Investigation of Ni-Cr-Si-Fe-B coatings produced by the electron beam cladding technique

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Abstract: This paper presents the results of structural investigations and results of tribological and microhardness tests of the coating obtained by electron beam cladding of a Ni-Cr-Si-Fe-B self-fluxing alloy on low-carbon steel. After electron beam treatment high-quality dense layer with a thickness of 1.2-1.8 mm was obtained. The structure of the coating consisted of dendrite crystals based on γ-Ni-solid solution and eutectic with complex composition. Microhardness of the coating achieves 370 HV. Wear-resistance of the coating obtained by electron-beam cladding technique was 1.6-fold higher than that of low-carbon carburized steel.

Keywords: wear-resistant coatings, electron-beam cladding, microstructure, microhardness.

1. Introduction

One of the most advanced directions of the modern material science is protective coatings processing which provides significant increase of lifetime of machine components working at high temperatures and abrasive wear. Currently, surface hardening techniques based on highly-concentrated energy sources are developed extensively. Among these techniques, electron-beam treatment should be particularly emphasized. Such advantage as high efficiency (up to 75 %), high thickness of hardened layers, high adhesion between a substrate and a coating singularizes this technique from others technologies of surface hardening based on highly-concentrated heating sources [1-2, 6-7]. Ni-Cr-Fe-Si-B self-fluxing alloys are widely used for formation of coatings and for building-up of worn-out parts [3,4]. These alloys are characterized by high stability to abrasive and impact wear. Superior wear-resistance of cladded layers can be explained by the presence of hard strengthening phases such as carbides, borides, silicides [5]. High Ni and Cr content have a positive effect on heat-resistance of these alloys. Si and B reduce melting point (up to 1050 ° C) and act as fluxing components. These chemical elements appear to be the active chemical reducing agents for majority of metal oxides. B and Si generate a thin glassy layer, which protects the coating surface from oxidation [3,5].
The aim of this work consisted in structural investigation and evaluation of tribotechnical characteristics of the Ni-Cr-Fe-Si-B self-fluxing coating obtained by the electron-beam cladding technique on a low-carbon substrate.

2. Materials and methods
To form the coating, electron-beam cladding in vacuum was used. Cladding was realized by the electron-beam device ELU-5, developed in Institute of Physics of Strength and Material Science of the Siberian Branch of the Russian Academy of Sciences (Tomsk) and equipped with a system of powder delivery. A powder material was directly supplied to the electron beam operating area. Thickness of the layer cladded for one path achieved 0.4…0.7 mm. Coating formation was carried out in four paths according to the following technological parameters: current (I) – 40 mA, accelerating voltage (U) – 27 kW, speed of workpiece movement relatively to the outlet (v) – 3 mm/sec.

Low-carbon steel plates with dimensions of 100×25×10 mm were used as the base material. Commercial Ni-based self-fluxing powder with particle size in the range 40 – 100 μm was used as the surfacing material. Chemical compositions of the substrate and surfacing materials are presented at the Table 1.

![Table 1. Chemical composition of base and coating materials, wt. %](image)

Structural researches of obtained coating were carried out using Carl Zeiss Axio Observer A1m optical microscope (OM). To reveal the microstructure of coating, chemical agent consisted of ferrous chloride (FeCl₃), nitric (HNO₃) and hydrochloric (HCl) acids was used. For more detailed investigations the Carl Zeiss EVO 50 XVP scanning electron microscope (SEM) was utilized. Hardness of the obtained materials was estimated by the Wolpert Group 402MVD Vickers tester. The load on the tetrahedral diamond indenter was 0.98 N. Wear-resistance of the cladded coating was evaluated by friction test against embedded abrasive grains in accordance with standard GOST 17367-71. Silicon carbide with 80-100 μm particle size was used as an abrasive material. Low-carbon (0.2 % C) carburized and quenched steel (with subsequent low tempering) was used as a reference sample. Amount of wear was evaluated by mass loss measurement using Pioneer DA214C balance.

3. Results and discussion
The above described cladding conditions lead to formation of high-quality surface layer. The thickness of the cladded layer is 1.2-1.8 mm. At the Figure 1a a general view of obtained coating is presented. The key aspect of the coating, obtained by electron-beam cladding technique, is formation of gradient structure, which is characterized by gradual change of structure from the surface to initial material. Structure of the cladded coating can be divided into three significant zones: melted layer, transition zone and heat-affected zone, obtained because of the heat-dissipation into unheated layers of base material.

At the Figure 1b, c micrographs of surface and conversion zone of formed coating are presented, respectively. The formation of a dendritic structure is typical for the coating obtained by cladding of the self-fluxing powder. At the boundaries of dendritic crystals, eutectic structure is observed. According to the literature data, eutectic in this alloys may consist of borides, carbides, complex carboborides, silicides with γ-Ni [5]. More detailed studies confirmed the presence of precipitations of
hardening phases with size below 30 μm (Figure 1 d). At the near-border area Ni-base columnar grains appeared [3-5], elongated in heat-dissipation direction. It should be noted, that on boundary "coating-substrate" appears entire band, presented by γ-solid solution of Ni, enriched with Fe. An increase of the concentration of iron is associated with diffusion processes, occurred during the coating formation. The thickness of this area varied from 7 to 12 μm (Figure 1 c). The results of the hardness tests are shown in Figure 2 a. Microhardness of the coating reaches 370 HV. At the direction from surface to base material the hardness of the coating decreases. This could happen due to decrease in volume fracture of reinforced particles and due to dilution of coating material with base material at the bottom part of the coating.

Figure 1. Structure of the coating, obtained by electron-beam cladding technique (a) - general view of obtained coating, (b) - surface structure of the coating, (c) - transition zone ("coating-heat affected zone") structure, (d) - SEM-image of hardening phases.
Tribo logical tests were carried out to evaluate the performance of the cladded layers. Ideally, the conditions of the test should be close to the working conditions of material. In this case the results of the test can provide valuable information of materials behaviour in the real situation. Since the coatings of this type frequently work in abrasive environment, the wear resistance of the materials was evaluated by friction against fixed abrasive particles. The results of the tests are presented at Figure 2b. The relative wear resistance of the reference material was equal to 1. The wear resistance of the coating obtained by electron-beam cladding technique is 1.6 times higher in comparison with the reference sample. These data indicate efficiency of electron-beam cladding technique for fabrication of wear resistant materials.

4. Conclusion
Consequently, electron beam cladding is a perspective technique for obtaining dense highly-alloyed wear-resistant coatings. High treatment velocity allows to form surface layers possessing high-level mechanical properties.

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