SURFACE MODIFICATION OF TITANIUM ALLOYS BY INTENSE PULSED ELECTRON BEAMS

N.A.Nochovnaya
*All-Russian Institute of Aviation Materials, Radio Street 17, Moscow 107005, Russia,
Tel.: (7-095) 2638833, Fax: (7-095) 2678609, E-mail: roman@ fipc. ru*

The influence of intense pulsed electron beam (IPEB) treatment on the chemical composition and structure of titanium alloys surface layers is reviewed. The fatigue and oxidation behaviour of irradiated titanium alloys is analyzed. It is shown that IPEB processing allows one to improve service properties of titanium alloys dramatically. The recycling of some aircraft components after their "long life" operation have to be realized using IPEB treatment at high values of the energy density in a pulse is also described. The application of IPEB processing is illustrated for compressor blades of aircraft engines.

I. Introduction

Intense pulsed electron beam (IPEB) treatment is one of the most advanced methods for surface processing of metals and alloys [1-3]. It is conditioned by the possibility of carrying out high-speed melting, evaporation and solidification of surface layer materials. Furthermore, this method allows a record level of the operating characteristics to be achieved of some parts from steels, superalloys, ceramics etc. The present paper reviews the latest experimental data on IPEB treatment of the $\alpha+\beta$ (VT8M and VT9) and pseudo-α (VT18U, VT25U) titanium alloys and exhibits behaviour of irradiated samples and aircraft engine components (compressor blades) manufactured from these alloys.

II. Equipment

There are tow types of IPEB accelerators for surface modification in Russia: (ICE) low-energetic pulsed electron beam accelerator and (GESA) electron beam facility [4,5]. The ICE installation permits to form and transport low-energetic IPEBs having the following parameters:

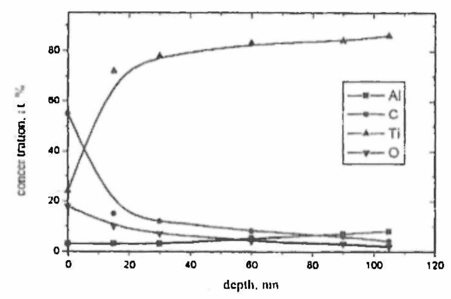
- maximum energy of electrons in a pulse 12-20 keV;
- average energy of electrons per a pulse 6-20 keV;
- frequency of pulse running f=0.1-0.2 Hz;
- pulse duration τ=0.15-5 μs;
- beam cross-section area S~5-50 cm^2;
- inhomogeneity of energy density distribution across beam cross-section 5-15 %;
- efficiency of accumulated energy transfer into beam energy 30 %.

This accelerator was formed in Tomsk (1992) [4]. Three years ago the electron beam facility (GESA) for investigation of material surface modification was developed in St. Petersburg and Karlsruhe [5]. The main parts of this accelerator are the following: electron injector; high voltage generator (HVG) with a pulse duration control unit; focusing magnetic coils; drift channel; chamber for sample treatment; radiation protection; controlling unit. The electron injector consists of a high voltage insulator, a multipoint explosive emission cathode, a controlling grid, and an anode, forming a triode arrangement. The controlling grid is connected with the grounded anode through the special resistor. The latter allows the current magnitude of the electron beam to be controlled in a certain range without of the injector and to be created a sufficiently high electric field strength near the cathode surface at the beginning of the pulse, necessary for homogeneity of electron emission. As a source of electrons a multipoint explosive emission cathode with stabilized cathode plasma [5] is used in GESA. The area of the cathode emissive surface is 700 cm^2. The HVG corresponds to the Marx scheme. It consists of four stages, which are artificial pulse forming lines, containing 8 cells with correcting networks. The duration of the flat part of the pulse is around 40 μs, the amplitude on a matched lead reaches 150 keV. The duration of the high voltage pulse τ, can be controlled by the pulse duration control unit with time increments of 1 μs. At the beginning of the pulse, the total voltage produced by HGV is applied to the cathode-grip gap, because the grid is grounded through the resistor. The latter ensures homogeneous excitation of the electron emission. The magnetic focusing system consisting of six coils provides formation, transport, and variation of the beam diameter in the range of 6-10 cm. Presently the electron beam of GESA has the following parameters: E=50-150 keV; w<50 J·cm^{-2} , power density on the sample - up to 2 MW·cm^{-2}. The pulse duration is controllable in the range of 5-40 τs in stops of 1 μs. Just that time in Russia there were undertaken the experiments on investigation of IPEB irradiation effect on physical and chemical state of surface layers and properties of titanium alloy parts; therefore, to the present moment a very limited for short of complete quantity of information, especially from the practical point of view, has been obtained.

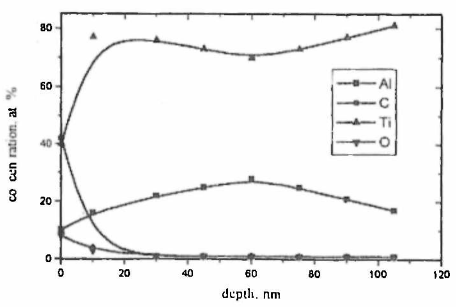
III. The effect of IPEB irradiation on the physical and chemical state of titanium alloy surface layer

In [1-5] the results of complex investigation were presented concerning the chemical composition and the structure of near surface areas of titanium alloy parts and samples after IPEB treatment (gas turbine engine compressor blades from VT6. VT9, VT8M, and VT25U titanium alloys). The irradiation of the targets was carried out using the ICE accelerator under the following conditions: E=20-30 keV; τ=0.7-2.5 μs; w=1-5 J·cm^{-2}). According to calculated data [6] at such irradiation regime an uniform surface melting must occur. Pulse numbers ranged from 5 to 100. Metallographic analysis results performed by authors [3, 6, 7] testify that during rapid quenching a badly amenable to an etching layer with thickness of 5-10 μm is formed. This layer has microstructure which can be changed from globular to columnar one as a function of irradiating conditions. The thickness of a molten layer is slightly increased with a rise of the pulse number. As a result of surface material melting, its roughness was decreased from 0.23-0.28 μm to 0.05-0.10 μm. In [3, 6, 7] the experimental data of irradiated surfaces investigation show that as a result of rapid solidification from melt it takes place the following:

- considerable modification of the chemical composition of surface layers with thickness of h>200 nm (one can see in Fig. 1 that surface purification from carbon and oxygen impurities occurs; with an increase of the pulse number an uniformity improvement of Al, Mo, and Zr distributions across surface layer thickness is observed; in this case the Al concentration in near surface zone increases up to 15-20 at.% that is considerably higher in comparison with an primarily state);
- modification of the phase composition in the surface with thickness of ~10 μm (it is practically observed a total decomposition of β-phase and formation of a large amount of α-phase and α"-martensite phase);
- formation of residual tensile stresses in the same layer that results in shifting X-ray lines to the side of smaller diffraction angles and in increasing microhardness values, especially visible at small loads.



a



b

Figure 1. Element distributions on a depth of VT8M alloy samples treated by IPEB (b: E=20-30 keV; w=2.5 J·cm^{-2}; τ=0.7 μs; n=20; a: initial state).

The formation of a great amount of microdefects having a shape of craters with the average diameter of 5-50 μm and the depth of 0.5-2 μm has been noted on the surface of targets at low values of the pulse number [6,7]. With a growth of the pulse number the amount of craters decrease and at n>40 their presence is not practically indicated. Irradiation-enhanced diffusion, sub-surface layer annealing, alloyed components mixing during frequent melting provide the formation of near surface area with the width of approximately 10 μm, having a high uniformity of the surface condition; therefore, subsequent IPEB irradiation doesn't already result in crater formation.

In the main, these conclusions are correct for the titanium alloy samples irradiated by IPEBs in the GESA accelerator [5]. The difference was observed only in the depth of remelting layer. It is showed that the thickness of modified layers reaches more than 20 μm if the irradiation is carried out using the GESA accelerator.

The comparison of these results published data, concerning the interaction between high-power pulsed ion beams nanosecond duration and solids [8,9] allows to conclude, that microsecond concentration fluxes of energy are more promising from the stand point such as craters. Moreover, the IPIB usage for the surface modification of titanium alloys (in contrast to high-power pulsed ion beams) permits to produce thicker remelting surface layers, that should provide in practice the achievement of a record level of service properties. At the same time the columnar structure formation in near surface area of irradiating parts is considered undesirable. As the columnar structure is formed at high values of the energy density and at a great number of pulses (w>5 J·cm^{-2}, n> 40 pulses, ICE accelerator; w>15 J·cm^{-2}, n> 3 pulses, GESA accelerator), than it can be recommended to use more "soft" irradiation conditions (w=2-3 J·cm^{-2}, ICE accelerator; w=10-12 J·cm^{-2}, GESA accelerator) for the surface modification of titanium alloy targets under retaining great number of pulses (for reducing the probability of crater formation if the irradiation is carried out in the ICE accelerator).

Besides, in [8,9] the necessity for conducting final heat treatment after IPEB irradiation at operating temperature of the parts is validated. It should be done for a relief of residual tensile stresses and structural stabilization of the material in the surface layer.

IV. Operating behaviour of titanium alloys treated by IPEBs

As the investigations of IIPEB irradiation effect on the surface state of titanium alloys have been began only 5 years ago there is no almost results of these affords in literature. Only scrappy information on the fatigue strength, the oxidation resistance, and the erosion resistance of the titanium alloy samples (VT18U and VTVT8M) irradiated by IPEBs in the ICE accelerator is presented in [6,7]. It is showed that ICEBs allows to increase the fatigue "long life" of titanium alloys by an order as a minimum. This value in comparable with the values obtained for the samples and blades irradiated by pulsed ion beams [8,9]. The results of investigating the fracture surface show [6] that the gain in the number of cycles to fracture after IPEB treatment is conditioned by two reasons: by changing fatigue crack nucleation mechanisms (surface mechanism is characteristic of the initial state and subsurface one proceeds into the irradiated samples) and by sharp decreasing the spacing of fatigue furrows within a gain (2-3 times). At the same time catastrophic breakdown of the samples with craters took place and moreover the centres of breakdown, as a rule, were in the vicinity of the craters. So fractography data for samples with IPEB treatment practically coincide completely with the results of investigating fractures surface of the fatigue samples and blades subjected to ion beams with nanosecond duration. The difference consists only of the depth of occurring the centre of fatigue fracture. After ion beam treatment the nucleations of failure are concentrated at the depths of 3-5 μm and after IPEB irradiation - 6-10 μm . The results of tests for the resistance to sand particle erosion (V=200 m/s; quartz; d=80-120 μm) has shown [6] that after irradiation and annealing, the duration of the period to fracture increases more than twice. However, this effect shows up only at low sand loads (not over 20 mg/mm^2). In testing for the oxidation resistance, after keeping titanium alloys at operating temperatures for 100 and 200 hours, no difference in specific mass losses between irradiated and unirradiated samples was detected by the weighting method. And only after 500-hours thermal exposure it was observed the improvement of this property as a result of IPEB irradiation and final heat treatment (in 2 times).

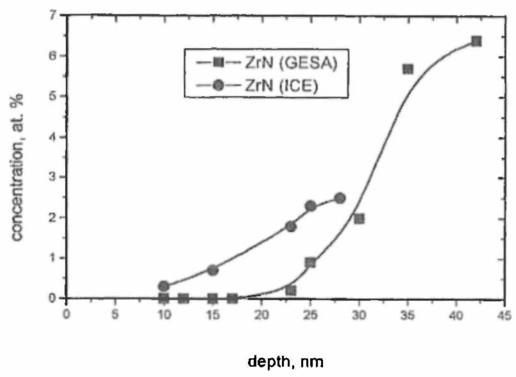


Figure 2. Effect of the energy density on the evaporation rate of ZrN coating from the surface of VT8M alloy compressor blade .

At high values of the energy density the process of intense ablation takes place during IPEB irradiation. The latter open wide prospects for the recycling of damaged parts (in particular, the blades a disks of gas turbine engines). It was shown [9] that the rate of ablation from a surface of VT8M titanium alloy compressor blades with ZRN coating (Fig.2) riches 2 μm during a pulse (ICE accelerator) and 6 μm during a pulse (GESA accelerator).

V. Conclusion

The major conclusions for this study can be formulated as follows:

1. IPEB allows one to ablate surface layers and resistant coatings damaged during operation of the compressor and turbine blades.
2. It is advisable to carried out IPEB irradiation at low values of the energy density for surface smoothing, modification of the surface layers and preparation of the surface for coating deposition.

References

1. *Ivanov Y.F., Itin V.I., Lykov S.V. etc.* // J. News of RAN. (in Runnian). - 1993. - v. 3. - p. 130.
2. *Ozur G.E., Proskurovski D.I.* // J. Technical Physics. - 1988. - v. 14. - N5. - p. 413.
3. *Shulov V.A., Nochovnaya N.A., Proskurovsky D.I., Rotshein V. P.* // Proceedings of Inter. Conf. "Beams-96"- Prague. - 1996. - v. 2. - p. 808.
4. *Nazarov D.S., Ozur G.E., Proskurovsky D.I.* // Proceedings of 25-th Inter. Conf. on Discharges and Elec. Insulation in Vacuum, Darmstadt. - 1992. - p. 716.
5. *Mueller G., Schumacher G., Strauss D. etc.* // Proceedings of Inter. Conf. "Beams-96"- Prague. - 1996. - v. 1. - p. 267.
6. *Nochovnaya N.A., Shulov V.A., Proskurovsky D.I. etc.* // Proceedings of 5-th Inter. Conf. on Electron Beam Technologies, Varna. - 1997. - p. 215.
7. *Nochovnaya N.A., Shulov V.A., Proskurovsky D.I. etc.* // J. Physics and Chemistry of Material Treatment. (in Russian) - 1998. - N1. - p. 21.
8. *Shulov V.A. and Nochovnaya N.A.* // J. Nuclear Instruments and Methods in Physics Research. - 1999. - v. B148. - p. 154.
9. *Shulov V.A. , Nochovnaya N.A. , Remnev G.E.* // J. Materials Science and Engineering. - 1998. - v. A243. - p. 290.
10. *Shulov V.A., Nochovnaya N.A., Engelko V.I. etc.* // Proceedings of 4-th Inter. Conf. on The Recycling of Metals, Vienna. - 1999. - p. 11.

SURFACE MODIFICATION OF TITANIUM ALLOYS BY INTENSE PULSED ELECTRON BEAMS

N.A.Nochovnaya
All-Russian Institute of Aviation Materials, Radio Street 17, Moscow 107005, Russia,
Tel.: (7-095) 2638833, Fax: (7-095) 2678609

The influence of intense pulsed electron beam (IPEB) treatment on the chemical composition and structure of titanium alloys surface layers is reviewed. The fatigue and oxidation behaviour of irradiated titanium alloys is analyzed. It is shown that IPEB processing allows one to improve service properties of titanium alloys dramatically. The recycling of some aircraft components after their "long life" operation have to be realized using IPEB treatment at high values of the energy density in a pulse is also described. The electron beam technologies allow the improvement of the following properties of refractory titanium alloys: the fatigue strength (by 40-50 %); the oxidation resistance (in 2 times); the sand particle resistance (in 2 times).