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Wear Resistance of Medium Alloy Tool Steels After Single-Component Surface Enrichment

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***Abstract*— Results are presented for the influence of the type of chemical-thermal treatment in single-component surface enrichment on the wear resistance of the formed diffusion layers on samples of chromium tool steels (1÷5%Cr). Wear resistance is defined as mass loss per unit area (g/cm^2) after a distance of 1÷5 km. The loading in the wear process is carried out by a lever system with a load of 3÷100 MPa, and the speed of rotation of the counterbody is 0.1÷7.0 m/s. Dependencies for the wear intensity of the studied steels in coordinates mass loss / distance traveled have been developed.**

***Keywords*— boriding, carburizing, chemical-thermal treatment, chromizing, nitriding.**

I. INTRODUCTION

Industry 4.0 represents a major step towards the future of manufacturing, combining technologies that are changing the way businesses produce and deliver goods and services [1] – [9]. This technological revolution promises to drive innovation, improve efficiency, and transform the manufacturing landscape, providing a better way to meet consumer needs in the future. In this regard, the development of technologies related to the application of CNC metalworking machines with robotic feeding [10], [11], the implementation of waste-free and low-waste technologies [12] – [15], as well as the combination of technological processes related to increasing the strength properties of parts in order to replace expensive alloy steels with structural carbon ones is of particular importance.

In this regard, the role of processes related to the chemical-thermal treatment of materials is essential [16, 17, 18]. This is a technology that allows the production of parts with high strength characteristics on the surface of the products while maintaining a tough core. Of particular importance is the application in the processing of long axisymmetric rotational parts operating in torsion, to which requirements are imposed for high wear resistance and resistance in aggressive environments.

This publication investigates the influence of single-component surface enrichment of medium-alloy tool steels on their wear resistance under dry friction conditions.

II. MATERIALS AND METODS

Samples of medium-alloyed heat-resistant steels with increased and high heat strength were tested. The chemical composition of the tested steels according to BDS EN 10027-1:2005 is presented in Table 1, and the dimensions of the tested samples are shown in Fig. 1.

TABLE 1 CHEMICAL COMPOSITION OF THE SAMPLES

Steel	Alloying elements, %									
	C	Si	Mn	Cr	Ni	W	V	Mo	Cu	Zr
54NiCrMoV6 DIN 1,2714	0,54	0,32	0,75	0,57	1,60	-	-	0,25	≤0,3	
60CrV7 DIN 1,2307	0,67	0,35	0,32	2,35	0,40	0,30	0,15	-	-	-
32CrMoV12 DIN 1,2365	0,38	0,89	0,49	1,45	-	-	0,38	0,54	-	-
55NiCrMoV7 DIN 1,2714	0,39	0,92	0,38	1,27	1,49	-	0,43	0,37		0,15
X38CRMoV5 DIN 1,2367	0,49	0,74	0,41	2,91	-	2,64	0,81	0,76	-	-
X30WCrV9-3 DIN 1,2581	0,37	≤0,3	0,38	2,50	≤0,3	8,50	0,42	≤0,5	-	-

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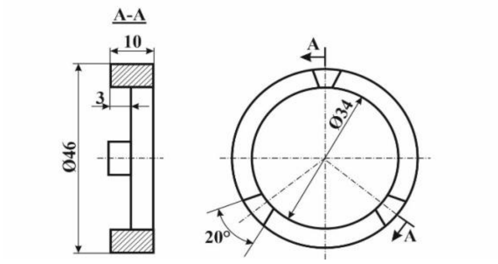

Fig. 1. Dimensions of the tested samples

The samples were subjected to single-component enrichment with carbon, nitrogen, boron and chromium. Nitrogen saturation was carried out in a dissociated ammonia environment at a temperature of 560ºC for 6h [19]. Carburization, boridization and chromium plating were carried out in liquid saturating environments at a temperature of 950ºC for 4h and bath composition 1, 2 and 3 respectively [20, 21, 22, 23, 24, 25, 26, 27, 28].

$$81\%[55\%NaCO_3+45\%K_2CO_3]+13\%SiC+6\%B_2O_3 \quad (1)$$

$$12\%Na_2B_4O_7 + 36\%B_2O_3 +10\%Al_2O_3 + 24\%NaCl + + 9\%SiC + 9\%Na_2AlF_4 \quad (2)$$

$$97\%[25\%Al_2O_3+75\%Cr_2O_3]+3\%NH_4Cl \quad (3)$$

After saturation, the samples were quenched from the saturation temperature in oil and subjected to high-temperature annealing at 560÷600ºC.

The wear resistance of the saturated samples was tested on a setup - Fig. 2, which allows the tests to be conducted in conditions close to production conditions.

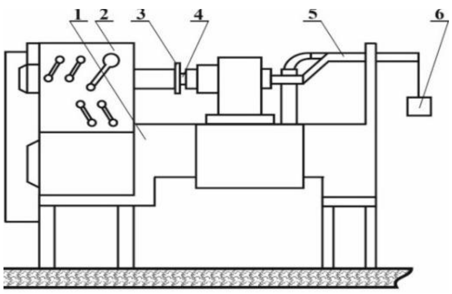

Fig.2. Scheme of the experimental setup (1 – lathe; 2 – gearbox; 3 – counterbody; 4 – clamp with the tested sample; 5 – lever system; 6 – load).

The methodology for studying wear resistance was used, which gives a quantitative assessment of the process - g/cm^2. The tests were carried out according to the friction scheme of a three-sector ring - Fig. 1, on a counterbody. The load of 3÷100MPa is carried out using a lever system, and the rotation speed of the counterbody varies within the limits of 0.1÷7.0 m/s [29] – [32].

III. Results and Discussion

Initial studies conducted at a load of 15 MPa, a rotation speed of 0.42 m/s and a distance traveled of 1 km – Table 2, show that the greatest increase in the wear resistance of the tested samples is provided by coatings based on metal-like compounds – carbides and borides.

TABLE 2 WEAR OF DIFFUSION-ENRICHED SAMPLES

Steels	Insatiable	Friction wear, g/cm^2			
		Diffusing element			
		C	N	B	Cr
54NiCrMoV6	410	340	300	60	65
60CrV7	320	230	300	59	60
32CrMoV12	380	260	290	57	65
55NiCrMoV7	400	240	290	61	65
X38CRMoV5	180	90	140	48	70
X30WCrV9-3	196	120	154	48	65

Note: *the values presented are the arithmetic mean of the measured results of five samples.*

These coatings effectively protect the surface of the samples from thermal wear (the main type of destruction on the working surfaces). The wear resistance of nitrided and carburized samples is significantly lower compared to those in which boride and carbide coatings are formed on the surface. This is due to the presence in the nitrided and carburized samples of a structure-free solid solution, which is inferior to borides and carbides (in boriding and chromium plating), both in hardness and in other mechanical indicators [33].

In cases where the wear process does not go beyond the boundaries of the diffusion coating, the wear resistance of the surface layers of the saturated samples significantly increases compared to the unsaturated ones – Table 2.

It has been established that depending on the strengthening parameters, both the dimensions of the diffusion coatings and the properties of the respective coating, as well as the properties of the area under the coating itself, can significantly change. In this regard, the type and method of alloying the base is of essential importance.

Fig. 3÷6 shows the wear kinetics of the diffusion layers and the transition zones to the metal matrix in steels with increased heat resistance, respectively 54NiCrMoV6, 60CrV7, 32CrMoV12 and 55NiCrMoV7.

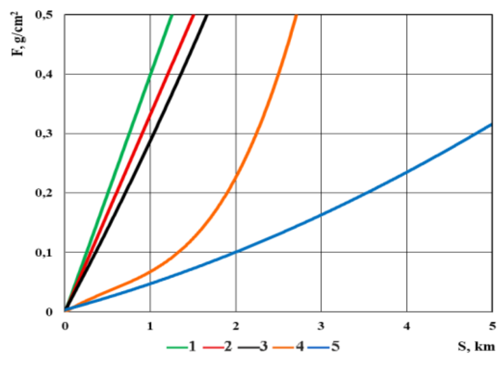

Fig. 3. Wear kinetics – F, distance traveled – S during dry friction of 54NiCrMoV6 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

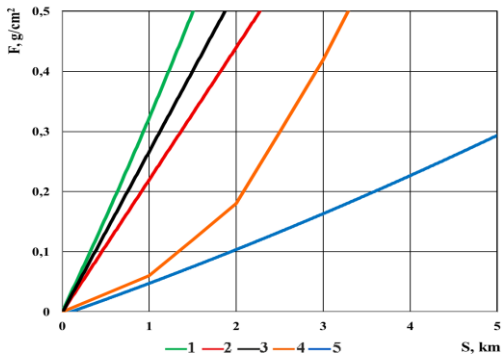

Fig. 4. Wear kinetics – F, distance traveled – S during dry friction of 60CrV7 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

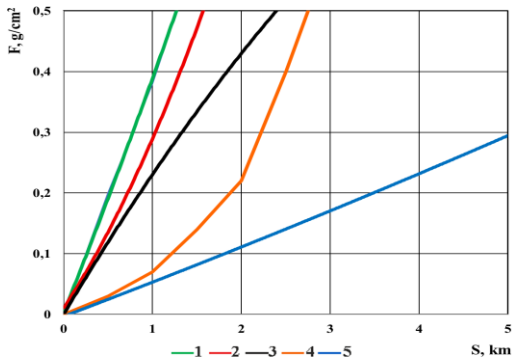

Fig.5. Wear kinetics – F, distance traveled – S during dry friction of 32CrMoV12 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

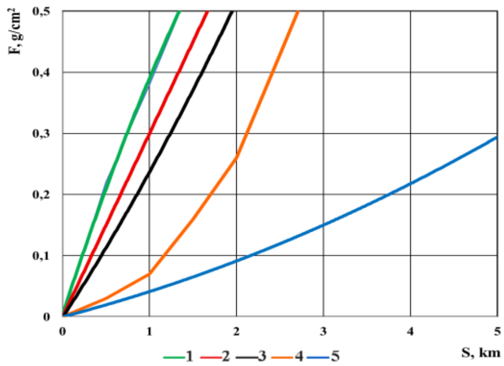

Fig.6. Wear kinetics - F, distance traveled – S during dry friction of 55NiCrMoV7 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

The figures show that the highest wear values compared to unsaturated samples are those after boronization. In them, the mass loss values are 6÷7 times lower compared to unsaturated samples. The samples subjected to carburization and nitriding change their wear resistance slightly compared to unsaturated ones and it is 1.2÷1.6 times lower. In the samples subjected to chromium plating, chromium carbides are formed whose hardness is lower than that of borides. For this reason, after chromium plating, the samples have lower wear resistance than the boronized ones and higher than those after carbonization and nitriding, and the mass loss in them is 3÷6 times lower compared to unsaturated samples.

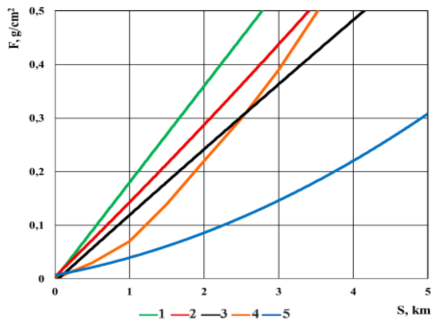

Fig.7. Wear kinetics - F, distance traveled – S during dry friction of X38CrMoV5 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

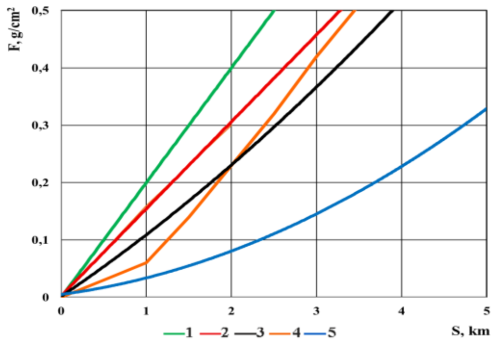

Fig.8. Wear kinetics - F, distance traveled – S during dry friction of X30WCrV9-3 samples after surface hardening: 1 – uncoated; 2 – nitrided; 3 - carburized; 4 – chromed; 5 -boronized.

It should be noted that fragments of the boride coating (Fe_2B) occur in the contact zone at a significantly later stage of wear, when the destruction process reaches the transition zone. In it, in addition to boride inclusions, we have an increased concentration of carbon and alloying elements. For this reason, the figures do not show a sharp increase in wear resistance after wear of the diffusion layer, but a smooth transition to the core of the part is registered. But it does not have a practical effect on wear.

Figures 3÷6 show that the wear of steels with increased heat resistance is uniform. In contrast, the wear kinetics of steels with high heat resistance (X38CRMoV5, X30WCrV9-3) show a number of peculiarities – Fig. 7 and 8. The figures show that, similarly to steels with increased heat resistance, high wear resistance is observed in steels with high heat resistance after boronizing, but unlike steels with increased heat resistance, the wear of the transition zone in them is identical to that in carbon steels.

The high heat resistance of steels X38CRMoV5, X30WCrV9-3 after carburizing is explained by the presence in the strengthened layer of dispersed carbide inclusions based on Cr, Ni, V and W. For this reason, with prolonged wear (more than 2.0÷2.5km), the values of the carburized samples exceed those of the chrome-plated ones [34], [35].

The results obtained in the process of research allow us to systematize the features of the destruction of the studied diffusion coatings based on carbides into four stages.

During the first stage of wear, along with oxidative wear, intensive occurrence and development of microcracks in the carbide layers is observed. They are mainly the result of the presence of defects or stress concentrators.

During the second stage, crack growth, fragmentation of carbide areas and chipping off of parts of the carbide layers are observed.

The third stage is associated with intensive fragmentation of the carbide zones and the appearance of the matrix phase in individual areas on the contact surface.

The fourth stage is associated with almost complete destruction of the diffusion layer and the entry of carbides knocked out of the layer into the matrix.

In coatings based on boride phases (FeB and Fe_2B) in the friction process, four stages of wear can also be formulated, the first two being analogous to those in carbide coatings [36], [37].

During the third stage, along with local destruction of the layer, there is a gradual smoothing of the destroyed areas. In this case, areas with brittle destruction in the wear process appear and fill in different places on the contacting surfaces with the counterbody. The wear has an oxidative nature.

In the fourth stage, a dense boride layer is absent. On the friction surface, areas of the matrix appear located between the boride needles (Fe_2B). In the places of the matrix phase that contact the counterbody, the wear process is analogous to unsaturated steels.

IV. Conclusions

The following more important conclusions can be formulated from the conducted research and the results obtained:

- It has been established that depending on the reinforcement parameters, both the dimensions of the diffusion coatings and the properties of the respective coating, as well as the properties of the area under the coating itself, can significantly change.
- It has been proven that for steels with increased heat resistance, the highest wear values compared to unsaturated samples are those after boronization. In them, the mass loss values are 6÷7 times lower compared to unsaturated samples.
- It has been proven that high wear resistance is observed in steels with high heat resistance after boronizing, but unlike steels with increased heat resistance, the wear of the transition zone in them is identical to that in carbon steels.

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