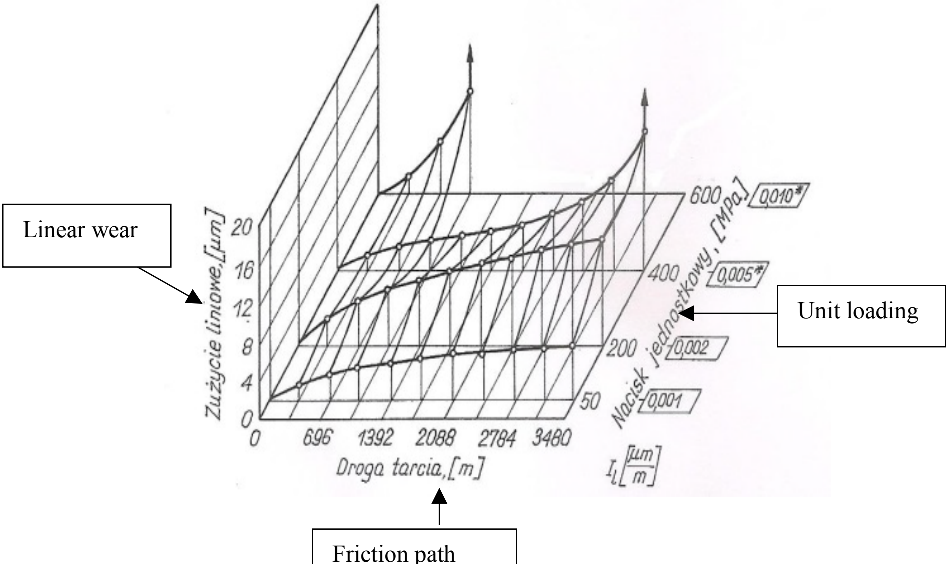

Fig. 2. **Linear wear of carburized layer vs. length of friction path and applied unit loading (numerical values next to plot – wear intensity, I_l). ↑ – denotes accelerated wear or seizure**

Rys. 2. Zużycie liniowe warstwy nawęglanej w zależności od drogi tarcia i nacisków jednostkowych (wartości liczbowe obok wykresu – intensywność zużycia, I_l). ↑ – zużycie przyspieszone lub zatarcie

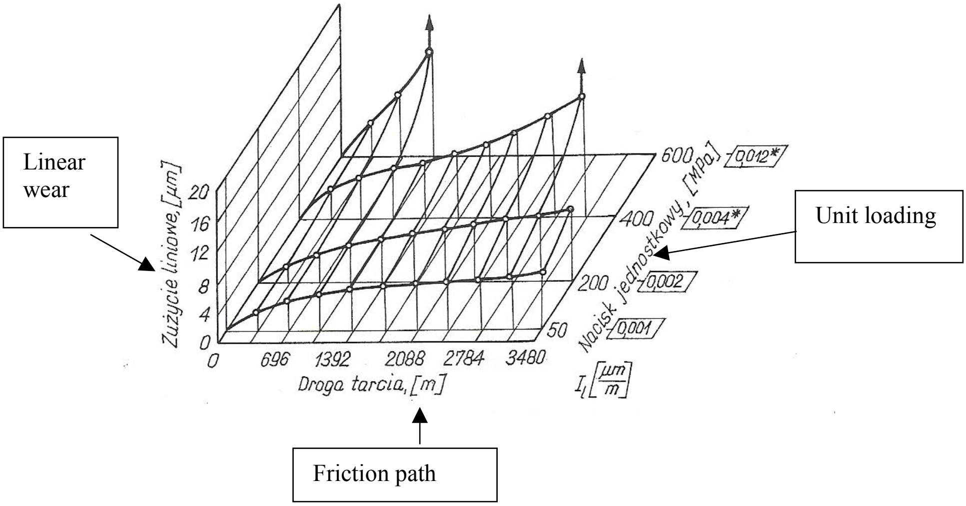

Fig. 3. Linear wear of nitrided layer vs. friction path and applied unit loading (numerical values next to plot – wear intensity, I$_l$). ↑ – denotes accelerated wear or seizure

Rys. 3. Zużycie liniowe warstwy azotowanej w zależności od drogi tarcia i nacisków jednostkowych (wartości liczbowe obok wykresu – intensywność zużycia, I$_l$). ↑ – zużycie przyspieszone lub zatarcie

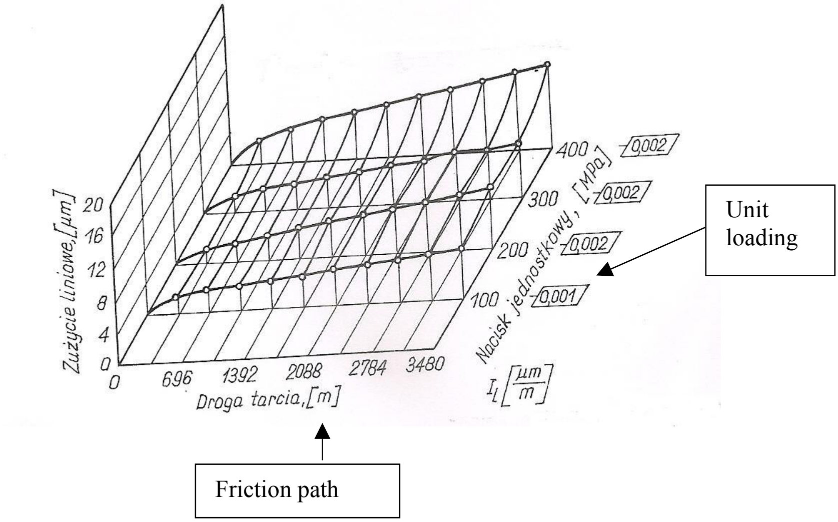

Fig. 4. Linear wear of chromized layer vs. length of friction path and applied surface unit loading (numerical values next to plot – wear intensity, I$_l$)

Rys. 4. Zużycie liniowe warstwy chromowanej w zależności od drogi tarcia i nacisków jednostkowych (wartości liczbowe obok wykresu – intensywność zużycia, I$_l$)

CONCLUSIONS

1. Results of the investigations of the tribological properties of diffusion layers for selected versions of thermo-chemical treatment have demonstrated a clear, directly proportional correlation between their wear resistance and the applied values of unit loading of the surface.
2. The investigations have demonstrated that resistance to wear by friction, determined for each type of the diffusion layers, is also similarly diversified, since these layers differed in structure and composition.
3. The investigated layers, exhibiting differences in microstructure, thickness and hardness, showed differences in total wear, as well as in wear rate, depending on their microstructure and composition. Thus, the thinnest and, at the same time, the hardest of the, i.e. the chromium carbide, exhibited the highest wear resistance.

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Streszczenie

W artykule przedstawiono wyniki badań odporności na zużycie przez tarcie metodą: „3 wałeczki–stożek" wybranych stali konstrukcyjnych i narzędziowych poddanych określonej obróbce cieplno-chemicznej, tj. borowaniu, nawęglaniu, azotowaniu i chromowaniu. Zauważono wprost proporcjonalną zależność ich odporności na zużycie od wartości nacisków powierzchniowych. Ponadto właściwości tarciowo-zużyciowe tych warstw wykazały pewne różnice zależne od ich struktury i budowy.