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Structure of surface layers produced by non-vacuum electron beam boriding

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ABSTRACT

The structure and mechanical properties of boronized layers produced on low carbon steel substrates by non-vacuum electron-beam cladding were studied. This process provides high performance and high thickness of coatings and can be used to process large workpieces. In this study, we investigated coatings obtained by one, two or three passes of the electron beam. The thickness of the coatings varied from 0.6 to 1.0 mm, and the maximum hardness achieved was 21 GPa. Structural analysis revealed the oriented growth of eutectic colonies near the primary crystals of iron borides, which was explained by the commonality of the boride phases in the primary Fe_2B and eutectic Fe_2B. The eutectic colonies formed during electron-beam cladding consisted of a continuous framework of borides crystals and segregations of α-Fe in the form of oriented fibers. Coatings produced by electron-beam cladding had higher contact-fatigue endurance than those produced by pack boriding.

1. Introduction

Out of many different surface layers used for hardening of machine components, boride layers can be particularly distinguished [1–3]. Due to the high strength and tribological properties of boronized layers, boriding processes are widely used in the manufacture of mining equipment and building and agricultural machines. The effect of boride layers is particularly evident in cases of abrasive wear. Dozens of boriding methods of metallic workpieces have been proposed for industrial applications [4]. Traditional manufacturing processes, including pack boriding in solid powder, though providing high hardness and wear resistance of steels, have several drawbacks, the most important of which are the long duration of the process and the relatively small thickness of the hardened layers. An effective solution to these problems can be based on the use of boron powder cladding on steel substrates [4–9]. Different types of equipment, including electron-beam guns and accelerators, have been developed to produce hardened surface layers by cladding.

In conventional accelerators, whose accelerating voltage is typically less than 200 kV electron-beam heating of materials is carried out in vacuum chambers. The depth of penetration of the electron beam in the material in these devices does not exceed a few tens of microns. Specialists of the Institute of Nuclear Physics (Siberian Branch of the Russian Academy of Sciences (SB RAS), Novosibirsk) have developed powerful industrial accelerators with electron accelerating voltage in range 1–2.5 MeV that provide the opportunity to output of the electron beam to the atmosphere, which allows one to process large-sized products with high performance and form on them hard surface layers of great thickness.

The processes of electron-beam cladding of boron powders and pack boriding in solid powders have significant differences, and, form layers of different structure, which ultimately determines the properties of surface-hardened steels. The structure of the layers obtained by pack boriding technology has been studied in sufficient detail [1–4,10–13]. At the same time, the structure of the surface layers, deposited by high power electron beam under atmosphere has been the subject of very few studies [14–16]. The purpose of this study was to investigate the structural features and mechanical properties of the surface layers formed by non-vacuum electron-beam cladding of boron powder on low carbon steel.

2. Materials, experimental techniques, and methods of investigation

Low carbon steel plates with a thickness of 14 mm were used as substrates. The composition of the steel was as follows: 0.18% C, 0.23% Si, 0.50% Mn, 0.04% S, and 0.035% P. Cladding of powder

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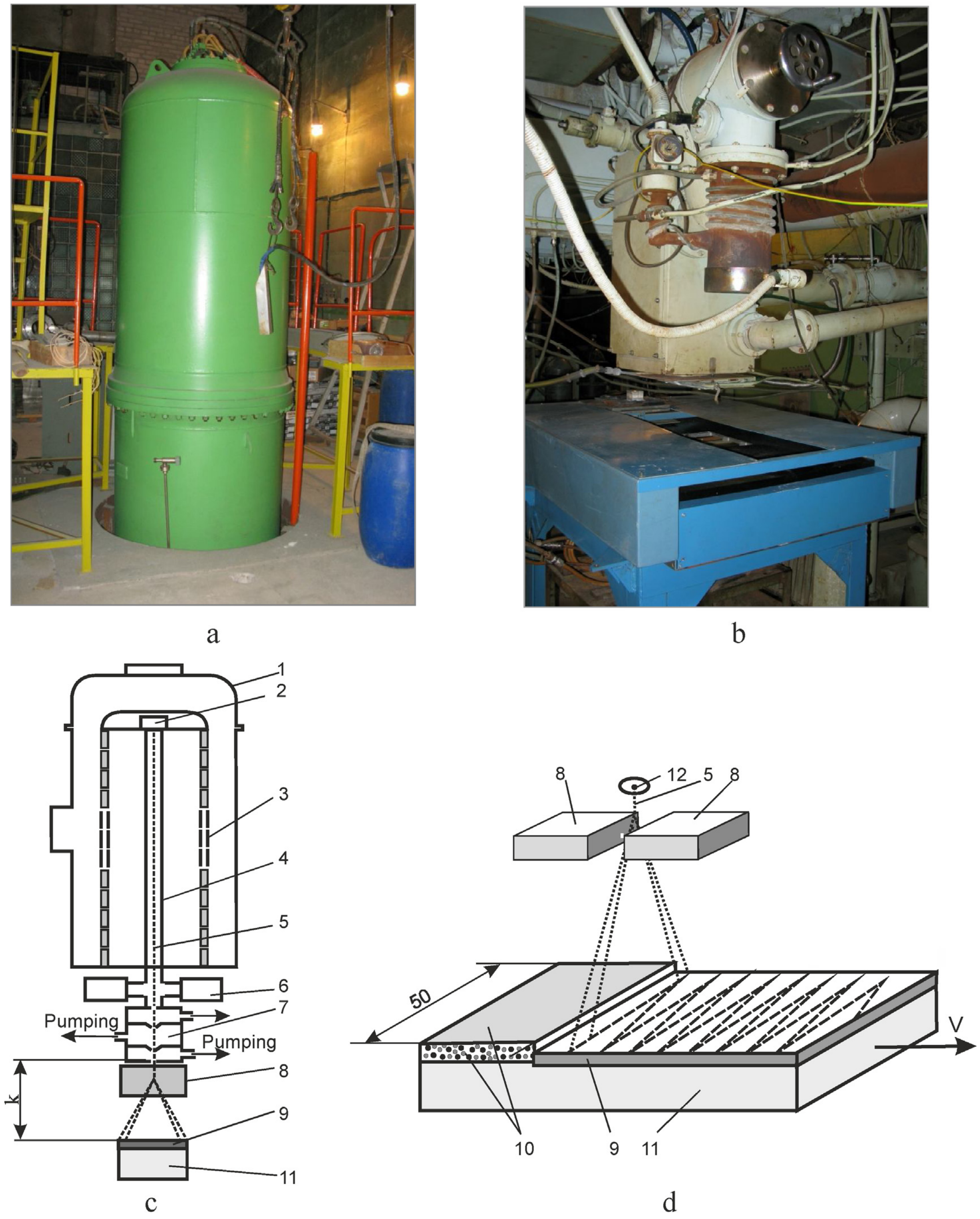

Fig. 1. Electron accelerator providing electron-beam extraction into air.
(a) Case of the accelerator, (b) zone of electron-beam extraction into air, (c) accelerator layout, (d) schematic diagram of the cladding process. (1) Case of the accelerator, (2) injector control unit, (3) high-voltage accelerator, (4) accelerating tube, (5) electron beam, (6) vacuum system, (7) electron injector, (8) electromagnetic scanning system, (9) clad layer, (10) fused powder (11) substrate (steel plate), (12) outlet.

mixtures was carried out on an ELV-6 electron accelerator produced by the Institute of Nuclear Physics SB RAS (Fig. 1a–c). A mixture of an amorphous commercially pure boron powder, a flux (MgF_2), and an iron powder were used for cladding. The powder mixture was poured on the surface of steel plates forming flat layer.

The velocity of sample movement relative to the electron beam was 10 mm/s. At the same time, the beam was scanned in the transverse direction by an electromagnetic system (Fig. 1d). The scan rate was equal to 50 Hz. The peak-to-peak value of electron-beam scanning was equal to 50 mm. The following process parameters were used for cladding: a beam current of 24 mA, distance from the outlet window to the workpiece of 90 mm, an electron-beam energy of 1.4 MeV, and a bulk powder density of 0.2 g/cm^2. Different concentrations of boron in the surface layers was provided by one-, two-, and three-layer cladding of the powder mixture. Plates of low carbon steel borided in a furnace using a powder mixture containing 65% amorphous boron, 30% NaF, and 5% Al_2O_3 were used for comparison. Pack boriding was performed at 900 °C for 6 h.

Metallographic examination of cladded specimens was performed with Carl Zeiss Axio Observer A1 m and Axio Observer Z1 m microscopes at magnifications ranging from ×50 to ×1000. The structure of the material was revealed by a chemical reagent