Deposition of Ti–Si–B Erosion Resistance Nanocoating with MAX-Phase on the Surface of Ti_6Al_4V Alloy Parts by Vacuum Plasma Method with Plasma Separation from Drop Fraction[1]

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Abstract – This paper reviews researches on deposition of TiSiB erosion resistance nanocoating with MAX-phase on the surface of Ti_6Al_4V alloy parts by vacuum plasma method with plasma separation from drop fraction, on physical and chemical state of surface layers, fatigue and erosion properties of samples and blades with these coatings.

1. Introduction

The Ti–Si, Ti–Si–B, Ti–Si–C, Ti–Si–B–N and other systems for more than 20 years attract researcher's attention as most advanced systems on which basis it is possible to synthesize unique on level of properties coating for increasing tool life [1, 2]. Among variety of works of this concept, first of all it is necessary to emphasize results of researches, carried out at Moscow Institute of steel and alloys by D.V. Shtansky, E.A. Levashov, A.N. Sheveyko and published abroad and in domestic periodicals [1, 2]. The authors first managed to obtain thin nanocrystalline film-coating of different contents of titanium-silicon-boron-nitrogen system by thickness of 3–4 μm layer and size of grain of only 2–5 nm. The last one provided very high values of hardness (more than 40 GPa) and record low values of dry friction coefficient. One more undoubted advantage of works [1, 2] is the authors' development of technological process of target production from exothermic blend of 55.2% Ti – 24.8% B – 20% Si (residual porosity was lesser than 5%) due to SHS-synthesis under external load.

The authors [1, 2] used for research of physical-chemical condition of nanocoatings besides atomic-force microscopy such fine methods of analysis as: electron Auger-spectroscopy, transmission and scanning electronic microscopy (TEM and SEM) and X-ray structural analysis (XSA) which confirms authenticity of provided results. This data provokes undoubted interest not only from the position of machine-instrumental industry task solving, but also from the possible usage of results in aviation engine-building. Therefore, by performing real works, the achieved results in some degree are based on experimental data published in [1, 2].

At the same time, unlike works [1, 2] the following requirements served as basic prerequisites by technical approach to research carrying out. It is necessary:

– to form coating on MAX-phase basis, which have high level of hardness, fatigue, erosion and corrosion properties by low and high temperatures (up to 1700 °C) as well;

– to increase thickness of modified surface layers up to 20–25 micron due to severe conditions of aviation equipment operation;

– to increase of productivity of coating process, which determined priority of chosen methods of surface treatment: vacuum-arch method with plasma separation from drop fraction and assisting of precipitation process by ion implantation.

2. Materials, equipment, and research methods

Samples and compressor blades from alloy VT6 (Ti6Al4V) were used in the present work as research objects. For realization of plating process of titanium-silicon-boron system it was necessary to fasten cathode material fragment produced in research Institution for Powder Metallurgy by SHS synthesis method at 1500 °C temperature from powder blend (Ti; Si; B) in argon with further hot pressing in special holder for usage in plating plant (Fig. 1).

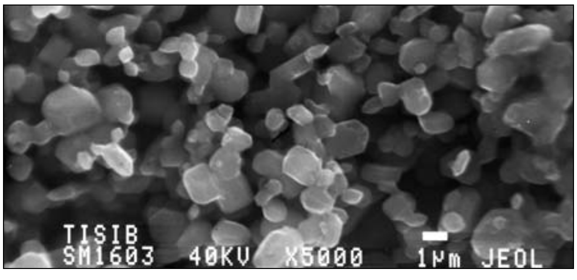

Fig. 1. Microstructure of cathode material, made by SHS method (TiB_2, Ti_5Si_3, Ti_3SiB_2)

Coating precipitation was performed with the help of experimental electro-arch evaporator with arch magnetic field and universal source of quick neutral molecules beam combined with metal vapor flow dispersed by ions of target argon. Firstly, the cleaning

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of surface by argon molecules beam was carried out, then impulse-arch ion implantation of cathode regular components at accelerating voltage of 25 kV, current density in a pulse from 0.1 to 1 c · mA/cm^2 and pulse repetition frequency of 30 Hz during 10 min and only after that the process of coating deposition. Stated operations were performed at permanent rotation of fatigue samples round their vertical axis. The blades were treated from one side without rotation. The thickness of coating varied from 1 to 6 micron.

Reference samples were cut from blades (dimensions 15×5 mm) on which the thickness of coating was determined by optical metallographic method and microhardness (on ПМТ-3 unit). The samples were being tested on fatigue resistance at 250 °C air temperature and at 2800–3000 Hz frequency of cycling and also on erosion resistance on Moscow Aviation Institute test bench. Physical and chemical state of material of samples and blades surface layer with coatings was determined by methods: electron Auger-spectroscopy (EAS), scanning electron microscopy (SEM), X-ray structure analysis (XSA) and optical metallography in polarized light.

3. Experimental data and its discussion

Figure 2 indicates research results of surface layer microstructure of HP Compressor blades from alloy VT6 with 2 micron coating of titanium-silicon-boron system, and Fig. 3 indicates diffraction pattern fragments, registered from blades surface.

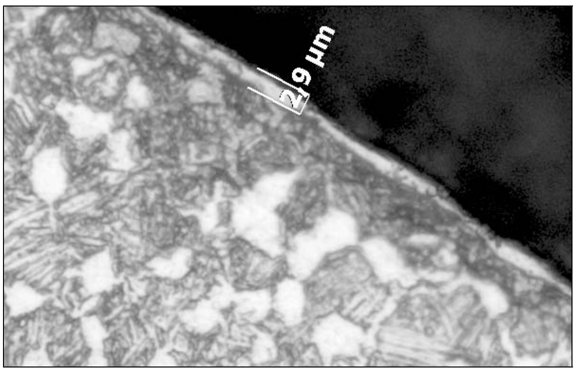

Fig. 2. Material microstructure in blade surface layer from alloy VT6 with Ti–Si–B coating

It was determined by visual inspection that formed vermiform coatings are characterized by full repetition of substrate surface relief: marks, scratches and other defects are clear observed. Modified surface layer is composed of 2 zones with total thickness of about 20 μm: zone 1 represents X-ray amorphous layer with thickness of 1–6 μm (two wide “halo” in interval of angles of incidence of 30–50 and 60–80°, corresponding to Ti_3SiB_2, Ti_5Si_3, and TiB_2 phases, are clearly observed) and zone 2 with thickness of 8–12 μm which forming can be connected with SHS-synthesis behavior directly on substrate by precipitation of coating with a large amount of heat release.

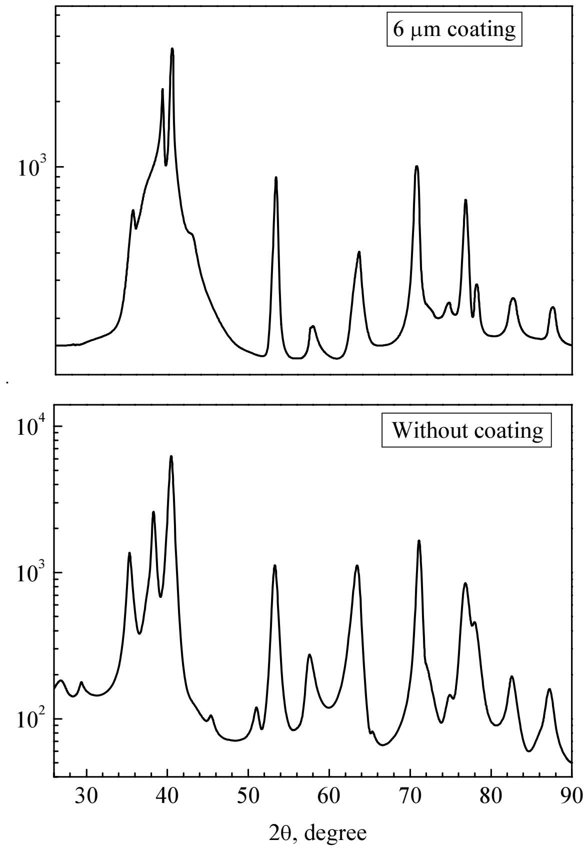

Fig. 3. Diffraction pattern fragments, registered from blade surface from alloy VT6 with Ti–Si–B coating, (data for blade without coating is introduced in lower part of the picture) – $Cu_{K\alpha}$ irradiation with monochromator

It results in high-speed heating in surface layer up to temperatures higher than temperature of α ↔ β conversion and after ending of layer precipitation stage a high-speed cooling is realized due to heat abstraction deep into target. The possibility of SHS-synthesis behavior by ion-beam treatment was indicated by B.I. Kuznetsov and A.E. Ligachev as early as in beginning of 80’s of last century. Namely, these researchers were the first to produce cathodes by SHS-synthesis method for multicomponent pulsed arc ion implantation realization.

The realization of SHS-synthesis process on target surface was not managed yet due to low current density which is usually typical for used in practice implanters (10–100 mA/cm^2).

Furthermore, a research of surface layers physic-chemical condition by EAS and X-ray methods was carried out (Fig. 4).

Only qualitative analysis from coating surface was realized. At the same time, the peak form was analyzed with determination of its location on energy axis.

It is observed that in surface layer of coating Ti_3SiB_2 MAX-phase is represented, which besides appears in relatively low values of coating microhardness, which values vary from 4.5 to 12 GPa.

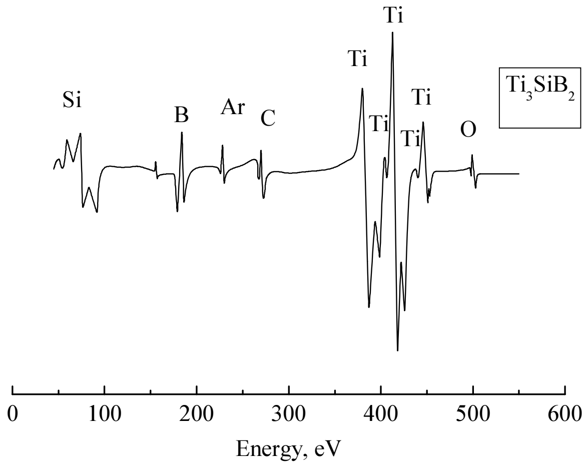

Fig. 4. Auger spectrum stated from samples surface with titanium-silicon-boron system coating

Results of erosion and fatigue tests of samples with coatings are represented in Fig. 5 and Table 1.

Table 1. Results of high-frequency fatigue tests at 25 °C in air (endurance limit of the samples without coating on basis of $2 \cdot 10^7$ cycles is equal to (250 ± 20) MPa) and of erosion tests (duration of exposition *T*, kind of particles – quartz sand of 80 micron in size, speed and angle of encounter are 200 m/s and 90 grades accordingly) of samples from BT6 alloy after coating of titanium-silicon-boron system

No.	Thick ness, μm	Material loss, μm	Cycle number	Load MPA
1	1	1.2	$1.9 \cdot 10^8$	350
2	1	1.0	$3 \cdot 10^5$	372
3	4	0.8	$3.8 \cdot 10^7$	367
4	4	0.9	$1.2 \cdot 10^7$	382
5	5	1.0	$9.3 \cdot 10^8$	371
6	5	0.8	$3.6 \cdot 10^7$	390
7	6	1.1	$2 \cdot 10^9$	387
8	6	1.0	$1.1 \cdot 10^9$	390

The results of fatigue tests produce maximum interest, which evidence that the formed coating prevents fatigue cracks outcome, originated in undersurface layer directly on the surface.

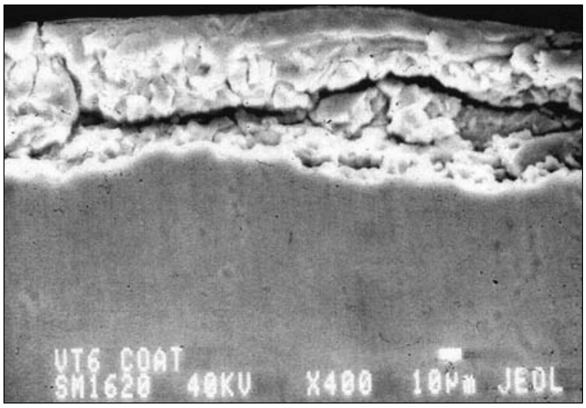

Fig. 5. SEM image of surface layer of sample with 6 μm coating after accomplishment of fatigue tests

It is especially astonishing because thickness of coatings is not too large. The latter can be explained by presence of MAX-phase in coating and low dispersion of material.

It is observed that fatigue crack repeatedly stopped and changed direction of its propagation, as it was marked by M. Barsoum by studying of fatigue behavior of laminated MAX-material [3].

4. Conclusion

It is revealed that erosion-resistant Ti–Si–B nanocoating forming (containing MAX-phase) on parts surface from alloy Ti_6Al_4V by vacuum plasma method with plasma separation from drop fraction enables to principally increase their fatigue resistance and erosion resistance.

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