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EFFECT OF SURFACE LAYERS OF STEEL ON WEAR-RESISTANCE ION ABRASIVE ENVIRONMENTS

Abstract

Introduction and aim: The article highlights the results of experimental research of the impact of different structures of steels with different thermal (hardening for different temperatures) and chemical-thermal (carburizing, ion nitriding, nitrohardening) treatments for their wear resistance in abrasive medium that simulated conditions of the extruder running when manufacturing feed grain mixed fodder with the additives of mineral saponite.
Material and methods: Structural steels including stainless steel. Test methods for wear in abrasive environments.
Results: There is a linear dependence of wear resistance on hardness in abrasive medium for alloys with stable surface structure.
Conclusion: For alloys with unstable structure that are able to change under the influence of abrasive wear, it is necessary to take into consideration the structural state of the material surface and wear resistance depends mainly on the completeness of structural changes in the wear process.

Keywords: Extruder, steel, wear resistance, mineral saponite.

WPŁYW POWIERZCHNIOWYCH WARSTW STALI NA ODPORNOŚĆ NA ZUŻYCIE ŚCIERNE

Streszczenie

Wstęp i cel: *Artykuł podkreśla wyniki badań eksperymentalnych wpływu różnych struktur stali z termicznymi (hartowanie w różnych temperaturach) i chemiczno-termicznymi (nawęglanie, azotowanie jonowe, nitro-utwardzanie) zabiegami dla ich odporności ścieranie w ośrodkach ściernych dla symulowanych warunków wytłaczarki pracującej przy produkcji mieszanek paszowych z paszowego ziarna z dodatkami saponitu mineralnego.*
Materiał i metody: *Stale konstrukcyjne, w tym stale nierdzewne. Metody badań zużycia w środowiskach ściernych.*
Wyniki: *Istnieje liniowa zależność odporności na ścieranie na twardość ściernego w przypadku stopów o stabilnej strukturze powierzchni.*
Wniosek: *W przypadku stopów o niestabilnej strukturze, które są w stanie zmienić się pod wpływem ścierania, konieczne jest wzięcie pod uwagę iż struktura stanu powierzchni materiału i odporność na zużycie zależy głównie od kompletności strukturalnych zmian w procesie zużycia.*

Słowa kluczowe: *Wytłaczarka, stal, odporność na ścieranie, saponit mineralny.*

1. Introduction

To study the influence of the structure of the surface layers on their wear resistance the samples were made of different steels (Tab. 1), that were treated in various thermal and chemical- thermal conditions (hardening for different temperatures, ion nitriding, carburizing and nitrohardening). This made it is possible to obtain different structures of base materials (martensite, austenite) and the surface layers with carbide and nitride phases.

Table 1. Chemical composition of steels for research

№	Steel grade	Chemical composition, %							
		C	Mn	Cr	Si	Ni	S	P	Cu
1	Steel 1	0.2	0.45	<0.25	0.2	<0.25	<0.04	<0.04	<0.25
2	Steel 2	0.45	0.6	<0.25	0.2	<0.25	<0.04	<0.035	<0.25
3	Steel 3	0.8	0.25	<0.2	0.25	<0.25	<0.028	<0.03	<0.25
4	Steel 4	0.98	0.3	1.5	0.25	<0.3	<0.02	<0.027	<0.25
5	Steel 5	2.1	0.35	12	0.2	<0.35	<0.03	<0.03	<0.3
6	Steel 6	0.4	0.5	1.45	0.3	<0.3	<0.025	<0.025	<0.3

The research was carried out on a special friction machine [1], [2] (Fig. 1) at the pressure of 4 MPa, sliding speed of 1.37 m/s and the temperature of 120-140 °C in model abrasive medium that simulated the conditions of the extruder running when manufacturing feed grain mixed fodder with saponite additives. Model abrasive medium was a water solution of flour with 10% of saponite. Saponite additive, containing more than 20 elements and microelements, significantly improves the livestock yield. Furthermore, mineral saponite includes abrasive particles of quartz sand.
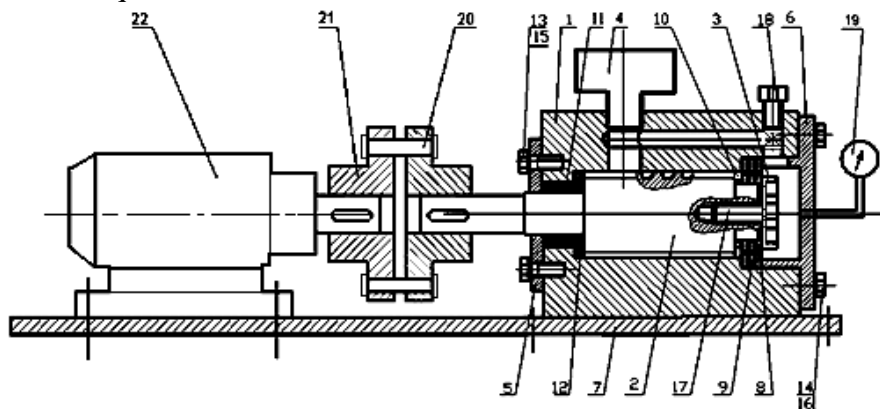

Fig. 1 Machine of friction:1 - trunk; 2 - shaft with sliced it turns screw, 3 - puck fixing samples, 4 - tank with the model solution, 5-6 - trunk lid, 7 - base, 8-9 - samples, 10 - bush; 11-12 - bushings with antifriction material, 13-14 - screws fixation lids; 15-16 - washers, 17 - screw fixation of samples, 18 - adjusting screw of environment pressure; 19 - gauge, 20 - pin couplings, 21 - clutch, 22 - engine
Source: Elaborated by the Authors

In the process of chemical-thermal treatment gradient hardening coatings are formed on the material surface. These coatings have different phases and negative hardness gradient in depth due to variable concentrations of diffusant and its compounds with the metal. Such compounds cause the changes in the structure of the material. Nitriding cause the generation of a solid solution of nitrogen in iron (α-phase, the concentration of nitrogen to 0.1%), which has lattice of bcc structure; solid solution based on compound Fe_4N (γ'-phase, the concentration of nitrogen to 6%) with face-centered lattice; solid solution based on nitrides $Fe_{2-3}N$ (ε-phase, the concentration of nitrogen to 11%), hexagonal lattice. ε-phase has a maximum hardness,

high corrosion resistance, but it is very fragile. γ'-phase is characterized by lower hardness but higher ductility. α-phase has the lowest hardness. Alloying elements (Cr, Mo, W, Al, V, etc.) in the structure of the material increase the surface hardness of the material due to the formation of nitrides of alloying elements. The hardness of steel 6 is almost 2 times higher than of steel 2.

2. Results of the research

Table 2 and Fig. 2 show the results of the research of steel 5 properties (hardness, retained austenite and wear intensity) after hardening for different temperatures. Studies have shown that the hardness of the nitrided layer varies with the change of hardening temperature. The maximum hardness is achieved at 975°C when its structure contains the maximum amount of martensite (44%), 36% of austenite and 20% of carbides. Decrease in hardness after hardening at temperatures below 975°C is explained by the formation of soft ferrite component in the structure of material that is a part of troostite, which is characteristic for incomplete hardening of tool steels.

At a hardening temperature above 975°C hardness also decreases, and this is explained the increases of retained austenite in its structure. The increase of hardening temperature increases the alloying of solid solution by chromium and carbon as a result of carbide dissolution. As a result, steel has more retained austenite and less martensite. The hardness of steel is continuously decreasing and at hardening temperature above 1150°C the structure of steel 5 contains 93% of retained austenite, 5% of carbides and 2% of martensite.

The study of steel 5 wear resistance in model solution showed that minimum wear intensity ($1,1 \times 10^{-8}$) is achieved at 1050°C of hardening with approximately 55% of austenite, 21% of martensite and 14% of carbides. Wear intensity at 900°C of hardening was 1.65×10^{-8}, that is 1.5 times higher than at hardening temperature of 1050°C. This happens because troostite structure contains ferrite and greater amount of martensite. Thus, the tendency of increasing steel wear resistance with the increased content of retained austenite in its structure and the decreased amount of martensite is observed.

Table 2. Characteristics of steel 5 after hardening.

№	Hardening temperature T, °C	Surface microhardness H_{100}, MPa	Content of retained austenite A, %	Wear intensity $I \times 10^{-8}$ after the way 3×10^3 м	Surface microhardness after friction way 3×10^3 м
1	900	6900	19	1.65	7000
2	950	7090	28	1.37	7100
3	1000	7040	40	1.15	7090
4	1050	6700	55	1.1	6900
5	1100	5900	72	1.65	6300
6	1150	4800	93	2.6	4900

The tendency of increasing steel 5 wear resistance structure with the increased amount of retained austenite and decreased amount of martensite in its structure at hardening temperature above 1050 ° C is likely to continue if the stability of austenite remains constant. However, the raised hardening temperature simultaneously with the increased content of austenite decreases its sensitivity to phase $\gamma \rightarrow \alpha$ transformation in abrasive wear in the model solution.

As a result, the value of surface strengthening is reduced and the total resistance to destruction in abrasive wear of steel 5 is reduced in comparison with the maximum value at a hardening temperature of 1050°C. Fig. 2 shows that wear intensity at 1150 °C of hardening was 2.6×10^{-8} that is almost 2.5 times greater than at 1050 °C.
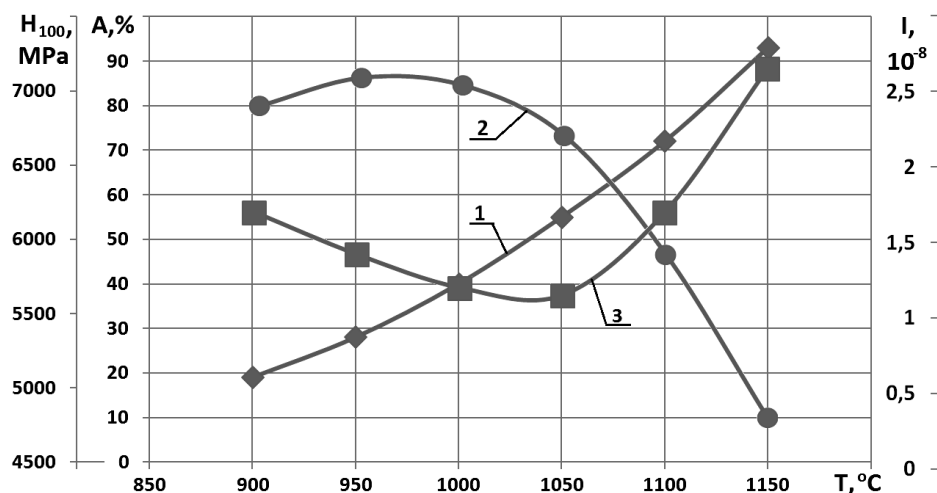
Fig. 2 Characteristics of steel 5 depending on hardening temperature: 1 - content of austenite A%; 2 - surface microhardness H_{100}, MPa, 3 - wear intensity $I \times 10^{-8}$
Source: Elaborated by the Authors

The ability of a large amount of retained austenite to resist the destruction by abrasive wear shows deep internal changes occurring in the austenite. Plastic deformation by abrasive particles in wear process causes decomposition of metastable retained austenite into martensite. This increases the hardness of the friction surface (fig. 3). This is confirmed by X-ray studies [3] of steel wear with high content of retained austenite in which the original content of martensite increased from 20% to 60%, and microhardness increased in 1.3 times.

Plastic deformation is accompanied by the slip of some layers of material. The slip as the result of plastic deformation is connected with the motion of a large number of dislocations on slip area and everything that obstructs their motion complicate the slipping. Therefore, the motion of dislocations in the structure of the material is obstructed by secondary phases, atoms of alloying elements, granule brims and even vacancies in the lattice. Pinning of dislocations generated during deformation of the material, maintains the hardened state in a material after removal of external loads. Therefore, the success of alloys hardening depends on effective obstruction to the motion of dislocations [4]. Metallographic studies [3] prove that in the process of abrasive wear the traces of plastic deformation can be observed at a considerable distance from the edge of the recess on the working surface, that is 10 microns on hardened and 30-40 on non-hardened steels. The number of dislocations in very deformed layers reaches 24.1×10^{12} per cm^2 [5].

Thus, phase transformations, a large number of dislocations under the influence of plastic metal deformation on friction surface and, as a consequence, the significant slowdown and pinning of dislocations are the reason of increasing ability of steels with high content of retained austenite to resist to abrasive wear and increase of their wear resistance.

The figure 4 shows the results of experimental study of the properties of steel 5 after nitriding with previous hardening and nitrohardening (nitriding followed by hardening).

The studies have shown that when nitriding steel 5 with previous hardening the surface microhardness gradually decreases with the increase of hardening temperature on linear dependence (fig. 4 straight line 3). This is caused by the increase of retained austenite in the structure after hardening. During nitriding retained austenite decomposes because of low temperature of its martensitic transformations (less than 290°C) at temperature of nitriding and its contents after nitriding does not exceed 10% (fig. 4 curve line 1).The structure of the material is almost stabilized due to the small number of metastable phases. The intensity of surface wear increases with the increase of steel hardening temperature that is explained by the decrease in the hardness of the material.
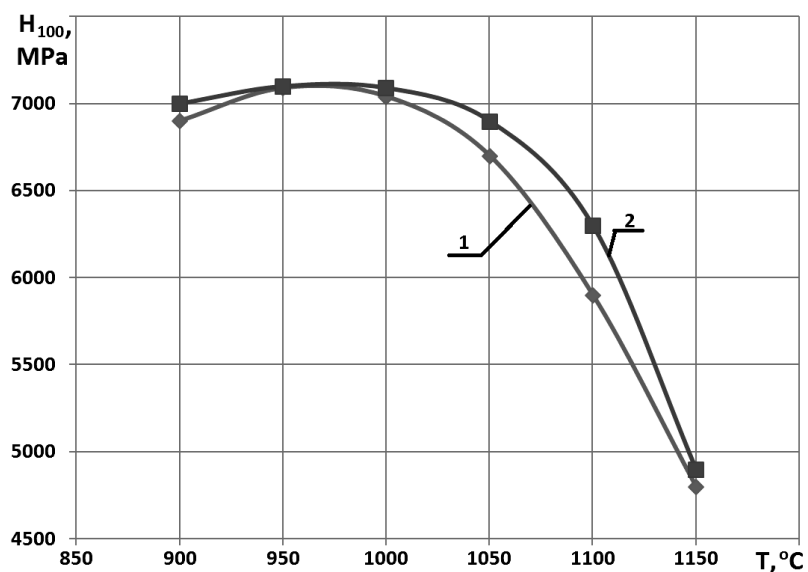
Fig. 3 The changes of microhardness of steel 5 surface layer depending on hardening temperature: the beginning of tests (1) and after tests (2) on wear in model solution (friction way 3×10^3 m).
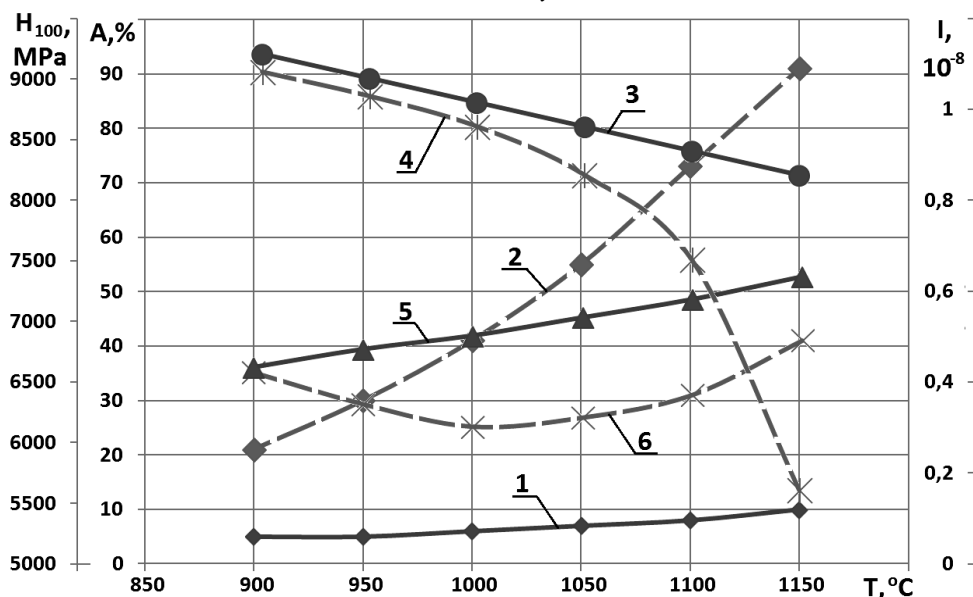*Source: Elaborated by the Authors*

Fig. 4 Characteristics of steel 5 after nitriding (continuous line) and nitrohardening (dashed line):
1-2 austenite content, 3-4 microhardness of the surface layer;
5-6 wear intensity after friction way 3×10^3 m.
Source: Elaborated by the Authors

At nitrohardening, unlike nitriding, hardening with the increase of temperature the content of retained austenite increases significantly and at 1150 $^{\circ}$C of hardening it is 91%. Maximum surface microhardness is 9050 MPa at 900°C of hardening, that is 150 MPa lower than at nitriding. Surface microhardness decreases depending on the temperature of nitrohardening and on greater amount of austenite in the structure of the material. The minimum hardness at nitrohardening is 5600 MPa, that is 1.5 times less than at nitriding. This is explained by a large amount of retained austenite, that has low hardness and a minimum amount of martensite. The increase of the minimum surface hardness at nitrohardening to 800 MPa in comparison with the minimum hardness at hardening is explained by the content of oxide and nitride phases in the surface. Wear intensity at nitrohardening is much lower than at nitriding (fig. 4 curve lines 5, 6). Minimum wear intensity (0.3×10^{-8}) is achieved at 1030-1050 $^{\circ}$C of hardening and 45-

55% of retained austenite, that is 1.5 times less when compared with nitrided and 3.7 times less when compared with hardened steel 5. The regularity of influence of retained austenite on wear intensity of nitrohardened steel 5 is similar to the regularity of its wear during hardening, but differs in the fact that the velocity of wear intensity increase after hardening temperature of 1050 ^{o}C is lower because of alloying retained austenite by nitrogen, that increases its stability.

Fig. 5 shows the diagram of wear resistance indicator ($\dot{I}^{-1}$) of various steels at abrasive wear in model solutions with different thermal and chemical-thermal treatment. The diagram shows that steel 5 has maximum wear resistance after nitrohardening, that is 3.7 times higher when compared with steel 20 without treatment, almost 2-3 times when compared with hardened steels, 2.4 times when compared with carburized steel 20 and 1.5 -1.7 times when compared with nitrided steels.

3. Conclusions

- Thus, there is a linear dependence of wear resistance on hardness in abrasive medium for alloys with stable surface structure.
- For alloys with unstable structure that are able to change under the influence of abrasive wear, it is necessary to take into consideration the structural state of the material surface and wear resistance depends mainly on the completeness of structural changes in the wear process.
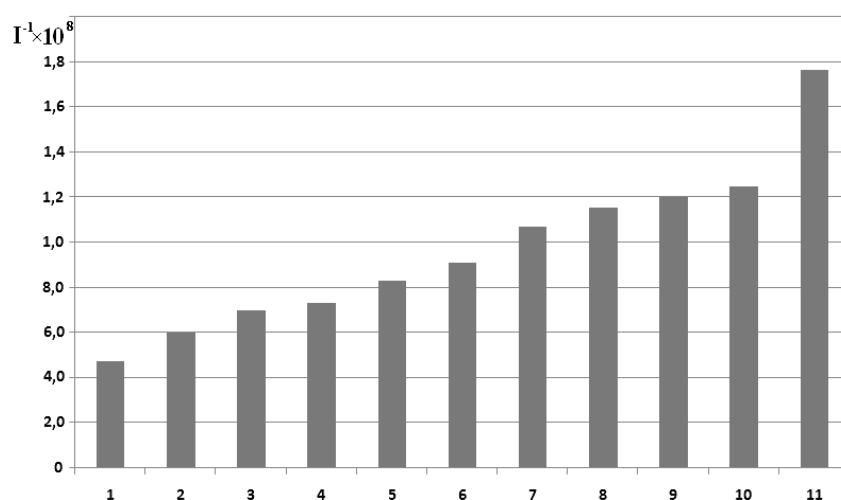

Fig. 5 Diagram of different steels wear at abrasive wear in model solutions with different thermal and chemical-thermal treatment: 1 – steel 1; 2 – steel 2 (hardening); 3 – steel 3 (hardening);
4 – steel 1 (carburizing); 5 – steel 4 (hardening); 6 – steel 5 (hardening); 7 – steel 2 (nitriding)
8 – steel 4 (nitriding); 9 – steel 6 (nitriding); 10 – steel 5 (nitriding); 11 – steel 5 (nitrohardening)
Source: Elaborated by the Authors

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