Structural transformations of martensitic class coatings deposited by a flux-cored wire with carbide-boride-nitride doping during tempering

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Abstract. This work examines the influence of tempering regimes on the structure and characteristics of a metal deposited with a high-chromium flux-cored wire of a martensitic class with carbide-boride-nitride doping. It is shown that tempering at a temperature of 800 °C provides acceptable for machining values of metal hardness. As a result of the release of the metal with borides, the structure decays with the formation of a ferrite matrix, the amount of eutectics and particles of the strengthening phases decreases, and their microhardness decreases to 358-438 HV for the matrix, to 548-754 HV for the eutectic and to 1071-1174 HV for hardening phases.

1. Introduction
Despite numerous researches, the optimal solution for the task of improving the performance of machine parts and mechanisms operating under heavy wear conditions has not yet been found. The main parameter that determines the quality of such parts is their wear resistance. At the same time, it depends on the material of the product and the heat treatment regime. Suchwise, it is a material science problem, the solution of which has a great practical importance for each specific material. This also applies to the flux-cored wires which are used for hardening of the working surfaces of parts with wear-resistant alloys. Among them, chromium wires were widely used to provide a metal coating with high strength and corrosion resistance [1–5].

2. Statement of a problem
The studies carried out at the Omsk State Technical University have shown the effectiveness of the use in a powder coating of a boride compounds complex that ensures the production of deposited metal of a martensitic class with increased wear resistance in a corrosive environment [6–9]. However, the coating metal obtained by surfacing with these wires has a very high hardness.

In order to recrystallize the structure, reduce the hardness and the level of residual stresses and ensure a satisfactory processability of the metal of such coatings when machining with a cutting tool, it is necessary to carry out its high-temperature tempering. At the same time, the tempering regimes and their effect on the structure and characteristics of the coatings, deposited by a complex-alloyed chromium flux-cored wired, are not fully investigated.

Therefore, the task is to select the optimal tempering temperature and study its impact on metal coatings based on martensitic chromium steel alloyed with a complex of boride compounds.

3. Theory
In this work we investigated the impact of tempering regimes on the durometric characteristics, microstructure and phase composition of coating metal deposited by high-chromium flux-cored wire alloyed with B₄C + BN + TiB₂ + ZrB₂ complex. We used a steel band of 08kp size 15 × 0.8 mm with...
a filling factor of 0.34 as a cover in accordance with GOST 503-81.

Surfacing was carried out on plates of St3 steel with a size of 200×50×10 mm with an experimental flux-cored wire of 2.4 mm diameter in argon in four layers.

Metallographic studies of the weld metal were carried out on an optical microscope AXIO Observer A1m (Carl Zeiss). The microstructure was detected by chemical etching in a reagent of the following composition: CuSO₄ – 4 g; HCl – 20 ml; H₂O – 20 ml.

Durometric studies were carried out on metal samples after surfacing and thermal treatment with a hardness tester TK-2 by the method of Rockwell and microhardness tester Shimadzu HMV-2 by the Vickers method. The microhardness was measured over the cross section of the deposited coating, starting with the base metal in 0.2 mm increments.

Electron microscopy examination was carried out with a raster-type electron microscope JEOL JSM-6610-LV with add-on device Inca-350 of energy-dispersive analysis (EDA).

The metal was studied in states after surfacing and tempering.

4. Results of the experiments and discussion

The deposited metal of the coating with borides after surfacing has a complex composite structure (Fig. 1) with a martensitic matrix, a large amount of eutectic and strengthening phase particles, including, apparently, the σ-phases [10, 11].

![Figure 1. The microstructure and measurement ranges of the structural constituents](image)

The results of the structural components microhardness investigation of such a deposited metal are given in Tabl. 1.

Table 1. Microhardness HV₀.₀₁* and HV₀.₀₅ of structural components of the metal with borides after surfacing

| Puncture № | 1   | 2   | 3   | 4   | 5   | 6   | 7*  | 8   | 9   | 10  | 11* | 12  |
|------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| HV         | 978 | 587 | 540 | 552 | 575 | 546 | 1342| 521 | 593 | 874 | 1262| 829 |

It is seen from the presented results that the microhardness of the structural constituents of the metal after surfacing is 521-593 HV for the matrix, 829-978 HV for the eutectic and 1262-1342 HV for the strengthening phases.

The hardness of such a metal reaches a maximum value of 58 HRC.
The tempering was carried out for 2 hours at temperatures of 600, 700 and 800 °C, recommended for this class of steels [12]. The results of measuring the microhardness along the cross-section of the coating metal after tempering in the selected modes are shown in Fig. 2. The microhardness distribution in the metal of the coating after surfacing is also given there.

In the metal of such a coating alloyed with a complex of boride compounds, the microhardness over the cross-section after surfacing varies within 600-850 HV (Fig. 2). It can be seen that after tempering both at 600 °C and at 700 °C the microhardness has fairly high values within 500-800 HV. Tempering at 800 °C significantly reduces the microhardness to 250-400 HV, although there are structural components with higher values of microhardness.

![Figure 2](image2.png)

**Figure 2.** Distribution of microhardness along the cross-section of the complex-doped coating after surfacing and tempering

In the microstructure of the coating metal with borides after tempering at a temperature of 800 °C, the structural components decay (Fig. 3). At the same time, the amount of boride eutectic and hardening phases has decreased, and their size has increased.

![Figure 3](image3.png)

**Figure 3.** The microstructure and measurement ranges of the structural constituents microhardness of a metal with borides after tempering at 800 °C – 2h

The microhardness of the structural constituents of the deposited metal after tempering at 800 °C of the coatings under investigation has substantially changed (Tabl. 2).
Table 2. Microhardness HV$_{0.01}$* and HV$_{0.05}$ of structural components of the metal with borides after tempering at 800 °C – 2h

| Puncture № | 1    | 2    | 3    | 4    | 5*   | 6*   | 7    | 8    | 9*   | 10*  | 11   | 12   |
|------------|------|------|------|------|------|------|------|------|------|------|------|------|
| HV         | 358  | 496  | 548  | 420  | 754  | 1144 | 486  | 358  | 1071 | 458  | 520  | 387  |

As it can be seen, the microhardness of the structural constituents of the metal with borides after tempering has decreased significantly in comparison with that after surfacing (see Tabl. 1). The microhardness has decreased from 521-593 HV to 358-438 HV for the matrix, from 829-987 HV to 548-754 HV for the eutectics, and from 1262-1342 HV to 1071-1144 HV for the strengthening phases.

Thus, to reduce the hardness of the deposited metal of the investigated coatings, we can recommend tempering at a temperature of 800 °C. For a complete picture of the durometric characteristics of coatings after tempering, we investigated the hardness distribution over the cross-section of the coating using the Rockwell method. The results are shown in Fig. 4.

![Figure 4. Distribution of microhardness along the cross-section of the complex-doped coating after surfacing and tempering](image)

After such a tempering, the total hardness is distributed evenly over the cross-section of the coating alloyed with boride compounds in the range of 32-37 HRC. This hardness of the metal allows its machining with a cutting tool.

The results of transmission electron microscopy of the fine structure of such a metal after tempering are given in Fig. 5.

![a) b) Images](image)
They have shown that a partial $\alpha$-$\gamma$-$\alpha$ transformation occurred during the tempering process. The rack structure of martensite largely disappears already in the early stages of tempering. The basis of the structure is ferrite. Particles of chromium carbides of the type $\text{Me}_2\text{C}_6$, $\text{Me}_6\text{C}$ are observed against the background of light sections of ferrite. The average size of the precipitates is about 0.1 $\mu$m with a minimum distance between particles of 0.5-0.8 $\mu$m. The electron diffraction pattern contains $\alpha$-phase reflexes of several orientations with the axes of the zones [111], [113] and [311] and chromium carbides $\text{Cr}_2\text{C}_6$ reflexes. This indicates that the doped cementite ($\text{Fe}$, $\text{Cr})_3\text{C}$ passes into a special carbide.

We can also observe extensive $\sigma$-phase separations at large magnifications (Fig. 6).

Thus, as a result of the metal with borides tempering, the structure decays with the formation of a ferrite matrix, the amount of eutectics and strengthening phases particles decreases, and their microhardness decreases to 358-438 HV for the matrix, to 548-754 HV for the eutectic and to 1071-1174 HV for the hardening phases.
5. Conclusion
The rational thermal treatment of the deposited coatings on the basis of chromium steel with carbide-
boride-nitride doping is tempering at 800 °C for 2 hours, providing hardness up to 32–37.5 HRC
acceptable for machining, and subsequent quenching at a temperature of 1020 °C, increasing the
hardness to 58 HRC.

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