Structure, phase composition and properties of borowolframed coating on steel 20 after microarc chemical heat treatment

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Abstract. The results of the research devoted to the study of structure, phase composition, microhardness and wear resistance of the borowolframed coating on steel 20, that was obtained by the method of microarc chemical heat treatment, are presented. With the help of microrentgenospectral analysis, it was found that during microarc borowframing, both grain-boundary and transcrystallite diffusion of boron, carbon and tungsten occurs, which avoided the formation of brittle carboboride eutectics along the boundaries of plastic grains of the layer base. X-ray phase analysis in the diffusion coating found iron and tungsten borides Fe₂B and W₂B₅, tungsten carbide WC, boron nitride BN and iron intermetallic with tungsten Fe₇W₆. The micro hardness of the borowolframed layer was 12-13 GPa. The wear rate of the borowolframed samples is reduced by 4.4 times in comparison with steel 20 in the initial structural state.

1. Introduction
Borating is an effective method of creating wear-resistant coatings on the surface of steel. However, the increase in wear resistance is associated with an increase in brittleness because of the high hardness of the borated layers [1-7]. To increase ductility, [8-12] two-component saturation of the surface of steel with boron together with carbide-forming elements, in particular tungsten, was proposed. It was noted [8] that diffusion saturation with tungsten after preliminary borating, leads to the formation of a layer that includes an iron-based solid matrix with scattered borides Fe₂B.

This work is devoted to the study of the structure, phase composition and properties of borowolframed layers obtained by the method of microarc chemical heat treatment (MaCHT) from coatings. The essence of the MaCHT is in heating of steel sample in coal powder by microarc discharges on treated surface when electric current is passed [13-15]. The source of diffusing elements is a gel-like coating based on an electrically conductive gel, which includes powders of substances containing boron and an alloying element. [16-18].

2. The purpose of the research
Study of structure, phase composition and properties of borowolframed coatings on steel 20 after microarc chemical heat treatment.
3. Methods and materials

Cylindrical samples of steel 20 with a diameter 12 mm were treated. Coating on the basis of an electrically conductive “Unigel” gel was applied to the treated surface in the volume ratio of the following composition: 50% “Unigel”, and 25% each of boron carbide (B₄C) and ferrotungsten powders (FW70 according to National Standard 17293-93). After application of the coating, the test sample was immersed in a metal container and filled to a height of 15 mm with coal powder with a dispersion of 0.4-0.6 mm. The voltage was supplied to the sample and container, and as a result an electric circuit was formed: “power supply source-container-coal powder-sample with coating” [16]. This led to the formation of a “microarc halo” around the surface to be treated, which ensured effective heating of the sample’s surface, conversion of the diffuser to an atomic state, and protection against oxidation during because of the coal powder pyrolysis. The borowolframing was carried out for 3 minutes at a current density of 0.53 A/cm². The maximum surface heating temperature was 1250 °C [15].

Microstructural analysis of the samples was performed using METAM PB-22 and Neophot-21 microscopes. Microstructures were recorded by a Canon digital camera with a resolution of 7.2 MP. Micro hardness was determined according to National Standard 9450-76 on the micro hardness tester PMT-3 at loads on the indenter 0.498 and 0.196 N [19]. For X-ray phase analysis (RPA), an ARL XTRA-435 diffractometer was used in CuKα radiation. Microrentgenospectral analysis of structural components was performed on a scanning electron microscope with a ZEISS Crossbeam 340 electron ion workstation with an Oxford Instruments x-max 80 microanalysis system.

The wear resistance of the borowolframed samples was estimated according to National Standard 17367-71 by friction against fixed abrasive particles on the machine K4-B [20,21]. The weight loss of the samples was determined using laboratory weights of grade VLT-150-P with a limit of permissible absolute error ± 0.005 g. In accordance with the recommendations of the experiment [21], mass wear of the borowolframed samples was compared with mass wear of the standard, as which samples of steel 20 were used in the initial structural state.

4. Results and discussion

After microarc borowolframing of steel 20 was identified a surface layer up to 200 μm, with a micro hardness of 12-13 GPa, under the layer there was a carburized zone of eutectoid concentration with a micro hardness of 3.6-3.8 GPa, passing into the initial ferrite-pearlite structure of steel 20 (Figure 1).

![Figure 1](image-url)
As it can be seen from the diffractogram (Figure 2), the phase composition of the borowolframed layer includes iron and tungsten borides Fe$_2$B and W$_2$B$_5$, tungsten carbide WC, intermetallic Fe$_7$W$_6$, and boron nitride BN, which was probably formed by the interaction of boron and nitrogen from the air under the influence of microarc discharges.

![Figure 2. X-ray diffractogram of steel 20 after microarc borowolframing](image)

The concentration of elements in the layer was determined by the microrentgenospectral method by the depth of the layer (spectra 23, 24, 25), and at the outer edge of the layer - in light areas in the form of a discontinuous grid (spectra 26, 27 are highlighted in Figure 3). The results are shown in Table 1.

![Figure 3. Image of the borowolframed layer obtained on an electron scanning microscope](image)
Table 1. Concentration of elements in the surface layer of the borowolframed sample, wt.%

| Name   | B     | C     | Si    | Mn    | W     | Fe    |
|--------|-------|-------|-------|-------|-------|-------|
| Spectra 23 | 0.00  | 0.77  | 0.29  | 0.46  | 0     | 98.48 |
| Spectra 24 | 0.00  | 0.83  | 0.33  | 0.43  | 4.55  | 93.86 |
| Spectra 25 | 1.63  | 0.87  | 0.28  | 0.42  | 3.86  | 92.94 |
| Spectra 26 | 2.23  | 1.23  | 0.24  | 0.35  | 64.19 | 31.90 |
| Spectra 27 | 3.46  | 1.41  | 0.25  | 0.37  | 15.49 | 79.02 |

As it can be seen from Table 1, boron is presented within the entire layer except the boundary with the original steel structure 20 (spectra 23 and 24). To the surface (spectra 26 and 27), the boron concentration increases. The increased content of tungsten in spectra 26 and 27 indicates the probability of tungsten-containing phases existence in these areas: tungsten boride W$_2$B$_5$ and intermetallic of iron and tungsten Fe$_7$W$_6$, which were identified by the RPA method.

The obtained results show that not only grain boundary, but also trans crystalline diffusion of boron, carbon and tungsten occurs during microarc borowolframing. This prevents the formation of a continuous carboborid grid along the grain boundaries that embrittles diffusion layer, especially under dynamic loads. In the absence of a strong carbide-forming element in the composition of the coating under microarc borating conditions, a similar grid is formed [17].

Nevertheless, the evaluation of abrasive wear resistance showed that the microarc borowolframed layer structure, which contains carbide, boride and intermetallic phases, has increased values. Thus, the abrasive wear resistance of the treated steel sample is 4.3 times higher than the reference steel sample 20 in the initial structural state, and, accordingly, the wear rate decreases from 7x10$^{-4}$ g/sec to 1.6x10$^{-4}$ g/sec.

5. Conclusions
1. After microarc borowolframing, a diffusion layer up to 200 μm and micro hardness of 12-13 GPa is formed on the surface of steel 20. Under the layer is a carburized area of eutectoid concentration with a micro hardness of 3.6-3.8 GPa and a thickness up to 150-170 μm passing into the initial ferrite-pearlite structure of steel 20.

2. Roentgen phase analysis in the layer revealed iron and tungsten borides Fe$_2$B and W$_2$B$_5$, tungsten carbide WC, boron nitride BN and intermetallic Fe$_7$W$_6$.

3. As the data of microrentgenospectral analysis showed, during microarc borowolframing, both grain-boundary and trans crystallite diffusion of boron, carbon and tungsten is realized, which eliminates the occurrence of a continuous carboborid grid along the grain boundaries.

4. Borowolframing of steel 20 using the MaCHT method leads to an increase in the micro hardness of its surface layer to 13 GPa and a decrease in the wear rate by 4.3 times in comparison with this indicator of steel 20 in the initial structural state.

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