The Effect of Surface Treatment with Intense Pulsed Electron Beams on the Oxidation Resistance of Ni-Base Superalloy Turbine Blades with NiCrAlY coating

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Abstract – The present paper reviews the results of investigations dedicated by the application of intense pulsed electron beams (IPEB) for surface processing of aircraft engine turbine blades produced of GhS26NK superalloy with the use of the serial technology. The irradiation of these components was carried out in the GESA-1 and GESA-2 accelerators. It is shown that IPEB treatment at low values of the energy density induces rapid melting, ablation and solidification leading to the formation of non-equilibrium microstructures. In this case the irradiation (w = 40–42 J/cm^2) leads to surface smoothing, rapid solidification of the material in the surface layer with thickness near 20–25 μm. As a result, surface roughness of the blades with NiCrAlY vacuum-plasma coatings can be decreased from R_a = 2.5–2.75 μm up to R_a = 1.1–1.3 μm. These regimes of irradiation were used for the increase of oxidation resistance and fatigue strength of turbine blades with NiCrAlY coatings. This increase is connected with improvement of adhesion, formation of pore-free coatings and creation of NiAl electron phase in the surface layer with thickness of 20–25 μm. At high values of the energy density (w = 60–80 J/cm^2) intense ablation takes place during a pulse. These regimes of irradiation were used for the repair of the turbine blades with NiCrAlY coatings.

1. Introduction

The development and introduction of new techniques for increasing reliability and life of GTE superalloy parts is one of most important problems of aviation engine construction science. This is stipulated that just the superalloy parts, being the most expensive components, determine life of the product and its reliability during operation. Ion beam treatment can be referred to the most advanced methods of various parts surface treatment, namely: continuous ion beams doping, pulse-arc implantation, ion and electron beam mixing, high-power ion beam and intensive-current electron beam of nanosecond and microsecond duration treatment etc. Some of these techniques have already found practical application, in particular in semiconductor and tool industry, in space technology. The usage of large-aperture ion and electron beam treatment gives the opportunity to carry out: thin surface layers doping, making them amorphous; phase composition and structure modification of near surface areas; change of surface roughness; melting of surface layer material and its removal by evaporation, sublimation and plasma formation processes etc.

The objective of this paper is the review of data, being issued in periodic publications, which concern the problems of properties modification of superalloy products with the use of electron beam treatment as well as manufacturing method development of surface treatment of gas turbine engine parts on the base of conducted investigations and the equipment creation for realising these methods in production quantities.

The present paper analyses only one type of beam treatment effect on the superalloy properties: intensive-current electron beam treatment of microsecond duration.

2. Experimental

The patterns and gas turbine engine (GTE) blades from GhS6U and GhS26NK nickel based alloys with 50 μm NiCrAlY coatings, the composition of which are given in [1], were used as the study and test objects. The determination of the surface layer physical and chemical state of these objects was carried out by electron Auger spectroscopy (chemical composition), X-ray analysis (phase composition and residual stresses), scanning electron microscopy (surface topography) and optical metallography. Besides, such characteristics as the surface roughness (R_a) and microhardness (H_μ) were also determined.

The electron beam treatment was performed with the use of "GESA-1" accelerator [2] at the rotation of targets under the beam. The irradiation compositions were as follows: accelerating voltage of 115–120 kV, pulse duration of 15–20 μs, energy density of 15–55 J/cm^2, beam cross-section area of 40–55 cm^2 and pulse number of 1–5. After irradiation the part of targets was annealed under vacuum (10^{-3} Pa) for 2 hours at 980–1100 °C. Initial, irradiated and

980–1100 °C. Initial, irradiated and annealed samples and blades were tested for fatigue at the operating temperatures in air with high (3000 Hz) loading frequency. High-frequency tests were realized on the magneto-strictional vibrobench with the use of directly the blades and plane wedge-shaped specimens. Furthermore, after the irradiation and vacuum annealing, the blades were subjected to tests for the oxidation resistance in air at 900 °C for 100–500 hours. Specimens and blades fractured or damaged during the tests were studied by the optical and electron fractographic methods.

3. Results and Discussion

It is well known [2–4], that the main technological parameter of the IPEB irradiation process is energy density (w) in a pulse, other parameters (energy of electrons and pulse duration) are not varied in the experiments. With a rise of the energy density the following phenomena proceed in a near-surface layer of refractory alloy targets during irradiation: evaporation of organic impurities, heating and melting of a surface material, crater and crack creation, evaporation and sublimation, plasma formation and ablation. These phenomena determine physical and chemical state of material in the surface layer of irradiating targets and result in modification of their properties. Thus, the optimal level of operating properties of components modified with ICEBs can be achieved only by variation of energy density values and following investigation of the surface state.

The effect of irradiating conditions on chemical and phase compositions and structure of nickel superalloy blade surface layers is illustrated in [2–6], Fig. 1 and Table 1.

Table 1. The effect of energy density in a pulse on the surface roughness of NiCrAlY vacuum-plasma coating deposited on the surface of GhS26NK alloy turbine blades

N	Irradiating regimes		Roughness, μm, ±0.05
	w, J·cm^{-2}	n, pulses	
1	–	–	2.12
2	26	5	1.14
3	26	10	1.03
4	42	5	0.36
5	42	10	0.32
6	55	5	0.99
7	55	10	1.12

The results presented in [2–6] and here allow to conclude that the most perspective regimes of irradiating the nickel superalloy samples can be achieved at the following energy densities: $w = 40–42$ J·cm^{-2}, when the crater creation doesn't take place, strengthening γ′-phase is conserved and amount of electron β-phase on the base of NiA increases in the surface layer of coating. Under these regimes the surface roughness decreases from 2.01–2.12 up to 0.31–0.32 μm.

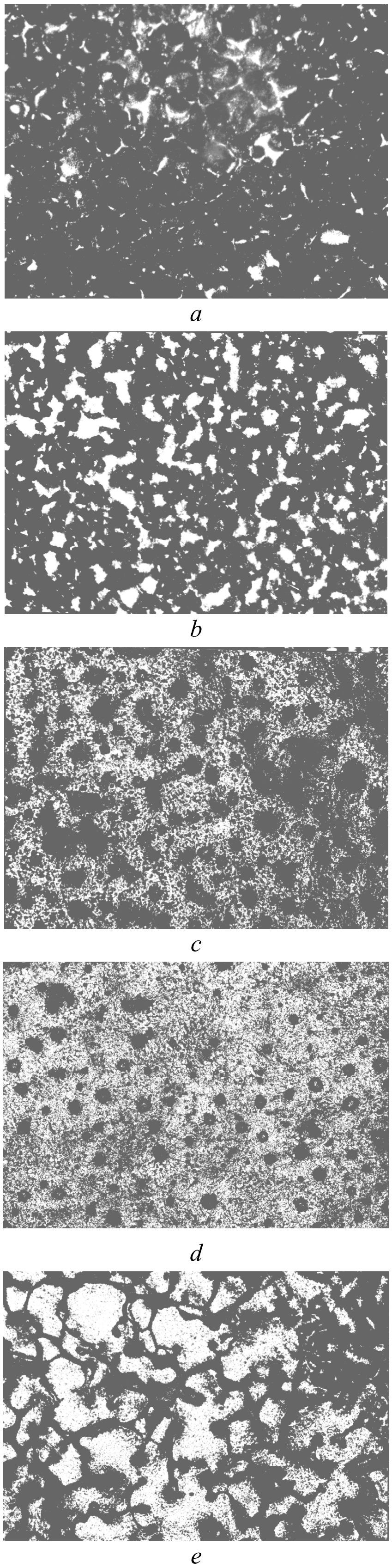


Fig. 1. The effect of energy density in a pulse on the surface topography of NiCrAlY vacuum-plasma coating deposited on the surface of GhS26NK alloy turbine blades: *a* – initial state; *b*, *c*, *d*, *e* – irradiation with w = 24, 36, 42, 55 J·cm^{-2}

The results of fatigue tests presented in Fig. 2 have shown that, in the optimal regimes of treatment, the endurance limit can be increased by 20%. Furthermore, these data from the viewpoint of the fatigue strength improvement point to the sufficiently highly effective electron-beam irradiation of turbine blades only after performing the post-irradiation annealing.

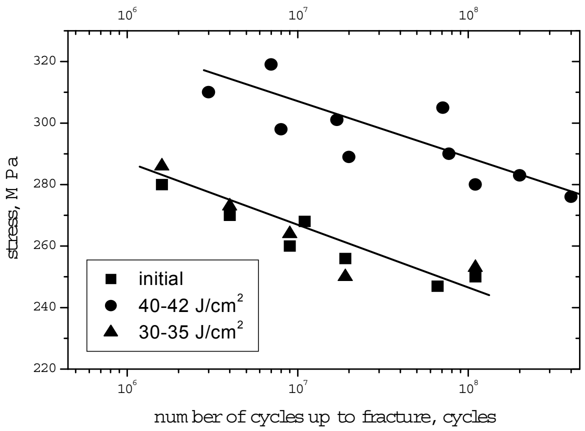


Fig. 2. Fatigue curves of GS6U nickel alloy samples before and after irradiation and annealing (T = 950 C, τ = 2 h)

Vacuum annealing of GhS6U alloy samples irradiated with intense pulsed electron beams leads to improvement of fatigue properties, if the duration of heat treatment is equal to 2 hours and the temperature of thermoexposure achieves operating one.

The results of the oxidation resistance tests are presented in Figs. 3 and 4. These tests were carried out for GS26NK alloy samples with 50-µm NiCrAlY coating at 900 °C during 500 hours.

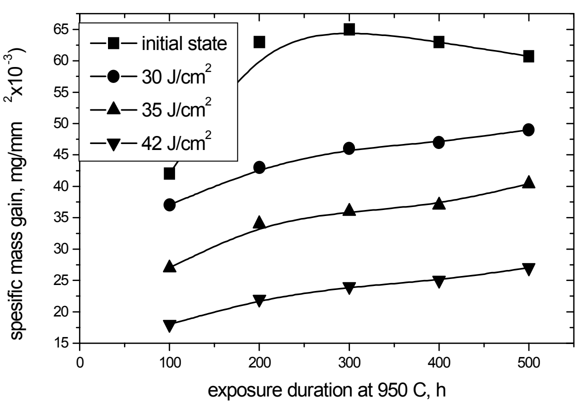
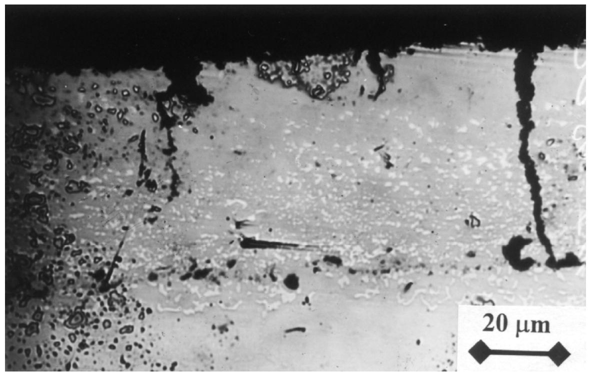
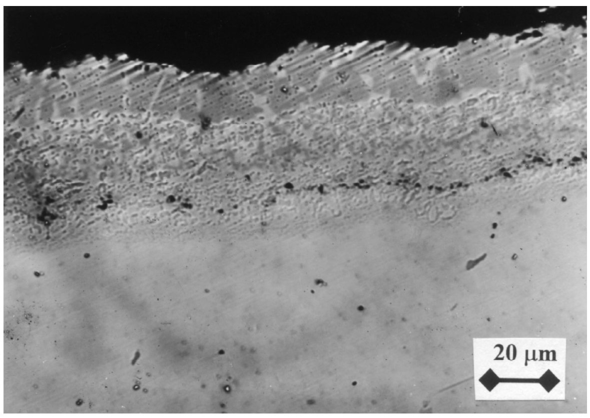


Fig. 3. Kinetic oxidation curves of GS26NK samples subjected to electron beam treatment and vacuum annealing at 950 °C during 2 hours

The obtained data allow to conclude that electron beam treatment with w = 40–42 J/cm^2 and final heat treatment ensure the increase of the oxidation resistance at 900 °C in 3 times. At the same time the irradiation with low values of the energy density and the absence of the post-process annealing can lead to even the oxidation resistance decrease. The latter is connected with the corrosion cracking taking place into the coating at high temperature. The irradiation with 40–42 J/cm^2 and the post-process annealing result in the formation of stable structure with optimal amount of β-NiAl-phase.The creation of β-NiAl phase) in the irradiated samples explains the oxidation resistance improvement and can lead to an increase of their oxidation resistance and fatigue strength.



a



b

Fig. 4. Microstructure of the surface layer of GhS26NK alloy samples with 50-µm NiCrAlY coating after 500 hours exposure at 900 °C in air: *a* – initial state; *b* – irradiation with w = 40–42 J/cm^2 and final heat treatment.

4. Conclusion

The experimental results exhibited in this research allow to conclude that IPEB treatment is the prospective method for surface processing of turbine blades fron Ni-superalloys with NiCrAlY coating. This method enables:

– to modify surface layers with thickness up to 20–30 µm;

– to smooth a surface of blades;

– to improve operating properties of turbine blades (the fatigue strength – up to 20%; the oxidation resistance – more than 3 times.

5. Acknowledgments

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