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COMPARISON OF ABRASION RESISTANCE OF BORON- AND VANADIUM-BASED COATINGS

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This research focuses on testing of abrasion resistance of boron- and vanadium-based coatings. Coating of samples with vanadium was completed by classic and duplex procedure with previous carburization. The samples were abraded by applying the ASTM G65-94 method of „dry sand/rubber wheel“. The greatest wear was recorded on boron-based coating, and the least wear was exhibited by the vanadium-based coating with previous carburization. The dominant form of „zero“ abrasion was determined by analyzing the sample wear traces.

Key words: coatings, abrasion, microstructure, boronizing, vanadiumization

INTRODUCTION

Surface properties of machine elements and tools, such as hardness and wear resistance can be modified of diffusion of different elements' atoms [1].

Boronizing is a thermochemical procedure that allows boron as a chemical element to diffuse into the surface and joins the iron to form the iron boride [2, 3]. Surface coated with boron has improved hardness and resistance to abrasion, adhesion wear and corrosion [4].

Vanadiumization is a thermochemical process, which diffuses vanadium into the steel surface and, by joining the carbon from the steel substrate, it forms a layer of vanadium carbide (VC).

Coating with vanadium can be performed by applying processes of chemical and physical vapor deposition (CVD and PVD), as well as thermal reactive diffusion (TRD) [5, 6].

Within the procedure of coating with vanadium, the base material under the VC layer is partially depleted by carbon (decarburization) because carbon diffuses from the austenitic interior towards the surface and joins the vanadium. As a result of this process, the area under the VC layer is of less hardness, thus negatively influencing the bearing capacity of the layer. In order to avoid such occurrence, a duplex process is applied to enrich the material surface with carbon (carburization) before vanadium coating. This results in greater hardness of the area underneath the VC layer. After vanadium coating, the thicker VC layer is of better bearing capacity [7].

Since boron- and vanadium- based coatings have very high wear resistance, many researches have been carried out to address the issue of wear with respect to different wear mechanisms [8-12].

The aim of this paper is to compare the abrasion resistance of boron- and vanadium- based coatings, by applying the appropriate testing method to determine the dominant form of abrasion during wear.

MATERIALS AND METHODS

Testing samples

Testing was performed on samples of 12 × 25 × 75 mm made of improved carbon steel C45E, of surface hardness 207 HB and of chemical composition as presented in the Table 1.

Table 1 **Chemical composition of base material / wt. %**

C	Si	Mn	P	S	Cr	Mo	Ni
0,46	0,29	0,68	0,026	0,029	0,024	0,08	0,02

Boron-based coating

Boronizing is carried out in the boronizing agent EKABOR 3, at a temperature of 1 000 °C, lasting for 4 hours. Obtained thickness of coating was 65 – 135 μm,

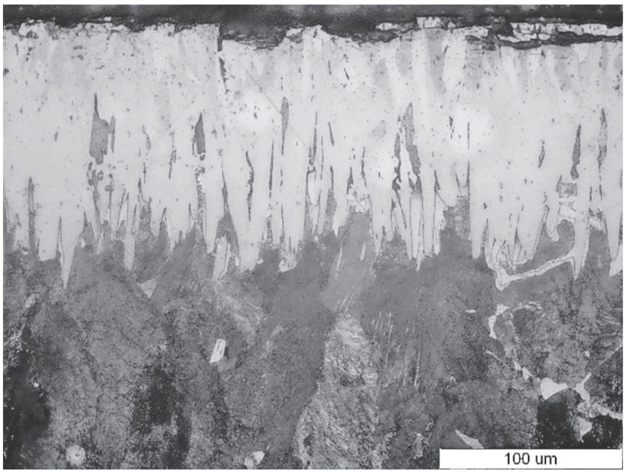

Figure 1 Boronated microstructure

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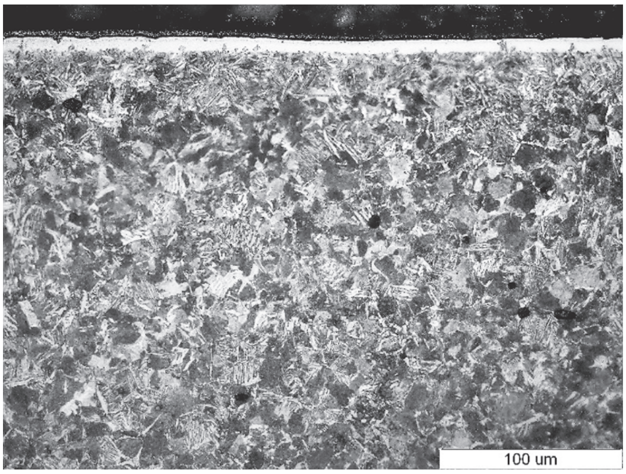

Figure 2 Classic vanadium-based microstructure

as presented in the Figure 1, and mean hardness value was around 1 320 HV 02.

Coating obtained by classic procedure of vanadiumization

Classic procedure of vanadiumization was carried out in a salt bath containing vanadium at a temperature of 950 °C, lasting for 4 hours (TRD).

Obtained thickness of coating was 5 µm, as shown in the Figure 2, with mean hardness value being around 2 100 HV 003.

Vanadium-based coating with previous carburization (duplex)

Before classic coating with vanadium, the samples were carburized in a gas atmosphere at a temperature of 925 °C by applying the „Carbomaag“ procedure. This resulted in the coating of the microstructure that is shown in the Figure 3.

Thickness of the obtained coating was around 7,5 µm, and the mean value of measured hardness was around 2 150 HV 003.

The base material under the VC-layer was of martensitic structure due to the increased content of carbon that was present because of the previous carburization.

Chemical composition of obtained coatings was analyzed by the Scanning Electron Microscopy (SEM) Energy dispersive spectroscopy (EDS) method, and the results are overviewed in the Table 2.

Table 2 **Chemical composition of coatings / wt. %**

Element	Boride coating	Vanadium coating	Duplex coating
B K	19,54	-	-
C K	6,06	25,00	23,20
Fe K	74,40	1,55	2,97
V K	-	73,46	56,40
O K	-	-	17,43

Method of testing

Testing was performed by abrading the samples with the "dry sand/rubber wheel" method, according to the standard ASTM G65-94 test, on the device presented in the Figure 4. Applied test used the pressure force of 45 N on each sample. The mass of samples was measured before the abrasion test, as well as in the abraded condition after 100, 200, 300, 400, 500 and 1 000 wheel revolutions.

RESULTS AND DISCUSSION

The wear of sample material during the abrasion test is expressed as a loss of mass, being determined by measuring the mass of each sample before and after the abrading process. Based on the mass losses, the volume losses are calculated and presented in the Table 3.

Dependence of the coating wear on the number of wheel revolutions was determined by the regression analysis, as shown in the Figure 5.

As presented in the diagram, there is the apparent square dependence of all coatings' wear on the number of wheel revolutions, with high determination coeffi-

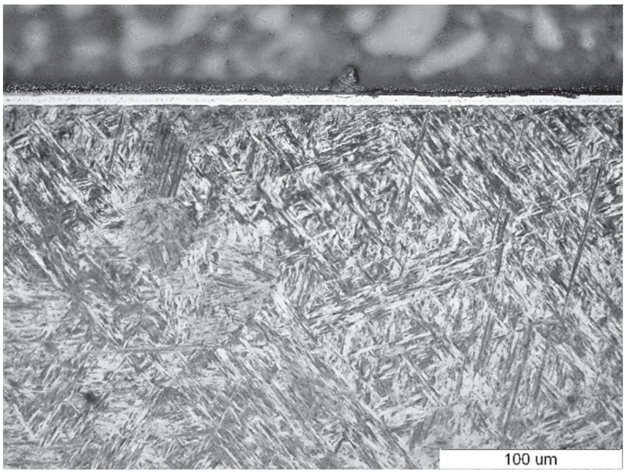

Figure 3 Vanadium-based microstructure with previous carburization

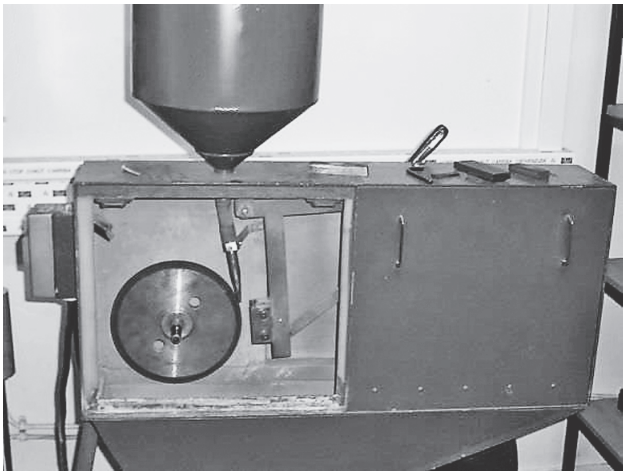

Figure 4 Device for abrasion testing

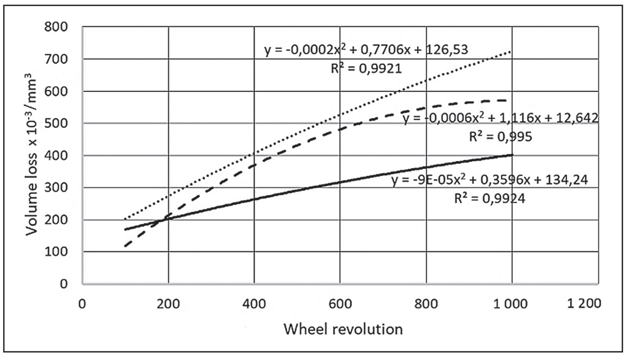

Figure 5 Dependence of the coating wear on the number of wheel revolutions

Table 3 **Volume losses of abraded samples' volume**

Wheel revolution	Volume loss (ΔV) / mm³		
	Boride coating	Vanadium coating	duplex
100	0,186	0,130	0,161
200	0,284	0,192	0,211
300	0,368	0,304	0,242
400	0,401	0,372	0,260
500	0,452	0,433	0,285
1 000	0,727	0,570	0,403

cients (R^2), which is also confirmed by a high degree of dependence of examined parameters in all coatings.

The highest volume loss was determined for the boron-based coating, which can be related to the less surface hardness of the coating when compared to the vanadium-based coating. The lowest volume loss, and thus the best abrasion resistance was exhibited by vanadium-based coating with previous carburization, which can be associated with the highest surface hardness that results from a better diffusion of carbon from carburized base material before the process of vanadiumization.

Analysis of sample wear traces

Analysis of wear traces was carried out on the surface of abraded samples, after 1 000 wheel revolutions, with the purpose of determining the dominant form of abrasion.

In all samples, traces of wear occurred within the framework of coatings cross-sections, i.e. during abrading, the coatings were not ruptured.

The Figure 6 presents the traces of wear on the sample of boron-based coating.

Presented traces of wear are related to the abrasive action of the sand particles. They mostly consist of numerous dots that occurred because of smoothing of the tops of surface irregularities, with rare short and shallow scratches.

Abrasive action did not cause significant surface destruction, so this occurrence can be referred to as the wear in the form of “zero” abrasion, which is in line with the available referential data [13].

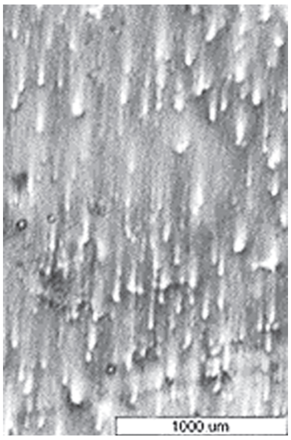

Figure 6 Traces of wear on boron-based coating

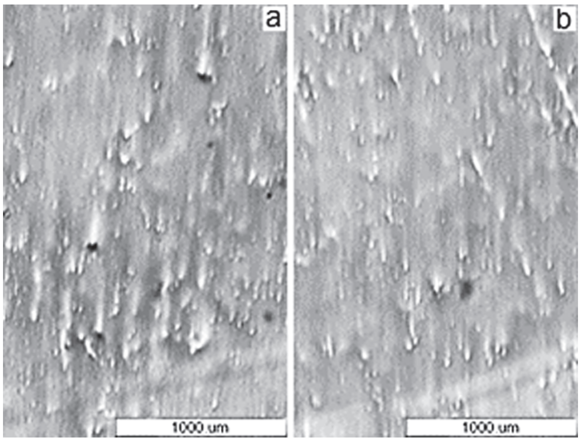

Figure 7 Traces of wear on vanadium-based coating

The Figure 7 presents the traces of wear on the samples of classic vanadium-based (a) and duplex coatings (b).

Presented traces of wear indicate a significantly lower material removal from the surface of both types of coatings if compared to the boron-based coating, which is in accordance with the previously determined abrasion resistance. There is a noticeable direction of abrasive particle action, which left traces in the form of dots and short lines.

Duplex coating exhibited smaller dots and shorter lines as a result of wear, which proves its better abrasion resistance than the classic vanadium-based coating.

In both coatings, the wear can be observed more as smoothing of the existing surface irregularities than as destroying the material surface, so these cases can be also taken as examples of the “zero” abrasion.

CONCLUSION

The research performed on selected hard coatings proved that the vanadium-based coating with previous carburization was the most resistant to abrasion.

This result is associated with the effects of such coating process, as it provides higher surface hardness, better bearing capacity and greater thickness of the coating. Therefore, the research results confirm that the previous carburization is required in the process of coating with vanadium.

Boron-based coating showed lower abrasion resistance compared to the vanadium-based coatings, still it completely fulfils the criteria for abrasion resistance, as it also did not exhibit the coating rupture or damage of the base material during the wear test.

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Note: Responsible translator: Martina Šuto, Master of Arts in English and German language.