SURFACE MODIFICATION OF REFRACTORY ALLOYS WITH HIGH-POWER PULSED ION-BEAM TREATMENT AND ARC-PULSED ION IMPLANTATION

V.A.Shulov[1)], N.A.Nochovnaya[2)], G.E.Remnev[3)], A.I.Ryabchikov[3)]
[1)] *Moscow Aviation Institute, Volokolamskoye chosse 4, Moscow 125871, Russia, Tel.: (7-095) 1584424, Fax: (7-095) 1582977, E-mail: roman@ fipc. ru*
[2)] *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*
[3)] *Research Institute of Nuclear Physics, Lenin Street 2a, Tomsk 634050, Russia, Tel.: (7-382) 2423980, Fax: (7-382) 2423934, E-mail: alex @ alpha. rpi. tpu. ru*

High-power pulsed ion beam (HPPIB) treatment and arc-pulsed ion implantation (APII) were combined consecutively to be the improvement of service properties of high temperature refractory alloys. The influence of this combined processing on the physical and chemical state of refractory alloy surface layers was studied. It is shown that it is possible to combine the positive effects of each technology in order to obtain an ideal smooth surface (without craters, R_a =0.06-0.10 μm) and to increase the alloyed surface layer thickness due to irradiation-enhanced diffusion. Consequently, the positive effect of this combined treatment on the fatigue strength, salt corrosion resistance, and oxidation resistance is connected with the following processes: smoothing of a surface microrelief; high-speed-solidification; surface alloying; structure stabilization during a post-process vacuum annealing.

I. Introduction

Irradiation by high -concentration fluxes of energy (especially HPPIB treatment and APII [1,2] is one of the most advanced treatments among the methods for the surface processing of high load components of aircraft engines [3]. For example, HPPIB and APII application allows one to improve service properties of compressor and turbine blades dramatically [4]. It has a good prospect to carry out two-stage irradiation of these components using HPPIB treatment and final APII.

The objective of this paper is the determination of the combined effect of these processings on the fatigue strength, oxidation resistance and salt corrosion resistance of the blades from the refractory alloys.

II. Experimental

Two types of accelerators have been used for HPPIB irradiation and APII (Temp-M and Raduga-4). The main parameters for HPPIB treatment are: (1) the energy of ions, E=300 keV; (2) beam composition, carbon ions and protons (30 %); (3) ion current density in a pulse, j=60-120 A cm^{-2}; (4) pulse duration, τ=50 ns; (5) pulse frequency, f=0.2 Hz; (6) beam cross-section area, S=60-100 cm^2. Ion implantation by Sm, Hf, La and B ions was carried out after HPPIB irradiation under the following conditions: E=30-80 keV; j=0.2-0.5 mA·cm^{-2}; τ=200 μs; f=30 Hz; a dose of irradiation, D=10^{16} - $5\cdot10^{17}$ ion·cm^{-2}.

Titanium alloys (VT6, VT8M, VT9, VT33) [3], a nickel alloy (EP718ID), and a steel (EP866sh) [3] samples and compressor blades prepared according to conventional mechanical and thermal treatments have been irradiated in the Temp-M and Raduga-4 accelerators consecutively. Some targets were studied by Auger electron spectroscopy (AES), X-ray diffraction analysis (XDA), scanning electron microscopy (SEM), measurements of microhardness (H_μ), exo-electron emission (Ieee) and roughness (R_a) after tow- stage irradiation. Other irradiated samples were subjected to vacuum annealing for 2 hours at the given operating temperature for each alloy, in particular, VT6, VT8M.VT33, VT9 - 500^{0}C, VT18U - 550^{0}C, EP866sh - 600^{0}C, EP718ID - 650^{0}C. After completing of the pointed heat treatment the studying cycle was repeated again.

III. Results and discussion

According to the experimental data published in [1-6] and presented in Table 1, 2 and Fig.1-3 the following totality of phenomenon takes place in the surface layer of materials during HPPIB irradiation, APII and a post-process annealing:

i. surface layer melting, gas-dynamic removal of elements, spreading of a shock wave in a depth, formation of point and linear defects generated by the shock wave;
ii. gas absorption into a liquid phase, irradiation-enhanced diffusion during cooling, high-speed solidification (V=10^7-10^9 K·s^{-1}), formation of surface microdefects having a shape of craters and deposition of vapour-plasma cloud elements on the surface (these processes proceed after completion of pulse action);
iii. ion beam alloying of the surface layer material by implanting ions, irradiation-enhanced diffusion of implanting ions during bombardment of the target surface (thickness of alloyed layer is increased almost in tow times, formation of new point and linear defects and modification of the defect structure formed on the stage of HPPIB treatment; intense sputtering of the surface material, especially during ion implantation of heavy elements (the latter leads to smoothing of crater sharp edges);
iv. formation of α-phase crystal plate structure with highly uniform α-phase crystal plate orientation in each α-colony (VT18U alloy);

Table 1. Characteristics of concentration profiles of implanted elements (HPPIB treatment: E=300 keV; τ=50 ns; APII: U=30 kV; f=30 Hz; τ=200 μs), where: R_p is projective running; x_{max} is the concentration of implanted element in the R_p - point; h_{max} is thickness of the alloyed layer; I_{eee} is the intensity of exo-electron emission; * is the results after annealing.

N	Alloy	HPPIB treatment j, A/cm²	n	APII ion	dose, ion/cm²	R_p, nm	x_{max}, at. %	h_{max}, nm	I_{eee}, pulses s^{-1}
1	VT18U	-	-	-	-	-	-	-	75±10
2	VT18U	120	3	-	-	-	-	-	100±10
3	VT18U	-	-	Sm	$5\cdot10^{16}$	15±4	24±3	42+5	200±30
4	VT18U	-	-	Sm	$5\cdot10^{17}$	10±3	68±3	78±5	500±10
5	VT18U	120	3	Sm	$5\cdot10^{16}$	20±3	28±3	40±5	250±20
6*	VT18U	120	3	Sm	$5\cdot10^{17}$	20±3	70+4	120±10	120±20
7	VT9	-	-	-	-	-	-	-	45±5
8	VT9	120	3	-	-	-	-	-	120+10
9	VT9	-	-	Hf	$5\cdot10^{16}$	15±5	23±4	30±4	160+20
10*	VT9	-	-	Hf	10^{17}	17±5	38±5	40±5	80+20
11	VT9	100	3	Hf	$5\cdot10^{16}$	18+5	25±5	35±4	200±20
12	VT9	100	3	Hf	10^{17}	22±5	40±5	50±5	150+20
13	VT9 (LaB_6)	-	-	La B	$4\cdot10^{17}$	15±3 120+20	28±3 8±2	32±5 >300	180±20
14	EP718ID	-	-	-	-	-	-	-	210+30
15	EP718ID	120	3	-	-	-	-	-	240±10
16	EP718ID (LaB_6)	-	-	La B	$2\cdot10^{17}$	16+3 110±10	18±2 6±2	28±4 >250	290±30
17	EP718ID (LaB_6)	120	3	La B	$2\cdot10^{17}$	25±4 120±10	22±3 5±2	35±4 >300	320+20
18*	EP718ID (LaB_6)	120	3	La B	$2\cdot10^{17}$	25±5 120±10	18±3 1±2	40+3 >300	160±30

Table 2. The results of fatigue and oxidation/salt corrosion tests (HPPIB treatment: E=300 keV; τ=50 ns; APII: U=30 kV; f=30 Hz; τ=200 μs), where: σ_{-1} is the fatigue limit; h_0 is the oxidized layer thickness; Δm/S is the increase of specific mass; is the results after annealing.

N	Alloy	HPPIB treatment j, A/cm²	n	APII ion	dose, ion/cm²	σ_{-1}, MPa	h_0, μm	Δm/S, mg/mm² ±0.02
1	VT8M	-	-	-	-	160±10	38±4	0.62
2*	VT8M	60	15	-	-	320±10	26±4	0.21
3*	VT8M	-	-	La, B	$4\cdot10^{17}$	220±10	18±3	0.30
4*	VT8M	60	15	La, B	$4\cdot10^{17}$	480±20	10±3	0.08
5*	VT18U	-	-	-	-	360±10	32±3	0.73
6*	VT18U	150	3	La, B	$5\cdot10^{17}$	440±20	8+2	0.09
7	EP718ID	-	-	-	-	320+20	74±6	1.94
8*	EP718ID	60	10	La, B	$2\cdot10^{17}$	390+10	23+4	0.36
9	EP866sh	-	-	-	-	330±20	68±6	1.98
10*	EP866sh	60	10	La, B	$2\cdot10^{17}$	400+10	19±3	0.42
11*	VT33	-	-	-	-	250+30	36+4	0.66
12*	VT33	120	3	La, B	$4\cdot10^{17}$	360±10	11±3	0.14
13*	VT33	60	10	La, B	$4\cdot10^{17}$	380±10	8±3	0.11
14	VT33	120	3	La, B	$4\cdot10^{17}$	210+30	44+3	0.84
15	VT33	60	10	La, B	$4\cdot10^{17}$	300+40	40±3	0.69

v. formation of residual compressing stresses in the surface layer with thickness of 4-7 μm ($\sigma \sim 10^8$ - 10^9 MPa);

vi. a decay of β-phase (titanium alloys) with the fixation of sub-plate microstructure (secondary α-phase crystal plates have to be integrated into homogeneously oriented sub-α-colonies, VT18U alloy);

vii. formation of a homogeneous structure with an average grain size of 40-60 μm and with low values of interplate distances (titanium alloys);

viii. complete dissolution of the β-phase (VT6, VT9, VT33, VT8M titanium alloys), χ-phase (ER718ID nickel alloy) and carbides (EP718ID and EP866sh);

ix. formation of fine despertional precipitates of borides, and oxides (La_2O_3 , TiB_2 , Al_2O_3 , HfO_2 ,

Sm_2O_3) in the surface layers with thickness of 300 nm.

It is obvious that this combined ion beam processing coupled with final heat treatment allows the transformation of the service properties of these refractory alloys. Test results (Table 2) have shown that, under the optimal treatment conditions, the following properties have to be improved: (1) the fatigue strength (by 50-300%); (2) the oxidation resistance (3-5 times); (3) the salt corrosion resistance (6-8 times). The best results of the tests were achieved for VT8M alloy samples treated using the next combined technology: HPPIB irradiation (E=300 keV; j=60 A cm^{-2}; n>15 pulses, τ=50 ns); implantation by La and B ions (D=4·10^{17} ion·cm^{-2}), post-process annealing (T= 450^{0}C, τ=2 hours).

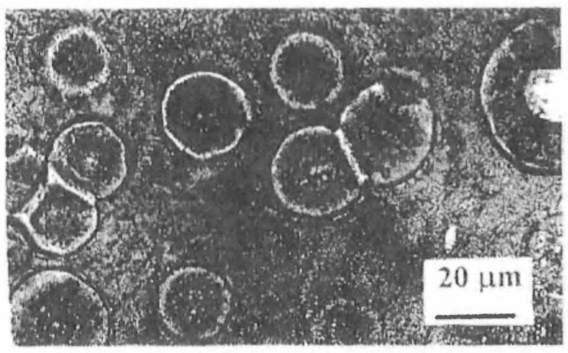

Figure 1. Optical micrograph of the VT25U alloy surface after HPPIB treatment (j=100-120 A·cm^{-2}, n=3 pulses)

Figure 2. SEM-micrograph of the EP718ID alloy surface after HPPIM irradiation (j=100-120 A cm^{-2}, n=3 pulses): formation of craters and microcracks.

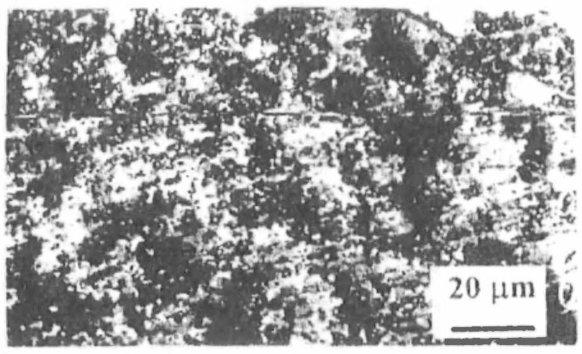

Figure 3. Optical micrograph of the EP866sh steel surface after HPPIB treatment (j=100-120 A·cm^{-2}, n=3 pulses) and ion implantation (LaB_6, D= 4 10^{17} ion·cm^{-2}).

IV. Conclusion

It is well known that HPPIB treatment and arc-pulsed ion implantation are the compatible and complementary technologies. Combining them, it is possible to add the positive effects of each process. The first evaluation of the test results shows a good prospect for applications of the combined technology in aircraft engine building. It is important that the technical combination of the high-power pulsed icn-beam and arc-plasma sources into a chamber has not principled difficulties

Acknowledgements

This work was support by the Russian State Committee of High Education.

References

1. *Remnev G.E. and Shulov V.A.* // J. Laser and Particle Beams. - 1993. - v. 11. - p. 707.
2. *Ryabchikov A.I.* // J. Rev. Science Instruments. - 1990. - v. 61. - N1. - p. 641.
3. *Shulov V.A., Nochovnaya N.A., Remnev G.E., Pellerin F., Monge-Cadet P.* // J. Surface and Coatings Technology. - 1998. - v. 99. - p. 74.
4. *Shulov V.A., Nochovnaya N.A., Remnev G.E., Ryabchikov A.I.* // J. Surface and Coatings Technology. - 1997. - v. 96. - p. 48.
5. *Shulov V.A. and Nochovnaya N.A.* // J. Nuclear Instruments and Methods in Physics Research. - 1999. - v. B148. - p. 154.
6. *Shulov V.A., Nochovnaya N.A., Remnev G.E.* // J. Materials Science and Engineering. - 1998. - v. A243. - p. 290.

SURFACE MODIFICATION OF REFRACTORY ALLOYS WITH HIGH-POWER PULSED ION-BEAM TREATMENT AND ARC-PULSED ION IMPLANTATION

V.A.Shulov[1)], N.A.Nochovnaya[2)], G.E.Remnev[3)], A.I.Ryabchikov[3)]

[1)] *Moscow Aviation Institute, Volokolamskoye chosse 4, Moscow 125871, Russia, Tel.: (7-095) 1584424, Fax: (7-095) 1582977, E-mail: roman@ fipc. ru*

[2)] *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*

[3)] *Research Institute of Nuclear Physics, Lenin Street 2a, Tomsk 634050, Russia, Tel.: (7-382) 2423980, Fax: (7-382) 2423934, E-mail: alex @ alpha. rpi. tpu. ru*

High-power pulsed ion -beam treatment and arc-pulsed ion implantation were combined consecutively to be the improvement of service properties of refractory alloys. The effect of this combined processing of the chemical and physical state of refractory alloy surface layers. It is shown that it is possible to combine the positive effects of each technology in order to obtained an ideal smooth surface and to increase thickness of the alloyed surface layer. The combined technology allows the improvement of the following properties of refractory alloys: the fatigue strength (by 50-300 %); the oxidation resistance (in 3-5 times); the salt gas corrosion resistance (in 6-8 times).