

# Physical and technical fundamentals of technology used to increase the wear resistance of working surfaces of large volume excavator buckets

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**Abstract.** Structural-phase states and tribological properties of the wear-resistant coating formed by electric arc surfacing with flux-cored wire on the low-carbon steel Hardox 450, used to protect large volume excavator buckets, are established.

## 1. Introduction

Intensification of mining technological processes demands higher standards of the mechanical properties of working surfaces of mining mechanisms and equipment.

To protect metals and alloys from various types of external influences – wear, corrosion, statistical and dynamic loads, electric arc surfacing is used, which ensures high performance properties of products.

A careful analysis of the relation “wear parameters – hardness – microstructure” is necessary for the scientifically substantiated practical use of various types of surfacing in products of critical use. Only in this case it is possible to obtain products with high performance parameters.

This makes it possible to solve one of the most important problems of ensuring an optimal correlation between the properties of the surface and the material volume. In this case, there is no need to use volumetric-alloyed materials and it becomes possible to solve to a certain extent the important problem of increasing the reliability and durability of parts in the operating conditions [1-3].

The purpose of this work was to analyze the research results of mechanical and tribological properties of the layer formed on Steel Hardox 450 by the electric arc surfacing of the *Fe-C-Ni-B* flux-cored wire.

## 2. Material and methods of research

As the base material the sheets of Hardox 450 steel were used (wt%): 0.19 C, 0.70 Si, 1.6 Mn, 0.025 P, 0.010 S, 0.25 Cr, 0.25 Ni, 0.25 Mo, 0.004 B, the rest – Fe). Because of the low content of alloying elements, it is well welded and processed.

Sheets of Hardox 450 steel are lining plates protecting the working surfaces of the excavator bucket Harnischfeger 2800 with a capacity 33 m<sup>3</sup>. Depending on the operating conditions, the service life of such lining is 12-18 months.

Surfacing of the reinforcing layer was carried out using the MIG/MAG method (Metal Inert Gas / Metal Active Gas – arc welding by the melting metal electrode with an automatic feeding of the filler wire) in the gas environment ( $Ar = 98\%$ ,  $CO_2 = 2\%$ ) with a welding current 250-300 A and voltage



30-35 V. The flux-cored wire with the following chemical composition (wt.%) was used as the welded electrode: 0.7 C; 2.0 Mn; 1.0 Si; 2.0 Ni; 4.5 B; the rest is Fe (figure 1).



**Figure 1.** Armoring of lining plates made of Hardox 400 steel by semi-automatic surfacing of flux-cored wire: a, b – semiautomatic surfacing of the grid; c, d – grid view; d – the bottom of the bucket; e – overall view of armoring the front bucket wall.

Tribological tests were carried out on a tribometer “CSEM Tribometer High Temperature S/N 07-142”, CSEM Instruments; counterbody – a ball with a diameter of 2 mm made of a hard alloy VK6, the wear rate was estimated by the cross-sectional area of the wear track using the 3D-profilometer MICRO MEASURE 3D station by STIL. The structure of the volume of the modified layer was analyzed by the cross-section method, for which the samples were cut into two parts perpendicular to the surface of the modification.

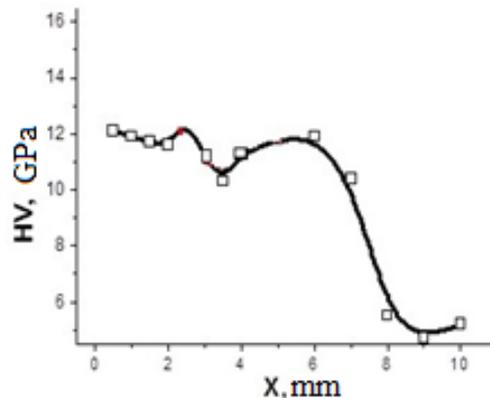
The defective structure of the material was studied by optical (microscope “Microvisor metallographic  $\mu$ Vizo - MET-221”), scanning (scanning electron microscope “SEM-515 Philips”) and transmitting diffraction (EM-125 FET Tecnai 2062 TWIN) electron microscopy [4-7]. The elemental composition of the surface layer was determined by methods of X-ray microanalysis (microanalyzer EDAX ECON IV, which is an add-on device to electronic scanning microscope SEM-515 “Philips”). The phase composition of the surface layer was analyzed by X-ray diffraction methods (diffractometer XRD-7000s, Shimadzu, Japan) [8-9].

### 3. Results and discussion

The main difference of Hardox 450 steel from the widespread wear-resistant steels is a low content of alloying elements. Due to this fact, the steel is well welded and processed. High hardness of Hardox steels is achieved due to a special sheet hardening system, which allows a fine-grained structure to be obtained. The essence of hardening is in the rapid cooling of the rolled sheet without subsequent tempering.

The formation of a layer deposited on the steel surface by the electric arc method is accompanied by poorly controlled heating of the material. This results in a tempering of the hardened state. The steel tempering leads to the release of particles of the carbide phase (cementite) located in the volume of the plates and at their boundaries. The particles have an acicular shape, typical for cementite, formed during low-temperature tempering of hardened steel [10, 11].

Investigations of the mechanical and tribological properties of the deposited layer showed that the microhardness at one pass varies within 10.5÷12.5 GPa and  $\approx$ 15 GPa at a double pass, which is 2 and 3 times, respectively, higher than microhardness of the base (figure 2).



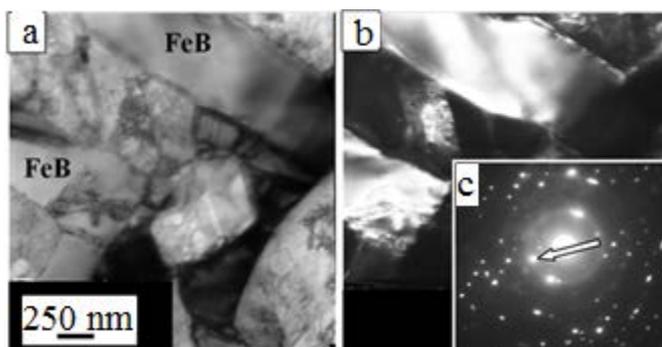
**Figure 2.** The profile of system microhardness “welded layer/steel”.

At one pass, the wear resistance is 2 times higher, and the coefficient of friction is  $\approx 2.2$  times lower than the corresponding values of steel in the initial state.

The difference in the hardness of the deposited layers is due to the difference in the phase composition of a single and double layers. After one pass in the deposited layer, an iron boride of composition  $Fe_2B$  is formed, after a double pass –  $FeB$ , the hardness of which differs by 1.5 times.

In addition to that, the increased mechanical and tribological properties of the deposited layer are due to the formation of a multiphase submicro- and nanoscale structure caused by the hardening effect (the formation of an ultra-small martensitic structure of  $\alpha$  phase) and the presence of inclusions of iron borides of composition  $Fe_2B$  and  $FeB$  of submicron sizes forming a plate-type eutectic. Iron borides do not contain a dislocation substructure, which is apparently due to their high hardness (figure 3). The scalar dislocation density reaches  $10^{11} \text{ cm}^{-2}$  in  $\alpha$  phase.

The presence of flexural extinction contours indicating the formation of internal stress fields at the phase interfaces  $Fe_2B/\alpha-Fe$  and  $Fe_2B/FeB$  was noted. In the contact layer on the side of Hardox 450 steel a substructure of the plate type with a scalar dislocation density  $\sim 5 \cdot 10^{10} \text{ cm}^{-2}$  were revealed. In the volume and at the boundaries of the plates, the cementite particles 20-30 nm in size and borides Fe of composition  $FeB$  were detected. On the side of the surfacing in the contact zone, the structure of the plate eutectic  $\alpha-Fe +$  borides  $Fe$  of composition  $Fe_2B$  was formed.



**Figure 3.** Electron microscopic image of the structure of the deposited layer with iron borides: a – bright field; b – dark field obtained in reflexes  $[103]FeB + [110]\alpha-Fe$ ; c – microelectronogram (the arrow indicates the reflexes in which the dark field is obtained).

The application of the surfacing technology by flux-cored wire on the lining plates made of Hardox 450 steel makes it possible:

1. To reduce the amount of money spent on protection of the bucket with 33 m<sup>3</sup> capacity from 5 million rubles with a service life 12-18 months to 4.3 million rubles for 21 months.
2. To reduce the time between repair of the excavator, including overhaul and rearmouring by 6 days.
3. To reduce the dependence of enterprises-customers on the supply of imported components.

#### 4. Conclusion

The study of the structure, phase composition, defective substructure, mechanical and tribological properties of coatings deposited on a low-carbon steel by electric arc method in different modes in one and two passes by a powdered boron-containing wire was performed by the methods used in the modern physical material science.

The surfacing created by *Fe-C-Ni-B* wire forms a high-strength layer of thickness  $\approx 7$  mm with a microhardness 10.5-12.5 GPa at a single pass and thickness 10 mm with a microhardness  $\approx 15$  GPa at a double pass, that is 2 and 3 times, respectively, higher than the microhardness of the base metal. The wear resistance of the deposited layer is two times higher than the wear resistance of the original steel, and the coefficient of friction is 2.2 times lower.

When surfacing in one pass by the wire, the eutectic of a plate-type containing submicron borides of composition  $Fe_2B$  is formed, and for the double deposited layer – *FeB*. The formation of the hardened ultra-fine martensitic structure of  $\alpha$ -phase, a high scalar dislocation density ( $\sim 10^{11} \text{ cm}^{-2}$ ), and the presence of a large number of flexural extinction contours contribute to further increase in mechanical and tribological properties.

The results of the work have been implemented at mining enterprises to protect buckets of excavators from abrasive wear.

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