APPLICATION OF PULSED PLASMA STREAMS FOR MATERIALS ALLOYING AND COATINGS MODIFICATION

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Results of pulsed plasma streams processing of material surfaces with previously deposited FeB and TiAlN coatings are presented. Under the plasma treatment intensive mixing the materials of coating with the material of substrate was achieved. In the first case this provided boronizing of the modified layer with aim of corrosion properties improvement, in the second case – formation of intermediate mixed layer for subsequent deposition of the hard alloyed coatings. Materials alloying with pulsed metal-gas plasma is discussed also.

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INTRODUCTION

It is well known that modification of constructional steels with powerful pulsed plasma streams results in hardening their surfaces and increasing the wear resistance of steel samples [1,2]. Under the pulsed plasma influence the high speed heating and melting of treated surface, high gradients of temperature arising at the near-surface layer of material contribute to anomaly high speed diffusion of plasma stream ions into the depth of the modified layer, structure- phase changes in a surface layer (change of crystal morphology and topography) and formation (under the fast cooling of molten layer) of the fine-grained structure that is similar to roentgen-amorphous one [1].

At the same time pulsed metal-gas plasma processing can be applied for coatings deposition [3] and also for doping of melted layer with plasma brought atoms [4].

This paper discus the possibility of improvement of different coatings deposited with other methods, presents the results of pulsed plasma streams processing of material surfaces with previously deposited FeB and TiAlN coatings as well as the results of materials alloying with pulsed metal-gas plasma.

EXPERIMENTAL DEVICES

The experiments were carried out in the pulsed plasma accelerator (PPA) “Prosvet” and rod-type injector IBIS.

The PPA facility consists of coaxial plasma accelerator (with anode diameter of 14 cm, and cathode diameter of 4 cm) and the vacuum chamber of 120 cm in a length and 100 cm in a diameter. The power supply system of the accelerator is a capacitor battery with the stored energy W=68 kJ at the discharge voltage 35 kV. The amplitude of the discharge current is 400 kA. The time duration of the plasma generation is 3-6 μs. The accelerator generates plasma streams with ion energy up to 2 keV, plasma density $2x10^{14}$ cm^{-3}, average specific power up to 10 MW/cm^2 and an energy density of the plasma stream in the range of 5-40 J/cm^2.

Rod-type plasma injector IBIS is described in details in [2]. The accelerator generates pulsed plasma beams of energy density ranging up to 10 J/cm^2, mean energy of ions equal to about 10 keV, and the average pulse duration equal to about 1 μs. As working gases nitrogen or argon were chosen.

Analysis of cross-sections of processed samples was carried out with optical microscope MMR-4 and scanning electron microscope JEOL with X-ray analyzer LINK. Elements content in modified layers was investigated with using the laser mass-analyzer EMAL-2.

MODIFICATION OF FeB AND TiAlN COATINGS

Coatings FeB and TiAlN were previously deposited on steel samples of 40H, H12, steel 45 by vacuum arc method in “Bulat” installation [5]. Thickness of deposited coating was 1 micrometer.

FeB coated samples were processed with “Prosvet” facility by pulsed nitrogen plasma streams for investigation of boron mixing process in the melt layer. Such mixing promotes creation of boronized modified layer with improved corrosion and friction properties. Results of element content analysis in modified layer of steel 45 sample with FeB coating after the treatment with 15 pulses are presented in Tab. 1.

Table 1. Element content for sample of steel 45 with FeB coating after plasma processing

Element	% mas. in layer on the depth 3-5 μm	% mas. in surface layer (depth 0.1-0.2 μm)
B	**0.98**	**0.45**
C	0.91	0.58
N	0.024	0.18
O	0.027	1.41
Si	0.5	0.56
P	0.008	0.008
S	0.01	0.06
Ti	0.035	0.041
Cr	0.42	0.22
Mn	0.66	0.84
Fe	base	base
Co	0.011	0.011
Ni	0.092	0.11

Mo	0.12	0.16

As follow from element content analysis due to plasma processing it is possible to introduce boron to the material bulk on the depth of more than 5 μm, i.e. to create boronized surface layer. It should be pointed that boron concentration in the layer depth became even higher in comparison with it content on the surface. The reason for boron concentration decrease at the surface of modified layer in comparison with material depth could be increasing the back flux of boron atoms from the melt layer surface at the end of plasma pulse (when plasma stream pressure and energy of incident ions were rapidly decreased). Also boron is partially replaced by nitrogen on the sample surface. Increasing nitrogen concentration on the sample surface up to 0.18% is observed. Initial concentration of nitrogen in the sample material was <0.005%.

Cross-section analysis of boronized modified layer has been performed. The thickness of modified fine-grained layer achieves 11-12 μm (Fig. 1).

Fig. 1
Cross-section of steel 45 sample with previously deposited coating of FeB after plasma processing

As result of plasma processing of TiAlN coatings effective mixing of coating with substrate material has been realized also. Element content of surface layer for steel H12 sample initially covered by TiAlN is presented in Tab. 2 after plasma processing with 5 pulses. Content of iron on the surface achieved 58% with simultaneous rather high level of concentration of titanium, aluminum and nitrogen (17%, 7.4% and 5% respectively). This effect can be used for creation of mixed intermediate layers for following coating deposition. It is well known such intermediate mixed layers provide much better adhesion and quality of coatings. Therefore pulsed plasma streams processing can be effective for "sewing" the deposited hard alloyed coatings.

It should be noted that the optimal regimes of pulsed plasma processing for different coatings depend on their thermophysical properties (melting temperature, heat conductivity and other) and should be analyzed for each material in real experimental conditions. On the one hand it is necessary to choose precisely the heat load to the sample surface to provide the coating melting, but to avoid coating evaporation. On the other hand, obtained thickness of modified layer in recent experiments with FeB coatings is not optimal and can be increased for "Prosvet" processing up to 30 μm at least [6].

Table 2. Element content for sample of steel H12 with TiAlN coating after the plasma processing.

Element	% mas. in surface layer (0.1-0.2 μm)	Element	% mas. in surface layer (0.1-0.2 μm)
C	0,95	V	0,21
N	**5,01**	Cr	7,82
O	2,84	Mn	0,22
Al	**7,38**	**Fe**	**57,59**
Si	0,44	Ni	0,076
P	0,015	Co	0,014
S	0,021	Cu	0,125
Ti	**17,02**	Mo	0,26

That is why additional analysis of samples cross-sections was performed for different materials processed with helium, oxygen and nitrogen plasma streams. Adjustment of plasma treatment regimes of processed materials was done to achieve optimal thickness of modified layer with simultaneously minimal value of surface roughness. Examples of modified surface layer structures for different materials are presented in Fig.2.
Depth of aluminium modified layer under oxygen plasma treatment achieved 50 μm, microhardness in modified layer ~ 316 kg/ mm^2.

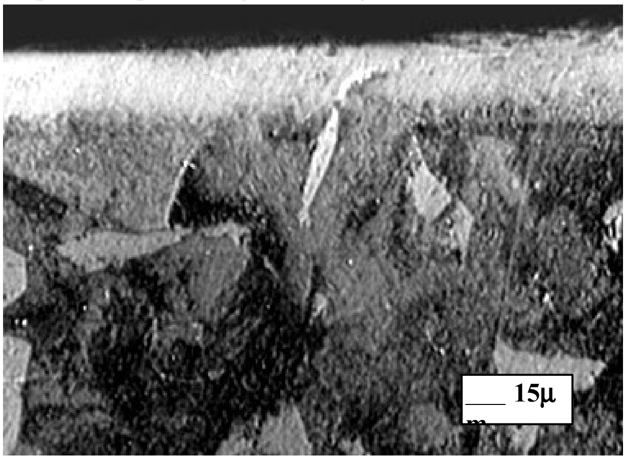
Using the light-weight gas for material treatment allowed to increase both pulse duration (up to 10-15μs) and energy density load to the sample surface (up to 50 J/cm^2). Therefore it was possible to increase the depth of modified layer for titanium alloy samples up to 100 μm under processing with He plasma streams. Modified layer of titanium alloy is not polarised and possibly consist on amorphous or β-Ti.

MATERIALS ALLOYING WITH PULSED METAL-GAS PLASMA STREAMS

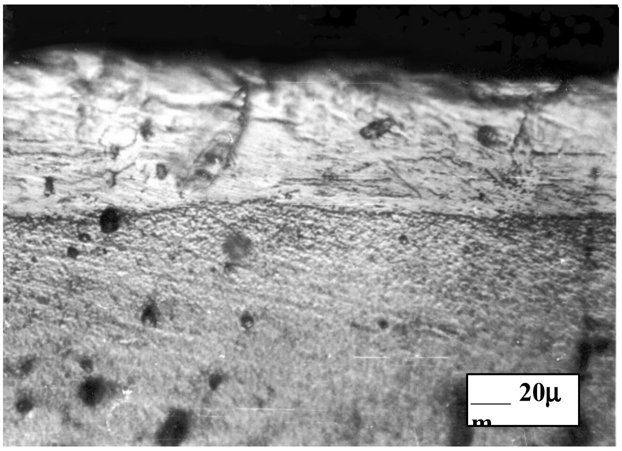
In these experiments the samples of different industrial steels were processed by IBIS in DPE mode (Deposition by Pulse Erosion) characterized by relatively short time delay τ_D between moment of injection of the working gas and high voltage discharge ignition. In these conditions working gas does not reach electrodes end and intensive erosion of electrodes end takes place. Therefore plasma beam in such mode is enriched by ions of electrode material. Also the vapor of this material is produced. Plasma processing of samples in this mode is accompanied by deposition of electrode material film to the sample surface and mixing of deposited material with material of sample in surface layer of 1-2 μm by consequent plasma pulses. Changing the electrode material it is possible to produce alloying of surface layer of steel samples by different elements. In these experiments titanium and nickel electrodes were used.

Investigations of elements content in modified surface layers of samples processed by IBIS in DPE operation mode [3] with Ti and Ni electrodes and nitrogen working gas were carried out with using X-ray analyzer LINK. Measurements were performed for area 300x300 μm. Depth of examined layer was about 2 μm. The average content of some elements in this modified layer is presented in Table 3.

As follows from obtained results plasma processing in DPE mode characterized by essential increase of electrode material contentment in the modified layer of samples. For processing with using of Ti electrodes,



a



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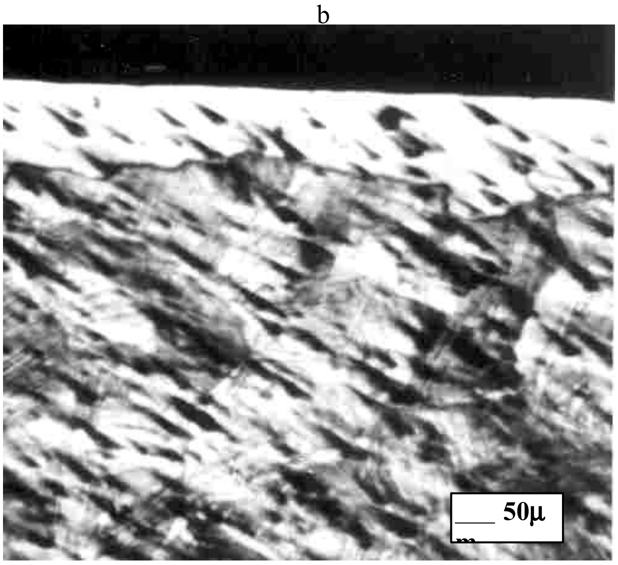

c

Fig. 2
Cross-sections of modified layers of processed materials:
a- steel 40H processed with nitrogen plasma,
b- Al processed with oxygen plasma, c- titanium alloy VT22 processed with helium plasma.

content of mixed Ti in this layer achieved 16.5 % after 25 pulses. For consequent treatment with using of Ti and Ni electrodes, increase of both elements is registered. All this indicates that effective alloying of surface layer takes place. However it should be pointed that content of Ni is considerably higher and achieved 30% as result of processing with 7 pulses only. Alongside with possible more effective nickel deposition (higher deposition rate per pulse) this difference can be explained by both processes: particular sputtering of Ti from the surface and mixing of previously deposited Ti in more deep layers by following pulses with Ni plasma.

Table. 3 Element content in modified layer of steels processed with IBIS in DPE mode

Steel	Treatment regime	Elements content, atom.%					
		Fe	Cr	Ni	Si	Ti	Mo
12HN3A	15 pulses with Ti electrodes	82.02	0.91	3.82	1.51	**11.74**	
H12	25 pulses with Ti electrodes	63.08	15.87	1.5	2.32	**16.49**	0.74
Steel 45	15 pulses with Ti + 7 pulses with Ni	61.95	0.11	**29.65**	1.88	**6.41**	

CONCLUSIONS

Experiments on processing of samples with previously deposited coatings of FeB or TiAlN have shown that under the plasma treatment intensive mixing the materials of coating with the material of substrate was achieved. In the first case this provided boronizing of the modified layer with aim of corrosion properties improvement, in the second case – formation of intermediate mixed layer for subsequent deposition of the hard alloyed coatings. Possibility of successful combination of vacuum-arc deposition with modification by pulsed plasma processing is demonstrated.

Results of materials processing with IBIS facility in DPE mode show the possibility of creation of mixed layer without previous coating deposition, but during one process of treatment with metal-gas plasma.

Thus alloying of materials is realized as by mixing of previously deposited coating with material substrate as directly by pulsed gas-metal plasma processing.

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