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TECHNOLOGICAL PROPERTIES OF DIFFUSION BORIDE COATINGS FOR STEEL

Alexandr A. Afanasiev*, Sergey N. Glagolev, Sergey N. Sanin

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Abstract

The results of steel wear resistance research are presented. The steels are hardened by boride coatings and subjected to wear under static and dynamic loads. The steel 45 was subjected to hardening steel 45 by the boron coating with constant and reverse current and using boron chromium, boron zirconium and boron tantalum coatings. The coefficient of dynamics during durability tests of hardened components varied from 1 to 2. In all cases, the highest wear resistance was presented by the hardened parts with reversed current. In terms of static loads the microhardness of hardened part surface layers is of crucial importance. In terms of dynamic loads the structural and the stress state of a diffusion layer is of crucial importance.

Keywords: diffusion boride coatings, wear resistance, surface hardening by diffusion coatings, the structure of diffusion layers.

Introduction

The saturation of a steel surface by alloying elements together with boron was carried out to improve the wear resistance of the surface layers under the terms of their abrasive wear. The compositions obtained by the author previously [1, 2, 3] were used as saturating media to obtain various kinds of boride layers on a reinforced steel part. The part hardening technology by diffusion boride coatings was based on the author's work results [4, 5]. New ideas about the structure of boride layers and the conditions of their development were taken into account in the process of boride layer experimental obtaining [6]. The durability tests on hardened parts were conducted using the domestic machine to determine the frictional heat resistance of MFT-type materials. The machine MFT-3 belongs to the front friction machines and fully meets the modern requirements for wear resistance tests, both by technical data, and by friction scheme. According to the work [7] the front friction scheme is used to test wear resistance, frictional heat resistance in order to test the materials on friction in aggressive environments, to study the adhesion and the curing of materials. This is explained by the fact that this friction scheme provides an overlapping coefficient, which is the ratio of friction areas and a contacting pair equal to one. The change of the overlapping coefficient can change wear by several orders. The front friction and the generator friction give dramatically different effects in boundary lubrication terms, as the terms of a lubricant film development change. The coefficient of overlapping makes a decisive influence on heat transfer - one of the most important characteristics of wear. In order to stabilize the pressing force of the samples the pneumatic pressing device in the machine was replaced by the lever one. This device associated with a special drive with a changeable cam let create the dynamic loads on a test specimen. The aim of research was to establish the dependence of a hardening type, a boride layer structure, the quantitative indicators of hardened steel wear on testing conditions [8, 9].

Methods

The cylindrical samples reinforced by thermochemical processing had an outer diameter of 28 mm, and an inner diameter of 20 mm, the height of 10-15 mm and were tested in together with bronze ones (BrOTsS5-5-5). The friction zone of a reinforced and a bronze sample was supplied with a universal lubricant Uss 10% periodically via a dispensing device according to abrasive mass (quartz sand).

Main Part

The dependence of reinforced sample wear during the friction of bronze BrOTsS 5-5-5 on the specific pressure at the sliding speed V = 0,1 m/s is shown on Fig. 1. According to the graph, the wear depends essentially on the specific pressure, since the increase of the latter by 15 times increases the wear by 5-6 times. The lowest value of wear is observed in boron coated samples using the direct and the reversed current and in boron zirconium coated samples. Boron zirconium coated samples are inferior ones before borated samples, but superior to boron chromium and boron tantalum ones by wear resistance. At the static loads under friction, accompanied by the development of wear particles after microcutting, the hardness of wear surface makes a decisive influence on wear. Boron coated samples (curves 1 and 2, Fig. 1) had the highest hardness [10] among the hardened samples subjected to the durability tests.

In order to compare the value of wear on Fig. 1 shows the wear and tear of steel 45 dependence on specific pressure is presented (curve 6). This steel is hardened by heat treatment up to HRC 25-28.

In practice of machine parts and tools operation the wear resistance under dynamic loads is of great interest. In the present studies the dynamic loads were characterized by dynamics factor $K_д$, which is the maximum load ratio to the average one: $K_д = \frac{P_{max}}{P_{ср}}$. The maximum specific pressure made 10 MPa in all cases.

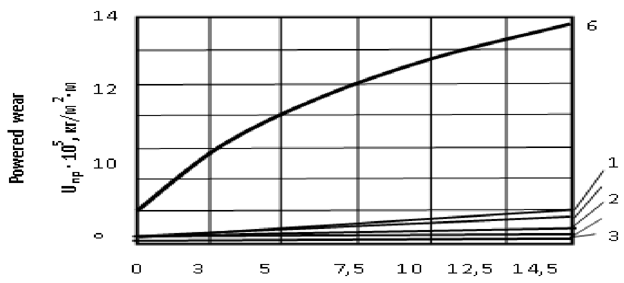

Fig.1. The dependence of steel 45 wear during bronze friction BrOTsS5-5-5 on specific pressure and hardening type at V = 0,1 m/s.

Lubricant USs + 10% of abrasive:1 – boron coating with reverse current; 2 – boron coating with direct current; 3 – boron zirconium coating; 4 – boron chromium coating; 5 – boron tantalum coating;

6- improvement up to HRC 26-28.

The period of load fluctuation was set at 1.5 seconds. The influence of dynamic loads on the wear resistance of samples reinforced by different variants of chemical-thermal treatment at their friction on bronze BrOTsS 5-5-5 with the speed of 0.1 m/s is shown on Figure 2. The dynamics factor makes a significant impact on the wear resistance of improved steel 45 (HRC = 26-28), borated and tantalum borated by constant current (curves 9, 1 and 7). If $K_д = 1$ their wear makes $11{,}8 \cdot 10^{-5}$ kg/m$^2 \cdot$ m, $0{,}75 \cdot 10^{-5}$ kg/m$^2 \cdot$ m and $1{,}25 \cdot 10^{-5}$ kg/m$^2 \cdot$ m, then at $K_д = 2 – 35 \cdot 10^{-5}$ kg/m$^2 \cdot$ m, $30{,}5 \cdot 10^{-5}$ kg/m$^2 \cdot$ m and $8{,}9 \cdot 10^{-5}$ kg/m$^2 \cdot$ m.

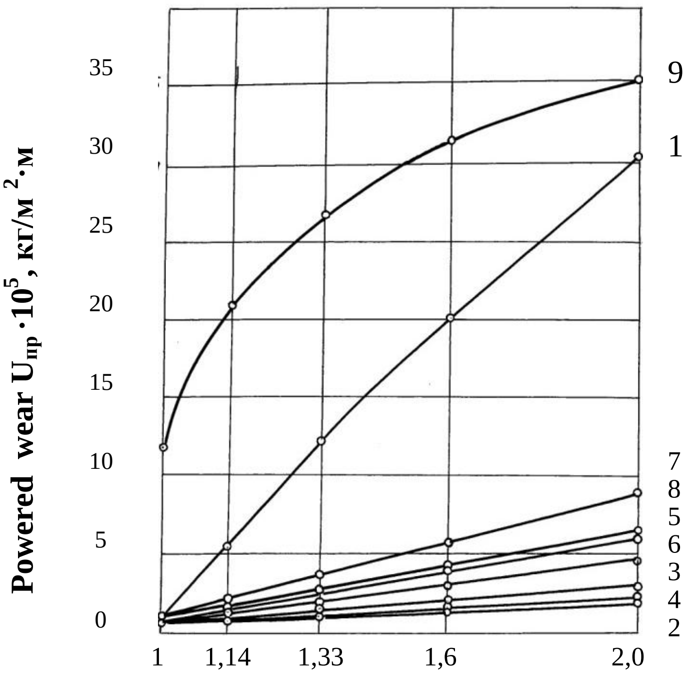

Fig. 2. The effect of dynamics factor $К_д$ on steel 45 wear, hardened by different methods:

1 - boration by DC; 2 - boration by reverse current; 3 - boron zirconium coating with DC; 4 - boron zirconium coating with reverse current; 5 - boron chromium coating with DC; 6 - boron chromium coating with reverse current; 7 - boron tantalum coating with DC; 8 - boron tantalum coating with reversed current; 9 - upgrade up to HRC 26-28.

The depreciation of steel 45, borated with reverse current, as well as strengthened by boron chromium coating, boron zirconium coating with DC and reverse current, and tantalum coating with reverse current varies insignificantly with the dynamic coefficient increase from 1 to 2. The increased wear of improved steel 45 (HRC 26-28) with the dynamic coefficient increase (curve 9) is explained by an increased activity of an abrasive located in a zone of friction which is degraded under dynamic loads into smaller fractions with sharp edges, loads a surface intensively and wears it out. The borating of steel is accompanied by the formation of structural stresses as the result of phase hardening, leading to the formation of micro cracks under dynamic loads.

This layer degrades in dynamic load conditions. It is observed in a lesser extent at tantalum coating of steel 45 in a melt by DC. They are relaxed partially during the boron coating and the saturation of boron with steel together with chromium, tantalum and zirconium with reversed current application during the anodic half-cycle stress period. The decreased wear of boron zirconium and boron chromium steels with DC use is explained by the ductility of corresponding borides which have a more flexible lattice (a standard deviation of complexes in the crystal lattice of chromium and zirconium borides is greater than iron borides.

Besides, the composition of several phases also affects the reduction of diffusion layer brittleness as the borides of corresponding elements zirconium, tantalum, chromium and iron are fastened by smaller iron compounds with these elements.

The dynamics coefficient makes a different impact on a surface roughness and the friction coefficient of hardened surfaces. Table 1 shows the effect of dynamic loads on the coefficient of friction f, surface roughness and the reduced wear $U_{пр}$ of steel 45, hardened by heat treatment up to 26-28 HRC and subjected to the hardening by boron chromium, boron zirconium and boron tantalum coatings at constant and reversed current. The diffused saturation was conducted at the temperature of 1173 K for 2 hours.

The cathode current density made 2000 A/m^2 at constant current. The reversed current parameters made: $[Tau]_a$: $[Tau]_к$ = 0,8 s : 0,4 s and $D_к$: D_a = =2000 A/m^2 : 1500 A/m^2. Here $[Tau]_a$ and $[Tau]_к$ the anode and the cathode half-lives of reversed current respectively. An original roughness of all samples made R_a = 0,4 micrometers. At the change of dynamic ratio from 1 to 2 the roughness increased. Thermally enhanced steel 45 (HRC 26-28) showed R_a = 12,5 micrometers; Borated steel at constant current increased this parameter up to R_a = 6,3 micrometers, and at reversed current R_a = 1,6 micrometers; Boron zirconium coated steel at constant current showed R_a = 2 micrometers, and at reversed current R_a = 1,6 micrometers;

In both cases the surface of boron chromium steel roughness R_a = 3,2 micrometers; the roughness of tantalum boron coated steel at constant current made R_a = 4,0 micrometers, and at reversed current it made R_a = 3,2 micrometers. Thus, the highest durability under dynamic loads were demonstrated by the steels hardened with diffusion saturation at reversed current.

Table -1: The influence of dynamics ratio К$_д$ on worn surface parameters.

#	$K_д$	Parameter	Steel 45 hardening type		
			HRC 26-28 upgrade	Boron zirconium coating with constant current	Boron zirconium coating with reversed current
1	1	$U_{пр}$, kg/m^2·m	$11,8 \cdot 10^{-5}$	$(0,74\text{-}0,85) \cdot 10^{-5}$	$(0,69\text{-}0,78) \cdot 10^{-5}$
		f	0.139	0,101 – 0,103	0,09-0,091
		R_a, mcm	3,2	0,4	0,4
2	1,14	$U_{пр}$, kg/m^2·m	$20,8 \cdot 10^{-5}$	$(1,20\text{–}1,24) \cdot 10^{-5}$	$(0,74\text{-}0,76) \cdot 10^{-5}$
		f	0,137	0,092 – 0,095	0,089-0,090
		R_a, mcm	6,3	0,8	0,8
3	1,33	$U_{пр}$, kg/m^2·m	27	$(1,47\text{–}1,55) \cdot 10^{-5}$	$(1,0\text{-}1,01) \cdot 10^{-5}$
		f	0,125	0,085 – 0,087	0,081 – 0,085
		R_a, mcm	6,3	0,8	0,8
4	1,6	$U_{пр}$, kg/m^2·m	31,6	$(1,90\text{-}2,08) \cdot 10^{-5}$	$(1,28\text{-}1,31) \cdot 10^{-5}$
		f	0,116	0,079 – 0,081	0,074 – 0,076
		R_a, mcm	6,3	1,6	1,6
5	2	$U_{пр}$, kg/m^2·m	35,0	$(2,94\text{-}2,99) \cdot 10^{-5}$	$(1,76\text{-}1,81) \cdot 10^{-5}$
		f	0,097	0,07 – 0,082	0,07 – 0,078
		R_a, mcm	12,5	2,0	1,6
#	$K_д$	Parameter	Steel 45 hardening type		
			Boron tantalum coating at constant current		Boron tantalum coating at reversed current
1	1	$U_{пр}$, kg/m^2·m	$(1,2\text{-}1,3) \cdot 10^{-5}$		$(1,1\text{-}1,2) \cdot 10^{-5}$
		f	0,107 - 0,109		0,106 – 0,109
		R_a, mcm	0,4		0,4
2	1,14	$U_{пр}$, kg/m^2·m	$(2,3\text{-}2,4) \cdot 10^{-5}$		$(1,85\text{-}1,95) \cdot 10^{-5}$
		f	0,103 – 0,106		0,097 – 0,103
		R_a, mcm	0,8		0,8

3	1,33	$U_{пр}$, kg/m²·m	(3,74-3,76) ·10^{-5}	(2,95-3,0) ·10^{-5}
		f	0,101 – 0,102	0,094 – 0,096
		R_a, mcm	1,6	0,8
4	1,6	$U_{пр}$, kg/m²·m	(5,74-5,76) ·10^{-5}	(4,35-4,4) ·10^{-5}
		f	0,096 – 0,099	0,090 – 0,093
		R_a, mcm	1,6	1,6
5	2	$U_{пр}$, kg/m²·m	(8,8-9,0) ·10^{-5}	(6,5-6,6) ·10^{-5}
		f	0,092 – 0,094	0,086 – 0,089
		R_a, mcm	4,0	3,2

#	$К_д$	Parameter	Steel 45 hardening type	
			Boron coating at constant current	Boron coating at reversed current
1	1	$U_{пр}$, kg/m²·m	(0,74-0,76) ·10^{-5}	(0,60-0,64) ·10^{-5}
		f	0,109 - 0,111	0,096 – 0,099
		R_a, mcm	0,4	0,4
2	1,14	$U_{пр}$, kg/m²·m	(5,2-5,4) ·10^{-5}	(0,79-0,81) ·10^{-5}
		f	0,105 – 0,109	0,086 – 0,091
		R_a, mcm	0,8	0,8
3	1,33	$U_{пр}$, kg/m²·m	(12,3-12,6) ·10^{-5}	(1,15-1,17) ·10^{-5}
		f	0,10 – 0,103	0,080 – 0,084
		R_a, mcm	1,6	0,8
4	1,6	$U_{пр}$, kg/m²·m	(20,2-20,5) ·10^{-5}	(1,4-1,6) ·10^{-5}
		f	0,090 – 0,095	0,075 – 0,078
		R_a, mcm	3,2	1,6
5	2	$U_{пр}$, kg/m²·m	(30,4-30,6) ·10^{-5}	(2,0-2,1) ·10^{-5}
		f	0,090 – 0,093	0,069 – 0,077
		R_a, mcm	6,3	1,6

#	$К_д$	Parameter	Steel 45 hardening type	
			Boron chromium coating at constant current	Boron chromium coating at reversed current
1	1	$U_{пр}$, kg/m²·m	(1,1-1,3) ·10^{-5}	(0,8-1,1) ·10^{-5}
		f	0,110 - 0,112	0,100 – 0,103
		R_a, mcm	0,4	0,4
2	1,14	$U_{пр}$, kg/m²·m	(1,86-1,92) ·10^{-5}	(1,46-1,58) ·10^{-5}
		f	0,096 – 0,098	0,090 – 0,092

		R_a, mcm	0,8	0,8
3	1,33	$U_{\text{пр}}$, kg/m^2·m	(2,76-2,84) ·10^{-5}	(2,1-2,2) ·10^{-5}
		f	0,089 – 0,091	0,086 – 0,088
		R_a, mcm	0,8	0,8
4	1,6	$U_{\text{пр}}$, kg/m^2·m	(3,9-4,05) ·10^{-5}	(3,06-3,15) ·10^{-5}
		f	0,085 – 0,088	0,080 – 0,082
		R_a, mcm	1,6	1,6
5	2	$U_{\text{пр}}$, kg/m^2·m	(5,8-6,2) ·10^{-5}	(4,3-4,7) ·10^{-5}
		f	0,081 – 0,084	0,079 – 0,082
		R_a, mcm	3,2	3,2

The types of hardening are presented in the following order by wear resistance decrease: borating, boron zirconium coating , boron chromium coating and boron tantalum coating.

In this paper, the specific loads were determined under the influence of which the cracks appear in diffusion layers and the destruction begins. For this purpose the friction of the studied samples was carried out for steel 45 (HRC 26-28) at the speed of 0.1 m/s at $K_{\text{д}}$ = 1,14, the load oscillation period $T_{\text{кол}}$ = 0,75 s using US$_c$ lubricant with 10% of abrasive for 3 hours. After the tests, the sample surface state was examined under the microscope, was compared with the sample surface state, with a different type of a diffusion layer and the conclusion was made. The test results for the diffusion layer resistance against dynamic loadings are presented in Table 2.

Table 2: The influence of dynamic loads on diffusive layer destruction.

Diffusive saturation type	Specific dynamic loads, MPa		
	The beginning of micro cracks formation	Intensive micro cracks formation	Intensive degradation
Boron coating at constant current	7,35	9,81	12,25
Boron coating at reversed current	14,7	19,62	24,5
Boron zirconium coating with constant current	14,7	19,62	24,5
Boron zirconium coating with reversed current	14,7	22,0	24,5
Boron chromium coating at constant current	12,25	17,17	19,62
Boron chromium coating at reversed current	14,7	19,62	24,5
Boron tantalum coating at constant current	7,35	9,81	12,25
Boron tantalum coating at reversed current	12,25	14,7	17,17

The application of reversed current in all kinds of diffusive saturation increases the resistance of samples against the action of dynamic loads. The samples borated at reverse current, boron zirconium coated at constant and reversed current, and boron chromium coated at reversed current were the most stable ones in these tests.

The influence of the structure nature concerning boride (borated) layer on the wear resistance under static ($K_д$ = 1) and dynamic ($K_д$ = 1) loads is shown in Table 3. With all types of loads during a layer increase (on the surface) of the top boride FeB the steel durability increases. At dynamic loads this trend is maintained only for the layers obtained by reverse current. This phenomenon is explained by the combined action of two factors: the increase of surface hardness due FeB and an optimum level of residual stress obtaining.

The studies of boride layers were conducted at their thickness of 150 - 200 mcm. The recent comparative tests of boride layers with their lesser thickness showed that during thickness decrease the heterogeneity of a structure begins to play a smaller role in the durability of boride layer enhancement on the surface of a metal-cutting tool.

Table 3: The influence of borated layer structure, the hardening method and the load character on its durability.

FeB and Fe_2B composition	$K_д$	Presented wear at different means of hardening $U_{пр}$, kg / m^2 · m	
		Constant current	Reversed current
25% *FeB* + 75% Fe_2B	1,0	(1,8–2,0) · 10^{-5}	(1,4–1,6) · 10^{-5}
	2,0	(32,3–32,5) · 10^{-5}	(3,5–3,6) · 10^{-5}
55% *FeB* + 45% Fe_2B	1,0	(1,4–1,5) · 10^{-5}	(1,1–1,2) · 10^{-5}
	2,0	(31,2–31,4) · 10^{-5}	(3,1–3,2) · 10^{-5}
70% *FeB* + 30% Fe_2B	1,0	(1,2–1,3) · 10^{-5}	(1,0–1,05) · 10^{-5}
	2,0	(30,8–31,1) · 10^{-5}	(2,7–3,8) · 10^{-5}
77% *FeB* + 23% Fe_2B	1,0	(1,0–1,1) · 10^{-5}	(0,8–0,9) · 10^{-5}
	2,0	(30,6–30,8) · 10^{-5}	(2,4–2,6) · 10^{-5}
100% *FeB*	1,0	(0,74–0,76) · 10^{-5}	(0,6–0,64) · 10^{-5}
	2,0	(30,4–30,5) · 10^{-5}	(2,0–2,1) · 10^{-5}

The decisive factor in in a workpiece surface durability provision was the influence of the friction coefficient on the considered performance indicator and the absence of the binding phenomenon between a boride layer and a processed material at very low thicknesses of a diffusive boride layer. This was particularly noticeable with the material of a solid alloy matrix and a coated boride layer at the thickness of no more than one micrometer.

This property of boride layers resembles the behavior of diamond-like coatings on a metal-cutting tool. This type of coating is obtained using a pulsed vacuum-arc coating. The coating thickness, as well as the process duration (15 - 60 minutes) is regulated with its help. The following regularity is set: the smaller the amount of supplied pulses, the thinner the coating is, and vice versa." The thickness makes 0.2 - 2 microns at these coating modes. The coating color depends on the thickness, like an oxide tint on steels. The properties of diamond-like coatings obtained using the technology of pulsed vacuum arc discharge, are similar to diamond properties according to graphite strength and properties in terms of slip values: density - about 3.2 g/cm3, microhardness - 80-100 GPa and the dry friction coefficient - about 0,1 (a diamond has the following values: 3.5 g/cm3 and 0.1 and 100 GPa, respectively. The durability of the tool reinforced by diamond-like coatings is 10-15 times higher than the value of the tool reinforced by titanium nitride according to existing technologies. Besides the temperature of a diamond-like coating application makes 100-150 C.

Summary

The materials presented in this article make the part of the general scientific work which solves the problem of machine part surface quality increase on the basis of research and development performed by the author. The posed problem is solved by improving the component and tool hardening technologies through the creation of surface diffusive boride layers. The materials of the work serve as the basis for further research in the field of part and tool hardening by diffusive coatings.

Conclusions

The results of performed work show that the use of reversed current in all cases of part hardening leads to machine part wear resistance increase at the abrasive wear under static and dynamic loads.

A direct effect of a boride layer structural and phase composition influence on its durability under static and dynamic loads, friability and other properties is discovered.

Since the use of reversed current is substantially the method of damping process activation, the study of diffusive boride coating with small thickness on the basis cubic boron nitride as the analog of a diamond material is a prospective one.

The work materials allow us to make a generalization: an intermittent or a pulsating nature of the steel reinforcement modes is the basis for new provisional or quality improvement technologies concerning steel surface layers unattainable by conventional classical methods.

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Corresponding Author:

Alexandr A. Afanasiev*,