Choosing modes for thermal treatment of deposited coatings based on chromium steel with carbide-boride-nitride doping

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Abstract. This work explores the regimes of thermal treatment of corrosion-resistant coatings obtained by surfacing with a flux-cored wire with carbide-boride-nitride doping. It was found that tempering at a temperature of 800 degrees Celsius reduces the hardness of the metal to acceptable values for machining. To increase the hardness of the metal after tempering, it was suggested to perform quenching at a temperature of 1020 degrees Celsius. Carrying out such heat treatment ensures the hardness of the metal practically coinciding with the hardness of the metal after surfacing.

1. Introduction
Surface hardening of machine parts and mechanisms operating in difficult operating conditions is one of the important tasks of the machine-building industry. A significant reduction in the price of such products can be ensured by manufacturing them from relatively cheap steels with subsequent surface hardening with the help of wear-resistant flux-cored wires.

Therefore, a large range of details of machine-building production is surfaced with chromium-bearing flux-cored wires creating coatings with high corrosion resistance [1–3].

2. Statement of a problem
However, the operational period of details surfaced with such wires under abrasive wear is low. This is due to the small number of strengthening phases in the structure of the deposited metal. Increasing the wear resistance of such a deposited metal is possible by alloying it with boron [4–8]. A number of studies have established the effectiveness of using the boride compounds in flux-cored wires, which helps to receive coatings with increased wear resistance [9–12]. At the same time, the high hardness of such coatings makes their machining difficult. Hardness regulation of such a deposited metal is provided by its heat treatment. However, the thermal treatment regimes for such coatings had not been established.

Thus, this work explores the heat treatment regimes for coatings deposited by high-chromium flux-cored wire alloyed with a complex of carbide-boride-nitride compounds.

3. Theory
As the research object we chose the metal of coatings surfaced by high-chromium flux-cored wire, alloyed with a complex of boride compounds, its composition is: 15% Cr + 0.5% B4C + 0.5% BN + 2.5% TiB2 + 1.0% ZrB2. We investigated the effect of heat treatment regimes on the microhardness and microstructure of metal coatings.
4. Results of the experiments and discussion

It was established, that the deposited metal of the coating with borides after surfacing has a complex composite structure. It is characterized by a martensitic matrix and a large amount of eutectic and particles of strengthening phases. As a consequence, such a metal has a high hardness reaching values of 58 HRC.

The results of durometric research of the coating metal after surfacing are given in Tabl. 1.

| Table 1. Distribution of HV\(_{0.2}\) microhardness in the cross-section of the complexly alloyed coating after surfacing |
|---|
| Increment, mm | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.8 |
| HV | 615 | 674 | 680 | 693 | 773 | 654 | 705 | 680 | 663 | 740 | 725 | 654 | 753 |
| Increment, mm | 5.2 | 5.6 | 6.0 | 6.4 | 6.8 | 7.2 | 7.8 | 8.2 | 8.6 | 9.0 | 9.4 | 9.8 | 10.2 |
| HV | 649 | 712 | 894 | 650 | 693 | 674 | 750 | 741 | 789 | 742 | 970 | 800 | 840 |

It is noticeable that in the metal of such a coating alloyed with a complex of boride compounds, after surfacing, the microhardness varies within 615–970 HV over the cross section.

The microhardness of the structural components of such a deposited metal is shown in Tabl. 2.

| Table 2. Microhardness HV\(_{0.01}\) and HV\(_{0.05}\) of structural components of the metal with borids 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 |

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.

In order to carry out the mechanical treatment of the deposited metal it is necessary to reduce its hardness. For this purpose, tempering was carried out at the regimes recommended for this class of steels at temperatures of 600, 700 and 800 °C for 2 hours [13]. The results of measuring the microhardness over the cross-section of the metal alloyed with the B\(_4\)C+BN+TiB\(_2\)+ZrB\(_2\) complex after tempering in selected modes are given in Tabl. 3.

| Table 3. Distribution of HV\(_{0.2}\) microhardness in the cross-section of the complexly alloyed coating after tempering |
|---|
| Increment, mm | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.8 |
| HV | 590 | 514 | 585 | 615 | 623 | 580 | 550 | 580 | 565 | 555 | 745 | 598 | 530 |
| Increment, mm | 5.2 | 5.6 | 6.0 | 6.4 | 6.8 | 7.2 | 7.8 | 8.2 | 8.6 | 9.0 | 9.4 | 9.8 | 10.2 |
| HV | 545 | 590 | 570 | 627 | 594 | 674 | 851 | 652 | 680 | 715 | 685 | 674 | 692 |

The microhardness of the coating metal after tempering at 600 °C:

| Increment, mm | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.8 |
| HV | 590 | 514 | 585 | 615 | 623 | 580 | 550 | 580 | 565 | 555 | 745 | 598 | 530 |
| Increment, mm | 5.2 | 5.6 | 6.0 | 6.4 | 6.8 | 7.2 | 7.8 | 8.2 | 8.6 | 9.0 | 9.4 | 9.8 | 10.2 |
| HV | 545 | 590 | 570 | 627 | 594 | 674 | 851 | 652 | 680 | 715 | 685 | 674 | 692 |

The microhardness of the coating metal after tempering at 700 °C:

| Increment, mm | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2.0 | 2.4 | 2.8 | 3.2 | 3.6 | 4.0 | 4.4 | 4.8 |
| HV | 590 | 514 | 585 | 615 | 623 | 580 | 550 | 580 | 565 | 555 | 745 | 598 | 530 |
| Increment, mm | 5.2 | 5.6 | 6.0 | 6.4 | 6.8 | 7.2 | 7.8 | 8.2 | 8.6 | 9.0 | 9.4 | 9.8 | 10.2 |
| HV | 545 | 590 | 570 | 627 | 594 | 674 | 851 | 652 | 680 | 715 | 685 | 674 | 692 |
structure with a martensitic matrix, a large amount of eutectic and strengthening phases. The hardness of the metal reaches a maximum value of 58.5 HRC.

°C and 1100 °C according its hardness. For this purpose, after tempering the samples, we carried out their quenching metal are given in Tabl. 5.

range of 32–1144 HV. The hardness of the metal of such a coating, measured by the Rockwell method, is in the 55.5 HRC. The best results are obtained by quenching at 1020 °C.

Microhardness of the matrix has decreased from 521–829–1144 HV, to 340–450 HV, for eutectics – from 829–987 HV to 548–754 HV, and for the strengthening phases – from 1262–1342 HV to 1071–1144 HV. The hardness of the metal of such a coating, measured by the Rockwell method, is in the range of 32–37.5 HRC. Such hardness of the metal makes it possible to carry out its machining without any difficulties.

It can be seen that the microhardness of the structural constituents of the metal with borides after tempering has significantly decreased in comparison with that after surfacing (see Tabl. 2). Microhardness of the matrix has decreased from 521–593 HV to 358–458 HV, for eutectics – from 829–987 HV to 548–754 HV, and for the strengthening phases – from 1262–1342 HV to 1071–1144 HV. The hardness of the metal of such a coating, measured by the Rockwell method, is in the range of 32–37.5 HRC. Such hardness of the metal makes it possible to carry out its machining without any difficulties.

Therefore, we recommend tempering at 800 °C to reduce the hardness of the deposited metal of the examined coatings.

In order to provide high wear resistance of tempered metal after machining it is necessary to increase its hardness. For this purpose, after tempering the samples, we carried out their quenching according to the regimes recommended for this class of steels: at the temperatures of 950 °C, 1020 °C and 1100 °C [13]. The results of measuring the hardness over the cross-section of the coating metal are given in Tabl. 5.

Table 4. Microhardness HV$_{0.01}$ and HV$_{0.05}$ of structural components of the metal with borides after quenching at 800 °C for 2 hours

| 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 |

It can be seen that the microhardness of the structural constituents of the metal with borides after tempering has significantly decreased in comparison with that after surfacing (see Tabl. 2). Microhardness of the matrix has decreased from 521–593 HV to 358–458 HV, for eutectics – from 829–987 HV to 548–754 HV, and for the strengthening phases – from 1262–1342 HV to 1071–1144 HV. The hardness of the metal of such a coating, measured by the Rockwell method, is in the range of 32–37.5 HRC. Such hardness of the metal makes it possible to carry out its machining without any difficulties.

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Table 5. Hardness distribution over the cross-section of complexly alloyed coatings after quenching

| Quenching temperature, °C | 1   | 2   | 3   | 4   |
|---------------------------|-----|-----|-----|-----|
| 950                       | 52.5| 52.5| 52  | 54  |
| 1020                      | 54  | 53  | 55  | 58.5|
| 1100                      | 53  | 54  | 55  | 55.5|

Analyzing the obtained results, we can note that the hardness over the layers of the coating surfaced with the flux-cored wire with boride compounds after quenching at 950 °C is in the range of 52–54 HRC, after quenching at 1020 °C – 53–58.5 HRC, and after quenching at 1100 °C – 53–55.5 HRC. The best results are obtained by quenching at a temperature of 1020 °C.

The deposited coating metal with borides after such quenching has a complex composite structure with a martensitic matrix, a large amount of eutectic and strengthening phases. The hardness of the metal reaches a maximum value of 58.5 HRC.
The analysis of the microhardness structure of the metal after quenching at a temperature of 1200 °C is given in Tabl. 6.

**Table 6.** Microhardness \(HV_{0.01}\) * and \(HV_{0.05}\) of structural components of the metal with borids after quenching

| Puncture № | 1* | 2   | 3   | 4   | 5   | 6* | 7   | 8   | 9* | 10  | 11  | 12  |
|------------|----|-----|-----|-----|-----|----|-----|-----|----|-----|-----|-----|
| HV         | 1073 | 688 | 971 | 711 | 814 | 1052 | 773 | 723 | 1105 | 697 | 784 | 771 |

It is noticeable that the microhardness of the matrix is high and lies in the range of 688–784 HV, for eutectic it is 814–971 HV, for particles – 1052–1105 HV.

Thus, tempering at a temperature of 800 °C for 2 hours and subsequent quenching at 1020 °C are rational modes of thermal treatment of the deposited metal of the investigated coatings.

The results of the microhardness distribution of the metal of the coating under investigation after heat treatment performed at optimal conditions are shown in Fig. 1.

As it can be seen, such heat treatment leads to the stabilization of microhardness values at a high level, even slightly exceeding the microhardness level of the coating metal after surfacing.

**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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