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Influence of alloying (Cr, Fe, Ni) on the corrosion resistance of layers formed by electron-beam processing

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Abstract

The paper presents the results of comparative analysis of the properties of coatings based on chromium, nickel and iron borides. The alloy obtained in the process of electron-beam surfacing of the powder mixture “amorphous boron – 10 wt.% chromium” has the best properties. This is explained by the structures, fine chromium borides Cr_2B and complex iron borides $(Fe, Cr)_2B$, distributed in the austenitic matrix. The material modified in this way in a nitric acid solution corrodes at a rate of 0.02 mm/year. In sulfuric acid, its corrosion rate is 0.81 mm/year.

Key words

stainless steel
corrosion resistance
surface modification
electron beam
metal borides

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Key findings

- The greatest positive effect was obtained in the process of electron-beam surfacing of the powder mixture of "amorphous” boron and 10 wt.% chromium.
- The corrosion resistance of chromium-modified layers is related to the morphology of the chromium borides Cr_2B formed during surfacing.
- This result is novel, and the developed material can be recommended as a protective corrosion-resistant layer for products made of structural chromium-nickel steels.

1. Introduction

Chemical, oil and gas, power industries and mechanical engineering are among the strategically important industries in modern Russia. Chromium-nickel austenitic steels are widely used due to their high corrosion resistance and machinability for manufacture of critical structures in these industries [1, 2]. However, one of the problems limiting the use of chromium-nickel austenitic steels as materials for tribological applications is their low resistance to abrasive wear [3–5]. A rational solution that makes it possible to significantly improve these characteristics is the application of wear-resistant protective layers to wear surfaces by high-energy methods, for example, non-vacuum electron beam surfacing (EB) of powder mixtures [6–8]. However, increasing the strength of the surface layers can lead to a loss of the corrosion resistance of the material [9, 10]. Therefore, the determination of the influence of alloying elements on the oxidation resistance during surface hardening of stainless steels is an urgent task of modern industry [11–13].

2. Materials and methods

Surfacing of powder mixtures was carried out at Budker Institute of Nuclear Physics of Siberian Branch Russian Academy of Sciences (BINP SB RAS) at the industrial electron accelerator ELV-6. Processing was carried out in the scanning mode according to the following parameters: electron beam energy – 1.4 MeV; maximum power – 100 kW; scan rate – 5 Hz; speed of sample movement relative to the beam – 10 mm/s; beam current – 23 mA [14–16]. Amorphous boron (40 wt.%), Fe, Ni, Cr (10 wt.%), MgF_2 (wt.50%) were used as a deposited powder mixture [17–19]. The tests to determine the corrosion resistance of materials were carried out by anodic etching in inhibited sulfuric acid and in an oxidizing environment with weight loss control [20–22]. Unmodified steel 12X18H9T was chosen as a standard [8].

3. Results and Discussion

Corrosion resistance was evaluated by the gravimetric method by measuring the mass loss of samples during chemical reactions. The corrosion rate of materials was calculated according to the standard method ISO 11845:1995 "Corrosion of metals – General principles for corrosion testing".

It was established that the samples obtained using chromium as a wetting component have oxidation resistance 1.75 times higher than the reference material (steel 12Kh18N9T) [23–25]. The resistance of the nickel-modified materials is 1.4 times higher than that of the standard. The corrosion rate increased 1.3 times when using iron as a wetting component.

The results of the corrosion resistance analysis are shown in Figure 1.

The increase in the corrosion resistance of the analyzed materials is explained by the favorable effect of chromium and nickel, as well as the formation of chemically resistant chromium and iron borides in the surface layers [8, 26]. Structural features of the surface of the samples after corrosion tests were analyzed using the method of scanning electron microscopy.

The resulting images reflect the nature of the impact of acids on materials deposited by an electron beam [26]. One of the characteristic features recorded by scanning electron microscopy is etching of the interboride space (Figure 2). One of the reasons for corrosion resistance of chromium-modified layers is related to the morphology of the chromium borides Cr_2B formed during the surfacing. It is assumed that elongated borides contribute to the development of corrosion processes in the alloy to a lesser extent.

Figure 3 shows the data characterizing the mass loss of the samples obtained in the process of surfacing amorphous boron with different wetting components (Cr, Fe, Ni).

4. Conclusions

The creation of boron-containing layers on workpieces made of chromium-nickel steel by the EB method makes it possible to maintain or increase the level of corrosion resistance in boiling concentrated nitric acid and inhibited sulfuric acid. The greatest positive effect was recorded in the study of the samples obtained in the process of electron-beam surfacing of the powder mixture of "amorphous boron – 10 wt.% chromium”. The layer modified in this way in a nitric acid solution corrodes at a rate of 0.02 mm/year (the corrosion rate of steel 12X18H9T is 0.05 mm/year). In sulfuric acid, the corrosion rate of the deposited material was 0.81 mm/year, which is 1.7 times lower compared to 12Kh18N9T steel (1.4 mm/year). The developed material can be recommended as a protective corrosion-resistant layer for products made of structural chromium-nickel steels.

Supplementary materials

No supplementary materials are available.

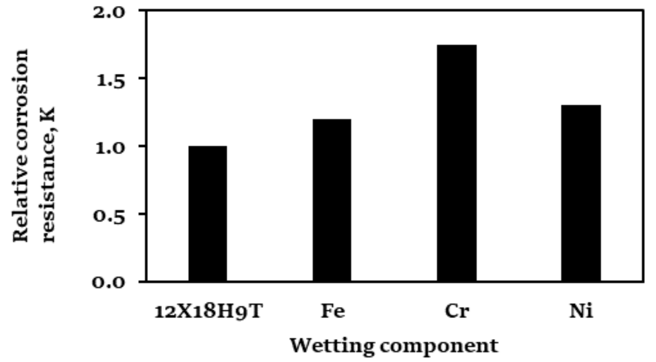

Figure 1 Relative corrosion resistance of 12Kh18N9T steel and samples obtained by surfacing amorphous boron and 10 wt.% wetting components (Fe, Cr, Ni).

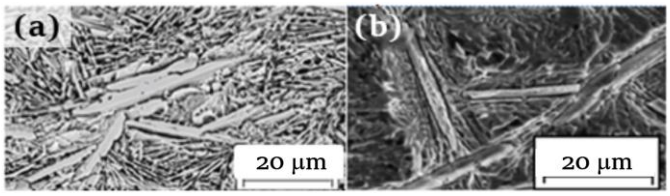

Figure 2 Surface morphology of alloyed layers (surfacing of amorphous boron and 10 wt.% chromium, I = 23 mA) after corrosion tests in inhibited sulfuric acid (a) and (b) nitric acid.

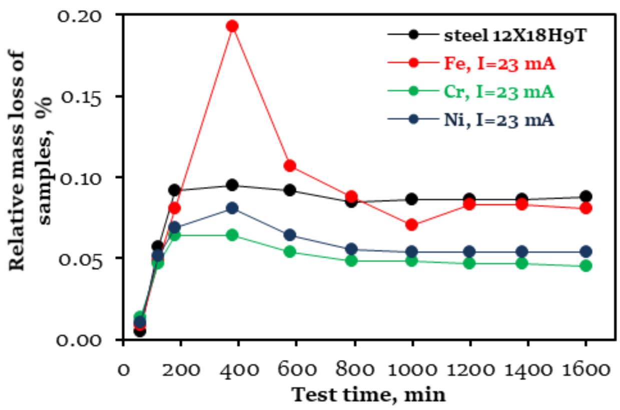

Figure 3 The nature of the change in the relative mass loss of samples obtained by non-vacuum electron beam surfacing of amorphous boron with various wetting components, from the time of exposure to nitric acid. Surfacing current is 23 mA.

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Conflict of interest

The authors declare no conflict of interest.

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