Mechanisms of Operating Property Alterations of EP866sh and EP718ID Steel Blades Modified by Intense Pulsed Electron Beams

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Abstract – The objective of the present research is the discussion of test results, dedicated to the effect of intense pulsed electron beam irradiation regimes upon the corrosion resistance of refractory EP866sh and EP718ID steels under the thermocycling conditions, the fatigue strength and the oxidation resistance. The electron beam treatment was realized by means of the GESA-1 accelerator under the following conditions: electron energy – E=115–120 keV; pulse duration – τ=10–40 μs; and the energy density in a pulse (w) as well as the number of pulses (n) were increased from w=20 J/cm^2, n=1 up to w=36 J/cm^2, n=4. Some targets after irradiation were subjected to vacuum annealing for 6 hours at their service temperatures. Corrosion tests of initial and irradiated samples were performed under the following conditions: heating up to the operating temperatures, cooling in the seawater down to the room temperature. The mechanisms of operating property alterations of EP866sh and EP718ID steel blades modified by intense pulsed electron beams are discussed.

1. Introduction

The salt corrosion resistance under the thermocycling conditions is one of the most important properties of compressor and turbine blades and disks of gas turbine engines. Namely this characteristic most commonly determines the operating life of a whole engine in naval aviation [1]. One of the main principles of developing the advanced technological processes, aired at the salt corrosion resistance improvement of any part is the surface modification, leading to the surface strengthening and alloying by corrosion resistant elements. As the electron-beam allows cardinally to change the material chemical and phase compositions as well as its structure in the surface layer with thickness of 20–30 μm, it's quite naturally to presuppose that this method is one of the most advanced methods for improvement of compressor steel blade service properties [2].

The objective of the present paper is development of advanced electron beam technology allowing to improve the operating properties of gas turbine engine blades produced of refractory steels and discussion of operating property alteration mechanisms of refractory steel compressor blades modified by intense pulsed electron beams.

2. Experimental

The patterns and gas turbine engine compressor blades from EP866sh and EP718ID steels 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), exo-electron emission (EEE) and optical metallography. Besides, such characteristics as the surface roughness (R_a) and microhardness (H) were also determined.

The electron beam treatment was performed with the use of "GESA-1" accelerator [3] at the rotation of targets under the beam. The irradiation compositions were as follows [3]: accelerating voltage (E) of 100–120 kV, pulse duration (τ) of 15–20 μs, electron beam energy density (w) of 20–24 J/cm^2, beam cross-section area (S) of 40–55 cm^2 and pulse number (n) of 5. After irradiation the part of targets was annealed under vacuum ($1.33 \cdot 10^{-3}$ Pa) for 6 hours at the following temperatures: EP866sh – 670 °C and EP718ID – 690 °C (optimal regimes of irradiation and annealing). Initial, irradiated and annealed samples and blades were tested for the salt corrosion resistance at the presence of Cl^- ions under the thermal cycling condition from the operating temperature to the room temperature (cooling in sea water).

High-frequency tests were realized on the magneto-strictional vibrobench with the use of directly compressor blades and plane wedge-shaped specimens with double one- and two-side radius transition from the texture zone to the loading zone. Such specimens are varied in the second bending shape and the stress value σ in the fracture zone cross-section is determined of $\sigma=kA$ linear dependence, where A is the amplitude of oscillations, k is the coefficient, given by a material strength properties, specimen shapes, temperature and oscillation frequency.

After the irradiation and vacuum annealing, the specimens and parts were subjected to the oxidation resistance tests in air at 600 °C for 100–500 hours.

Specimens and blades fractured or damaged during the tests were studied by electron Auger spectroscopy, X-ray analysis, optical and electron fractographic methods

3. Results and discussion

Some salt corrosion test results of patterns and compressor blades are given in Table 1 and Fig. 1.

Table 1. Corrosion test results of EP866sh and EP718ID steel specimens: number of cycles – 150; heating up to 600 °C (650 °C); cooling in seawater - 25 °C

Steel	Irradiating regime		Annealing		$\Delta m/S$
	w, J/cm^2	n, pulse	T, °C	τ, h	±0,03 mg/mm^2
EP866	–	–	–	–	1,98
EP866	20-22	5	670	6	0,33
EP866	20-22	5	–	–	2,11
EP866	26-28	5	670	6	1,39
EP718	–	–	–	–	1,89
EP718	22-24	5	–	–	2,06
EP718	22-24	5	690	6	0,41
EP718	34-36	5	690	6	1,56

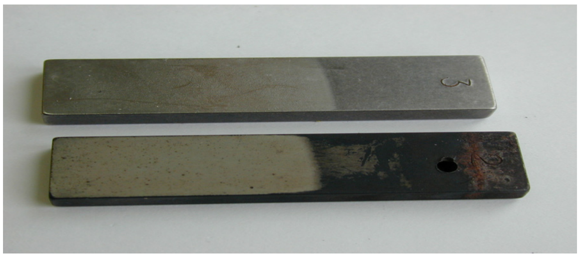
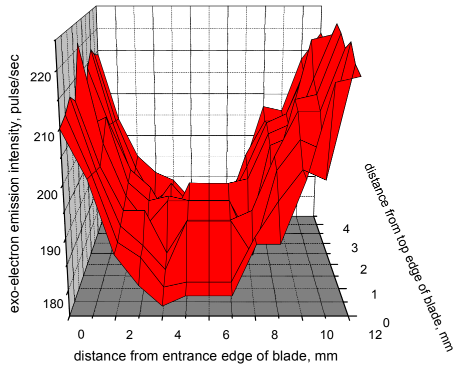


Fig. 1. Photograph of EP866sh steel spacimens before and after corrosion tests under the thermocycling conditions (T=600 °C, seawater at 20 °C, 20 cycles, irradiation with mask w=20–22 J/cm^2, n=5 pulses

The test results show that the corrosion resistance of samples, subjected to electron beam irradiation with the post-process vacuum annealing at the operating temperature, could be increased by 500 %. The study results of samples and blades after irradiation and heat treatment (Table 2, 3 and Fig. 2, 3) can be summarized as follows:

1. the decrease of surface roughness from 0.20–0.22 μm up to 0.06–0.10 μm as a result of electron beam treatment of EP866sh and EP718ID steels leads to a decrease of effective area of interaction between aggressive elements of sea water and components of the surface layer;
2. formation of low residual compressive stresses distributed uniformity after heat treatment of irradiated samples and blades ensures improvement of the plasticity characteristics and the crack creation resistance under the thermocycling conditions;
3. the increase of chromium concentration in the surface layer of blades due to redistribution of elements on the stage of solidification from liquid phase leads to a decrease of the oxidation rate as a result of resistant film creation on the base of Cr_2O_3.



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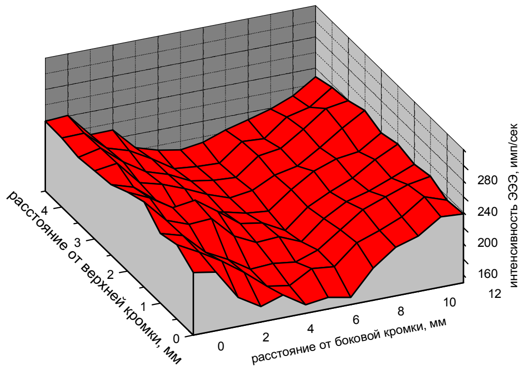

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Fig. 2. EEE scannograms of steel blades irradiated with electron beam: (a) – initial state; (b) – after IPEB processing with w=20–22 J/cm^2; n=1 pulse

The results of the fatigue and oxidation tests are presented in Tables 4, 5 and in [2]. These results have shown that, in the optimal regimes of treatment, the endurance limit can be increased by 20–40 %. Furthermore, these data from the viewpoint of the fatigue strength improvement point to the sufficiently highly effective electron-beam irradiation of metallic products only after performing the post-irradiation annealing.

Table 2. The effect of irradiarion on phase composition, residual stresses, texture, and lattice parameter of the surface layer material of EP866sh steel blades and spacimens ($Cu_{k\alpha}$-radiation)

Irradiating regime		Phase composion	Residual stresses	Lattice parameter, a, nm
w, J/cm^2	n, pulse	texture	σ, MPa	0,0003
–	–	α+$Cr_{23}C_6$, no	–520±45	0,2911
20–22	1	α+$Cr_{23}C_6$, no	+270±90	0,2925
34–36	5	α+γ $Cr_{23}C_6$, (200)	+1080±140	0,2933
18–20	3	α+$Cr_{23}C_6$, (310)	+310±90	0,2927

Table 3. The effect of irradiarion and heat treatment (670 ˚C, 6 hours, vacuum) on phase composition, residual stresses, texture, and lattice parameter of the surface layer material of EP866sh steel blades and spacimens ($Cu_{k\alpha}$-radiation)

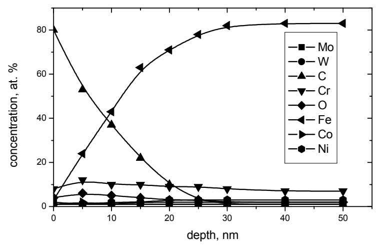
Irradiating regime		Phase composion	Residual stresses	Lattice parameter, *a*, nm
w, J/cm²	*n*, pulses	texture	σ, MPa	0,0003
–	–	$\alpha+Cr_{23}C_6$, no	–220±15	0,2911
20–22	1	$\alpha+Cr_{23}C_6$, no	–70±10	0,2901
34–36	5	$\alpha+Cr_{23}C_6$, no	+570±110	0,2929

Table 4. The results of fatigue tests after irradiation and annealing (*s* – samples; *b* – blades): *T*=600 ˚C; *f*=3000 Hz; τ=670 ˚C

w, J/cm²	*n*, pulse	Target	Annealing, *h*	σ_{-1} , MPa
–	–			328±12
20–22	5	s	–	310±10
20–22	5	s	6	350±10
26–28	5	s	–	295±15
26–28	5	s	6	325±10
32–36	5	s	–	280±10
32–36	5	s	6	305±15
–	–	b	–	380±10
20–22	4	b	2	390±20
20–22	4	b	4	405±10
20–22	4	b	8	420±10
20–22	1	b	6	290±30
20–22	2	b	6	250±30
20–22	3	b	6	230±40

Table 5. Oxidation test results of EP866sh steel specimens: duration – 500 hours; temperature – 600 ˚C; annealing – 670 ˚C for 6 hours.

w, J/cm²	*n*, pulses	H, μm
–	–	45 5
20–22	5	15 4
26–28	5	50 5
32–36	5	55 5
50–52	5	50 5
20–22	1	18 4



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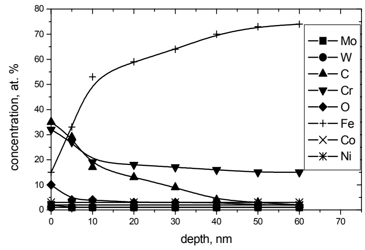

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Fig. 3. Element distributions on a depth of EP866sh steel initial blades (a) and the blades treated by IPEB: *E*=–115–120 keV; *n*=5 pulses; *w*=20–22 J/cm²

4. Conclusion

The experimental results presented in this paper allow to make conclusion on a high effectivness of electron beam treatment application for surface modification of the compressor blades from refractory steels.

Acknowledgments

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