Structural Changes in Surface Layers of Parts from Titanium Alloys Irradiated with Pulsed Electron Beams[1]

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Abstract – The paper presents experimental results concerning the effect of conditions of irradiation with intense pulsed electron beams on physical and chemical state of the surface layer of gas turbine engine blades made from VT6 and VT9 refractory α + β-titanium alloys. The major attention was paid to the results of structural investigations carried out with a transmission electron microscopy. High β-phase conglomerate dispersivity obtained in experiments is explained by a short time of existence of a structure in β-area that was concluded based on simulation of temperature fields during electron beam irradiation.

1. Introduction

It has been experimentally shown [1, 2] that irradiation with intense microsecond pulsed electron beams modifies of ~ 20-μm surface layer of blades made from refractory α + β-titanium alloys. It was established also that irradiation of the blade surface layers made from α + β-titanium alloys, depending on energy density of a pulse induces the large variety of the processes including melting, elements redistribution, cratering, change of phase composition and dislocation structure, ablation, high-rate solidification, change of microstructure (from needle to globular), formation of residual tensile and compressive stress.

Besides, the effect of conditions of electron-beam irradiation and finishing thermal or thermo-mechanical treatment on the blades service performances made from α + β-titanium VT6 and VT9 alloys was studied in works [1, 2]. As a result it was determined that irradiation with intense pulsed electron beams at accelerator "Gesa-1" with electron energy of 115–120 keV; energy density of 18–20 J/cm^2 and pulse number of more than 2 enhances the following blade performances: fatigue limit – from 10 to 40%; erosion resistance – more than twofold; oxidation resistance – more than threefold; heat salt corrosion resistance – more than fourfold. Nevertheless investigation of the substructure being formed in the surface layers on the irradiation stage was not carried out. Consequently, so far we have no a clear understanding the reasons of different behaviour of fatigue of blades made from VT6 and VT9 alloys subjected to irradiation by intense pulsed electron beams. Indeed, irradiation under the same conditions of blades made from VT6 alloy leads to 20% rise in fatigue limit σ_{-1} when carried out after irradiation with intense pulsed electron beams, and 40% rise when carried out after the following finishing thermal treatment at 520–560 °C in 10^{-6} mm Hg vacuum during 2 h. Whereas the blades made from VT9 suffer a sharp 80% decrease in the fatigue σ_{-1} after the irradiation and only the following finishing thermal treatment at 520–560 °C leads to the 20% rise in the fatigue limit.

So, the object of this work is the study of chemical composition and microstructure in the surface layer of blades made from VT6 and VT9 alloys, irradiated with intense pulsed electron beams. The study has been performed by transmission electron microscopy and X-ray microanalysis.

2. Materials, equipment and research technique

As the object for investigation in the work the gas turbine engine fan and compressor blades RD33 made from VT6 and VT9 by Chernyshev Machine Building Enterprise have been used. The material physical and chemical state in the blade surface layer was determined by the following methods: X-ray microanalysis, transmission electron microscopy and optical metallography. The irradiation of targets with intense pulsed electron beams [1, 2] was realized with "Gesa-1" accelerator under the following conditions: electron energy – 120 keV; pulse duration – 30 μs; energy density in a pulse – 18–20 J/cm^2; beam cross-section area – 80 cm^2; energy density inhomogeneity in beam cross-section was less than 10%. After irradiation the test-samples of 15×10 mm in size were cut off from the irradiated blades. From the test samples the thin foils were produced by machining, electrochemical and chemical methods for determination of microstructure in volume of recrystallizing layer at a depth of 10–15 μm by transmission electron microscopy.

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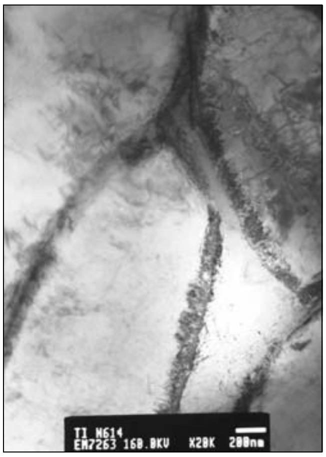
3. Results and discussion

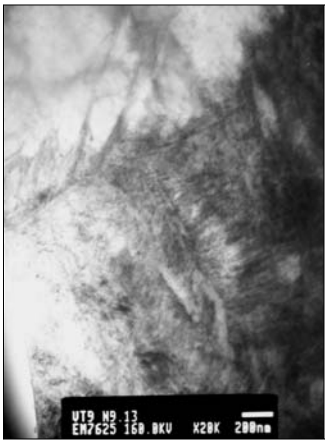
Some of the results obtained are presented in Figs. 1–3 and Table 1.

Table 1. Element composition of the blade material at a depth of 10–15 μm after the irradiation with intense pulsed electron beams obtained by X-ray microanalysis (mass %) at different characteristic macroregions

Alloy	Region analysed	Al	Mo	V
VT6	α′- and α-plates	6.1	–	2.7
	edge α′- or α-plates	6.1	–	3.9
VT9	α′- or α-plates	7.5	4.0	–
	edge α′- or α-plates	6.8	9.5	–
	globular formation	10.4	1.1	–



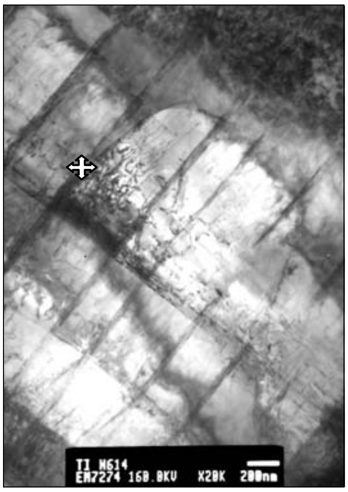
a



b

Fig. 1. TEM image of microstructure of the blades made from VT6 (*a*) and VT9 (*b*) alloys

Data of transmission electron microscopy revealed that microstructure of VT6 and VT9 alloys is globular-lamellar, two-phases, with a long α-phase 1–5 μm subgrains (light areas). At the sub-grains boundaries there are dark β-phase interlayers (edge) or transited β-phase (dark striped areas), which is, in reality, oversaturative martensite α′-phase. After the irradiation of the blades made from VT9 alloy, the surface layer microstructure looks like completely martensite with α′- and α′′-plates with different orientation.



a

b

Fig. 2. TEM image of microstructure of irradiated blades made from VT6 alloy at a depth of 10–15 μm; *a* – α′- or α-plates in α-colony limit; *b* – structural elements with developed dislocation structure

After irradiation the blades made from VT9 alloy with intense pulsed electron beams the microstructure in the surface layer looks like completely martensitive with α′- and α′′-plates with different crystallography orientation. These plates of 200 μm thickness, having needle form, could be observed both in the longitudinal section and in the cross-section of the blades. In comparison with α-plates, which present in the surface layers of the blades made from VT9 the martensitive plates have a needle shape and are characterized by substantially less dimensions, the primary and the secondary doubles and increased dislocation density. Besides, there are the fine dispersional fragments enriched with Al and Mo formed by a high-rate recrystallization of α′- and α′′-plates (Table 1). Such conglomerates formation is not observed in the blades made from VT6 alloy.

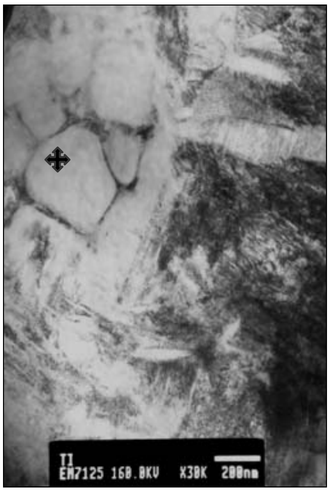


Fig. 3. TEM image of microstructure at a depth of 10–15 μm in irradiated blades made from VT9 alloy (pointer indicates the place of X-ray microanalysis)

The process of high-rate oriented crystallization takes place in the surface layer of the blades immediately after the pulsed action end of irradiating in “melting” mode [1, 2]. Similar to that case the edges of structural elements of alloy (plates or globules) are the nucleating centers, the direction of their growth will be determined by their orientation and the heat front direction. So when dendrite of the crystallites grown they interact each other, their growth directions intersect and formed α-plates orientation couldn’t be coincident with normal to the surface, what was shown in [1, 2]. Under conditions of high-rate and high-temperature gradient crystallization of titanium alloys there are conditions for segregation in the surface layer. There are the most favorable conditions for segregation in the surface layer of the blades made from VT9 alloy, that depend on high value of β-phase stabilization factor for VT9 alloy $K_\beta = 0.45$ (for VT6 alloy $K_\beta = 0.3$) and molybdenum propagation factor ($K_0 = 1.83$ – Mo, $K_0 = 0.80$ – V). Besides, vanadium has higher diffusion factor in titanium and solubility in α-phase (up to 3.5 mass %) than that of molybdenum (up to 2 mass %).

High β-phase conglomerate dispersivity is connected with the fact that treatment time of the surface layer material in β and α + β areas is less than some hundreds microseconds ($10^{-6} - 10^{-4}$ s, Fig. 4). During this time the growth of formed β-phase nucleuses under the high-temperature gradient condition set in forming finely dispersed plates (needle type of microstructure).

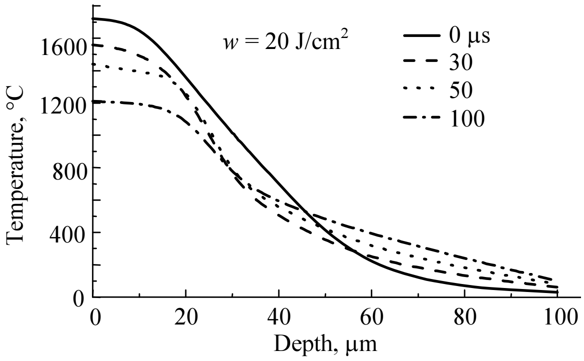


Fig. 4. Temperature profiles in the surface layer of titanium alloys at various points of time after end of pulse of electron beam

So that after crystallizing of the surface layers of parts from VT6, unlike targets from VT9 alloy, structural heterogeneities could be remove with finishing heat treatment in vacuum. It must be carried out the heat machining treatment for parts from VT9 alloy.

4. Conclusion

It was shown by TEM, that irradiation with intense pulsed electron beams in melting mode led to occurring of a fine dispersed plate (needle) microstructure in the surface layer of thickness of 20–25 μm. But, unlike the VT6 alloy blades, in the modified surface layer of the VT9 alloy blades the 10–100 nm globular formations with increased Al and Mo concentrations were noted.

References

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[2] A.G. Paikin, A.B. Belov, and V.I. Engelko et al., Strengthening Technologies and Coatings **11**, 9 (2005).