IN SITU SYNTHESIZED (TiB+TiC)/Ti COMPOSITE LAYERS FABRICATED ON CP-TITANIUM BY ELECTRON BEAM CLADDING

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Abstract

In the present study, the method of non-vacuum electron beam cladding of powder mixtures containing 10, 20 and 30 wt. % of boron carbide, titanium and welding fluxes (CaF_2, LiF) was used for the synthesis of titanium carbide and titanium boride particles. The structure, phase composition, microhardness and tribotechnical properties of the samples of commercially pure titanium after surfacing were investigated. The thickness of the obtained coatings was 1.4 ... 1.7 mm. The main phases of the cladded layers were alpha-titanium, titanium carbide with a cubic lattice of TiC (B1), titanium monoboride with an orthorhombic lattice TiB (B27). The obtained data were confirmed by the results of the microstructural analysis. The microstructure of the coatings consisted of hardening titanium carbide and titanium boride particles distributed in the titanium matrix. All coatings contained 0.2-0.89 vol. % of undissolved boron carbide particles. The factor, which was determined the microhardness and tribotechnical properties of the obtained materials, was the hardening particles content in the coatings. The average microhardness value of the coatings was 395, 521 and 565 HV at 10, 20 and 30 wt. % B_4C, respectively. The friction test against fixed abrasive particles exhibited that the relative wear resistance of the coating formed by cladding of 30 wt. % B_4C was three times higher compared to commercially pure titanium.

Keywords: Titanium, electron beam cladding, titanium carbide, titanium boride, wear resistance

1. INTRODUCTION

Titanium and its alloys are widely used in the aerospace, chemical and automotive industries due to its high strength, low weight and excellent corrosion resistance [1-3]. However, low tribotechnical properties limit an application of titanium alloys under abrasive wear conditions [4]. For example, an abrasive wear rate of titanium alloys is about seven times higher than a wear rate of carbon steel 1080 [4]. Traditional methods of chemical-thermal treatment lead to an increase in the hardness of the titanium surface layer but they are not attended by a significant increase in wear resistance.

The methods of surface hardening such as PVD, CVD, laser and electron beam cladding, plasma spraying are the proven technologies that allow increasing wear resistance of titanium alloys.

Laser processing allows improving the properties of the material surface layer without changing the properties of the base metal. The first papers which cover the laser hardening of titanium-based alloys appeared in the 1980s [5, 6]. Various types of ceramic phases such as carbides, oxides, borides and nitrides of metals were used as the hardening particles. Several approaches to the formation of the hardening phases in the surface layers of titanium alloys exist: the immediate addition the particles to the melt or the in-situ formation during the material crystallization. The second approach allows improving the adhesion to the matrix and increasing the quality and homogeneity of the coatings. However, considering the significant reflection of the laser beam from the materials surface, its energy is not always sufficient for the complete melting of refractory compounds. Using of an electron beam allows avoiding the above disadvantage. The electron beam is a volumetric source of energy and allows melting almost any material for a short time.

In this study, the electron beam energy was used for the in-situ synthesis of the composite coatings. Such investigations have been carried out using an ELV-6 industrial electron accelerator at the Institute of Nuclear Physics of the Russian Academy of Sciences (Novosibirsk, Russia) for many years [7-11]. The uniqueness of the accelerator consists in the extraction of an electron beam into the air atmosphere. In spite of the short-term processing, the oxidative effect on the material is high. The welding fluxes were used to avoid it. Numerous studies have shown that it was recommended to use LiF and CaF_2 fluorides for the high-quality protection of titanium alloys.

In the study [10], the efficiency of the flux protection of the melt bath from oxidation in electron-beam cladding of tantalum and niobium powders was evaluated. The gas content was estimated using a LECO TC-600 device. The method consisted in the melting of a metal sample in a graphite crucible in the helium stream. The oxygen released in the form of CO or CO_2 was determined by the method of molecular absorption spectroscopy in the infrared region, nitrogen was the detector of thermal conductivity. The authors have shown that the content of oxygen and nitrogen in the cladded layers did not exceed 0.192 % and 0.022 %, respectively. The obtained concentrations of impurities did not exceed the concentration regulated by GOST 19807-91.

Currently a lot of findings concerned with electron-beam hardening and surface alloying of cp-titanium were obtained [7-11]. This study is a continuation of the investigations in this area. In the study the effect of the boron carbide content in the initial powder mixture on the structure and tribotechnical properties of the obtained coatings was evaluated. The synthesis of titanium boride and carbide phases in the titanium surface layers using an electron beam is a promising task and allows not only increasing the hardness level at the room temperature, but also at high temperatures. In addition, TiC and TiB phases have densities closed to the density of titanium. It allows increasing the number of the hardening phases without a significant effect on the total density of the composite.

2. MATERIALS AND METHODS

The titanium alloy VT1-0 was used as the base metal. The dimensions of the plates were 12 x 50 x 100 mm. Boron carbide powder (10, 20 and 30 wt. %), titanium powder (20, 30 and 40 wt. %) and powders of the welding fluxes CaF_2 (40 wt. %) and LiF (10 wt. %) were used as an alloying material. The powder mixture was uniformly mixed, was distributed over the surface of the titanium workpiece in an amount of 10 g and was exposed to an electron beam. Technological experiments were carried out using an ELV-6 industrial electron accelerator at the Budker Institute of Nuclear Physics of the SB RAS (Novosibirsk) according to the following modes: the speed of sample movement was 25 mm / s; the electron beam current was 30 mA; the electron energy was 1.4 MeV; the distance from the outlet window to the workpiece was 90 mm. The electron beam was scanned in the transverse direction with the scan rate of 50 Hz to ensure cladding over the workpiece width.

Microstructural investigations of the transverse microsections were carried out using a Carl Zeiss Axio Observer A1m optical microscope. Evaluation of the size and volume fraction of the hardening phases was carried out on non-etched microsections using the ImageJ program. The microstructural features of the cladded layers were examined using a Carl Zeiss EVO 50 XVP scanning electron microscope. The phase composition of the layers was analyzed using an ARL X`TRA X-ray diffractometer. Diffraction patterns were obtained in Cu Kα radiation in a step mode with a step size of 0.05° and dwell time of 5 s per point. The microhardness distribution over the depth of the cladded layer was measured using a Wolpert Group 402MVD tester. The load on the diamond indenter was 0.98 N.

Tribotechnical tests of the materials obtained by electron-beam cladding were performed in accordance with GOST 17367-71 (the nearest analog is ASTM G132-96 standard) under fixed abrasive particles. The cylinder-shaped samples 2.5 mm in diameter were prepared for the test. The load was 3 N, the total test time was 35 s. Wear rate was estimated by the weight loss of the samples after the tests. The surface of the samples after wearing was examined using a scanning electron microscope.

3. RESULTS AND DISCUSSION

The optical micrographs of the materials obtained by non-vacuum electron beam cladding of the boron carbide and titanium powders are presented in **Figure 1**. In the results of electron beam treatment the surface of the base materials (titanium VT1-0) and powder mixture are melted, and the hardening particles are precipitated during crystallization. **Figure 1** shows a clear interface between the cladded layer and the base metal. The heat-affected area was located below the interface. The thickness of the specimens obtained by cladding of 10 and 30 wt. % boron carbide was varied from 1.4 to 1.7 mm. Defects such as pores and cracks were not determined. However, undissolved particles of boron carbide are presented in the lower area of the cladded layer of the all type of coatings (**Figure 1**). Its volume fraction did not exceed 0.89 %.

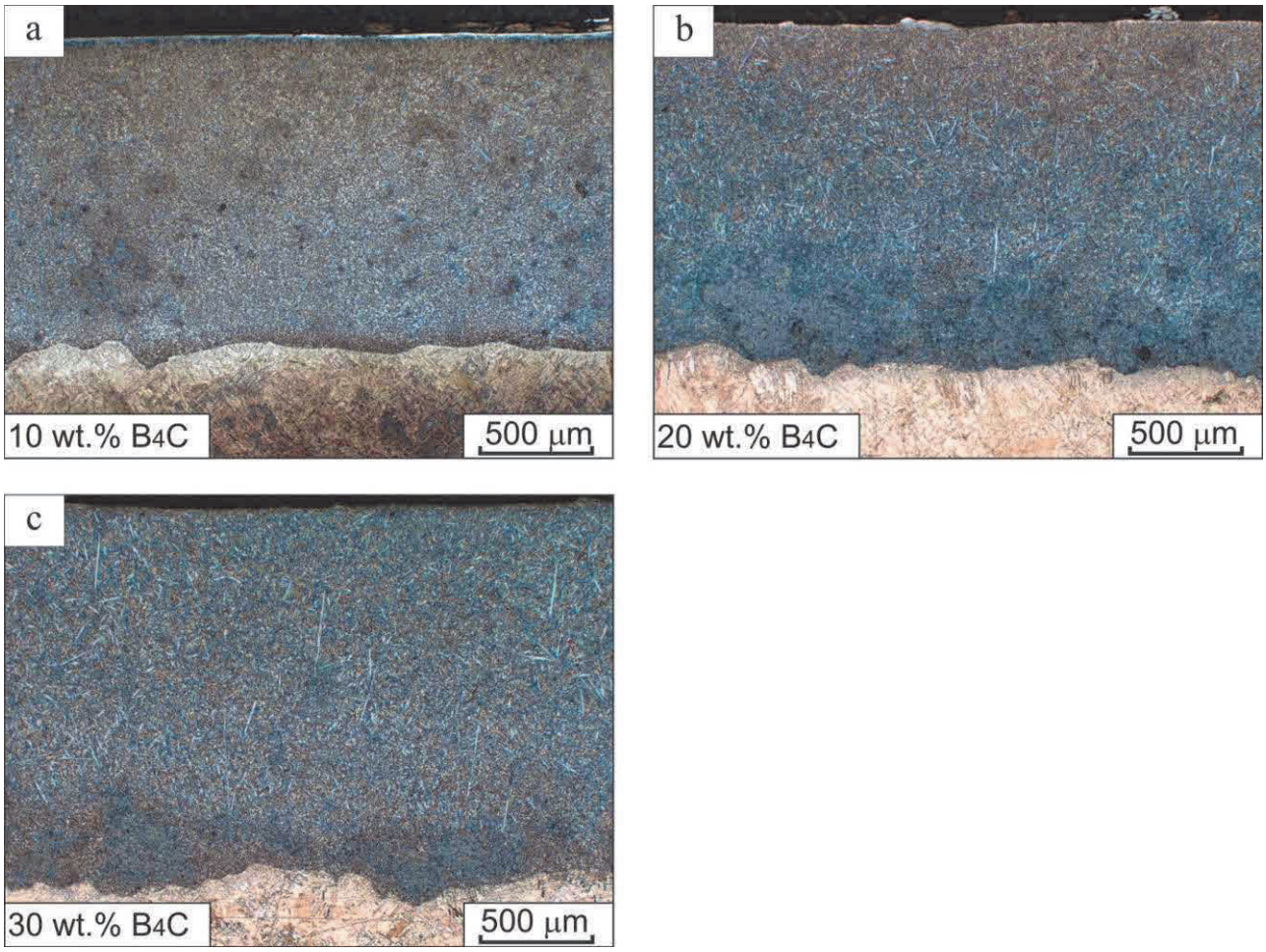

Figure 1 Structure of the titanium surface layers obtained by non-vacuum electron beam cladding of the boron carbide and titanium powders mixture (the beam current was equaled to 30 mA)

Figure 2 shows SEM micrographs of the cladded layer structure. The hardening particles of titanium carbides and borides with different morphology distributed in an alpha-titanium matrix are formed in the structure. Titanium boride is precipitated, as a rule, in the form of the particles of two types: the primary hexagonal prisms and fine acicular particles of the eutectic type. It should be emphasised that the titanium boride crystals of any type grow with a hollow core. The crystals are filled with alpha titanium inside. The particles of titanium carbide have dendritic morphology. **Figure 2d** shows that the growth of the dendritic titanium carbide crystals occurs on the side faces of titanium boride. The fine particles of titanium carbide formed during the eutectic reaction are also observed in the coating. The line scan profiles of Energy dispersive X-ray (EDX) analysis which confirms the data of scanning electron microscopy are shown in **Figure 3**.

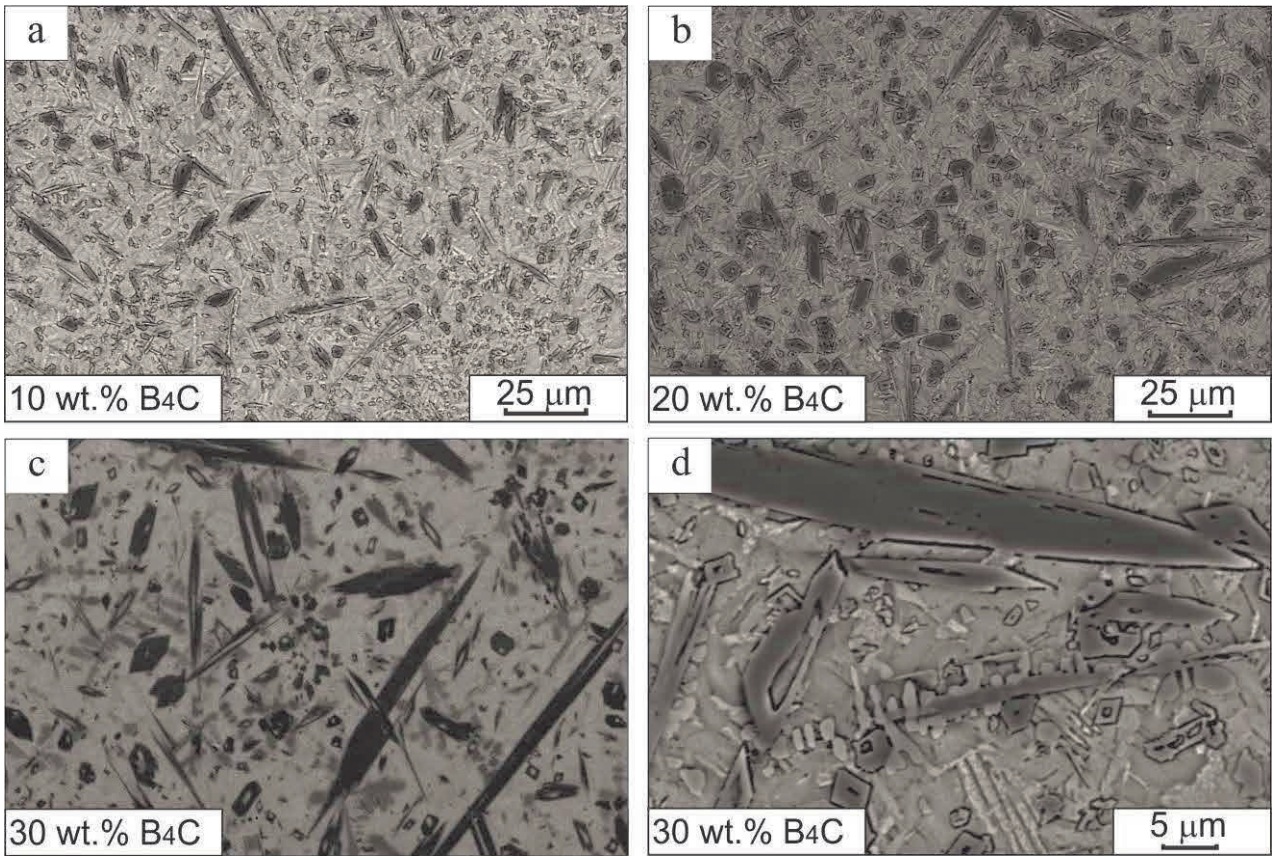

Figure 2 Scanning electron microscopy of the layers obtained by non-vacuum electron beam cladding 10 wt. % B_4C (a), 20 wt. % B_4C (b, d) and 30 wt. % B_4C (c)

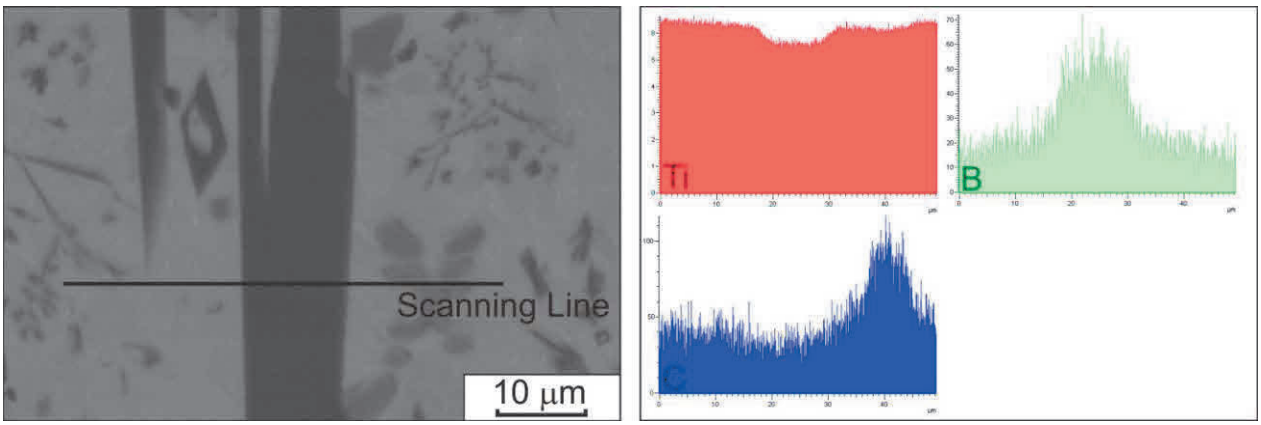

Figure 3 Distribution of Ti, B and C along the scanning line

An increase in the concentration of boron carbide powder in the initial powder mixture leads to the volume fraction growth of the hardening phases particles (TiC and TiB) from 21, 33 to 46 %. In addition, an increase in the volume fraction and sizes of the primary crystals of the hardening phases is observed.

The phase analysis of the samples obtained by cladding of boron carbide and titanium powders has shown the presence of the peaks of three phases: hexagonal α-titanium (α'-titanium) (A3), cubic titanium carbide (B1) and orthorhombic titanium boride (B27) (**Figure 4**). An increase in the concentration of boron carbide in the alloying mixture leads to enhancing the intensity of the peaks of titanium carbide and boride. The shift of the TiC peaks towards the major angles indicates a change in the lattice parameters. It means that TiC exists in

the form of TiCx (x < 1). The peaks of boron carbide on the X-ray diffraction pattern were not determined. It is concerned with their low volume fraction in the depth of the cladded layer.

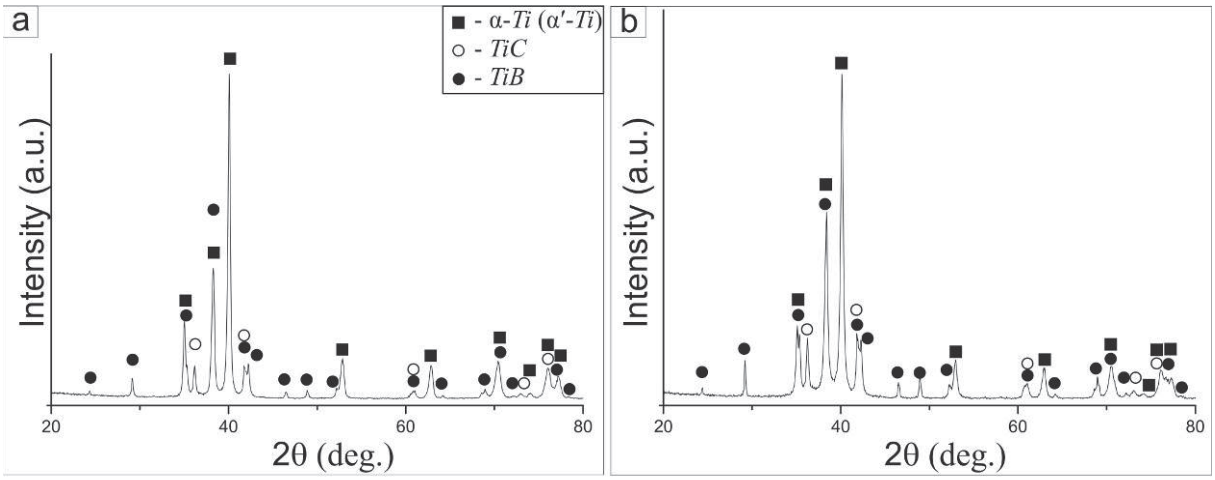

Figure 4 X-ray diffraction patterns of the Ti-B-C system layers obtained by non-vacuum electron beam cladding of the titanium powder mixture with 10 wt. % B_4C (a) and 30 wt. % B_4C (b) on the cp-titanium workpieces

Hardness measurements were carried out in the direction from the surface to the base metal. The obtained results are shown in **Figure 5a**. The average microhardness value of the coatings was equaled to 395, 521 and 565 at the concentration of 10, 20 and 30 wt. % B_4C in the initial powder mixture, respectively. The increase in the microhardness level is attributed to the high volume fraction of titanium carbide and boride in the coatings, the hardness of which exceeds considerably the hardness of the base metal.

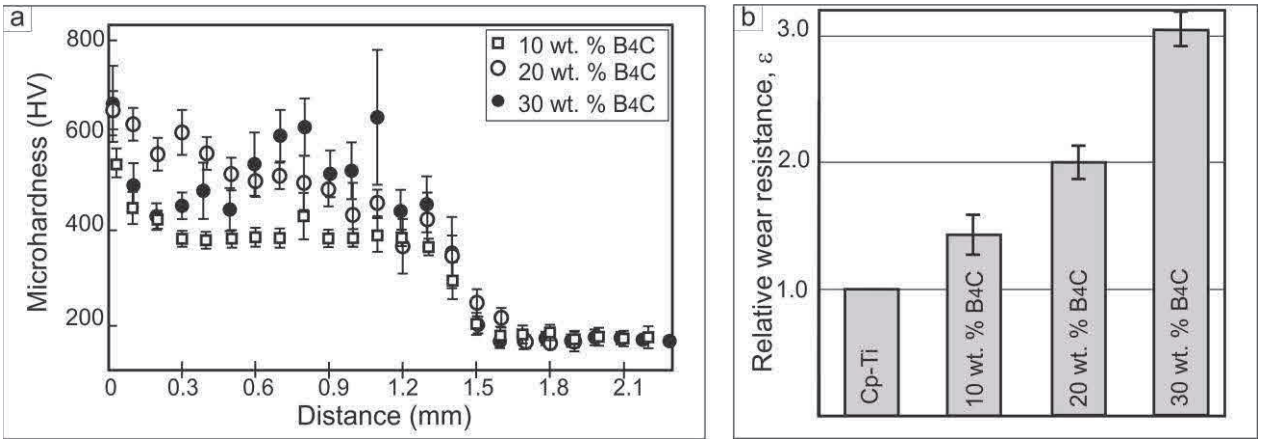

Figure 5 The microhardness distribution in the depth of the cladded layers (a) and the relative wear resistance of the materials under fixed abrasive particles (b)

The evaluation of the wear resistance level during the friction test against fixed abrasive particles was performed by a mass loss of the materials during the wearing. The test results are shown in **Figure 5b**. A joint analysis of **Figures 5a** and **5b** shows that enhancing the volume fraction of the hardening particles leads to an increase in the hardness and wear resistance of the materials. Thus, the sample obtained by cladding of 30 wt. % boron carbide possesses the maximum wear resistance. Its relative wear resistance is three times higher than the wear resistance of cp-titanium.

4. CONCLUSIONS

Thus, in the results of non-vacuum electron beam cladding of boron carbide and titanium powders on the cp-titanium workpieces the hardening particles of titanium carbide and boride were synthesized in the surface layers. The thickness of the layers was depended on the concentration of the boron carbide powder in the initial powder mixture and was equaled to 1.4 ... 1.7 mm. The structural-phase composition of the obtained materials did not vary with the concentration of boron carbide. The cladded layer contained inclusions of titanium carbide and boride distributed in the α-Ti (α'-Ti) titanium matrix. An increase in the concentration of boron carbide in the alloying mixture to 30 wt. % led to the growth of the volume fraction of the TiC and TiB hardening inclusions. It was attended by an increase in the hardness and wear resistance of the materials in three times in comparison with the base metal.

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