INFLUENCE OF PLASMA STREAM PARAMETERS IN PULSED PLASMA GUN ON MODIFICATION PROCESSES IN EXPOSED STRUCTURAL MATERIALS

O.V. Byrka, A.N. Bandura, V.V. Chebotarev, I.E. Garkusha, V.V. Garkusha, V.A. Makhlaj, V.I. Tereshin

Institute of Plasma Physics, NSC "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

E-mail: byrka@kipt.kharkov.ua

This paper is focused on investigation of helium, nitrogen and krypton plasma streams generated by pulsed plasma gun (PPA). The main objection of this study is adjustment of plasma treatment regimes for different materials that allows achieving optimal thickness of modified layer with simultaneously minimal value of surface roughness. Features of materials alloying from gas and metallic plasma as a result of the plasma ions mixing with the steel substrate in liquid phase are discussed also.

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1. INTRODUCTION

Surface processing with pulsed plasma streams of different gases is found to be effective tool for modification of surface layers of different materials [1, 2]. In particular, exposures with pulsed powerful plasma streams result in hardening their surfaces and increasing the wear resistance of industrial steels [3]. Fast heating and melting of treated surface, considerable temperature gradients (~10^6 K/cm) arising in surface layer of material under the pulsed plasma impact contribute to high speed diffusion of plasma stream ions into the depth of the modified layer, during the liquid stage, phase changes in the surface layer, and formation of the fine-grained or quasi-amorphous structures under the following fast resolidification. The cooling speed of ~10^6…10^7 K/s is achieved in this case due to the contact of thin melt layer (h_{melt} ~ 10…50 µm) with massive bulk of the sample. Plasma can also be considered as a source of alloying elements to be introduced into modified layer structure. That is why nitrogen is preferentially used for pulsed plasma processing of different steels.

Another possibility of alloying under the pulsed plasma processing is mixing of previously deposited thin (h_{coat}<h_{melt}) coatings of different predetermined composition with the substrate in result of powerful plasma impact. Results of pulsed plasma stream treatment for different kinds of steels are presented in [4, 5]. In this paper, features of surface modification for constructional materials, relevant to nuclear power systems, and different deposited coatings by pulsed plasma streams are analyzed.

2. EXPERIMENTAL SETUP

Experiments on materials treatment with powerful pulsed plasma streams were carried out with use of pulsed plasma accelerator (PPA) [1, 2]. Scheme of the device is presented in Fig. 1. Pulsed plasma accelerator consists of coaxial set of electrodes with anode diameter of 14 cm and cathode diameter of 5 cm, pulsed gas system on the base of fast gas valve, vacuum chamber of 120 cm in length and 100 cm in diameter, power supply, control and pumping systems.

The power supply system is condenser banks with stored energy of 60 kJ (for 35 kV). The amplitude of a discharge current is ~ 500 kA; plasma stream duration is 3…6 µs. The pulsed plasma accelerator generates plasma streams with ion energy up to 2 keV, plasma density (2…20)×10^{14} cm^{-3}, average specific power of about 10 MW/cm^2 and plasma energy density varied in the range of (5…40) J/cm^2. Nitrogen, helium, hydrogen, krypton and different mixtures can be used as working gases. The regime of plasma treatment was chosen with variation of both accelerator discharge voltage and the distance of the exposed samples from the PPA output.

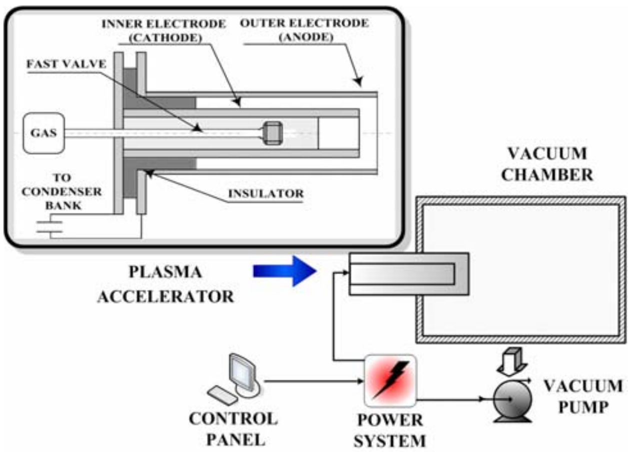

Fig. 1. Scheme of PPA device

For plasma parameters measurements a wide range of diagnostics was used: calorimetry, electric and magnetic probes, piezodetectors etc. Surface observations with optical microscopy and SEM were performed also.

3. EXPERIMENTAL RESULTS

3.1. PARAMETERS OF PLASMA STREAMS

Measured spatial distributions of plasma pressure and energy density are presented in Figs. 2, 3 for helium, nitrogen and krypton plasmas. The behavior of plasma pressure and energy density dependencies is similar for all gases.

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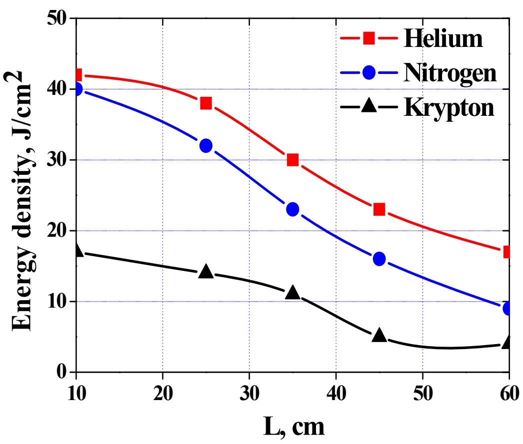

Fig. 2. Distribution of plasma energy density vs. the distance from the accelerator output

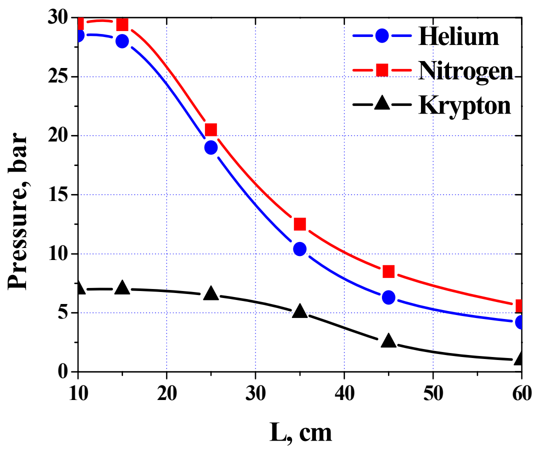

Fig. 3. Distribution of plasma stream pressure vs. the distance from the accelerator output

Plasma pressure value at the distance of 10…20 cm from the accelerator output is rather high. In such conditions development of surface roughness is observed on the sample surface in result of plasma exposures. At the same time, the effect of the plasma stream on the target surface is not homogeneous for large distances from the accelerator (more than 50 cm). However, technological applications of plasma streams require achievement of uniform thickness of modified layer, homogenous surface treatment for large size surfaces etc. So in these experiments the exposed samples were placed at the distance of 35 cm, which provides uniform surface treatment and moderate energy loads when discharge voltage is 20 kV. Pressure value for helium, nitrogen and krypton plasma streams at the sample position was measured as 10, 12, and 5 bar for these gases respectively. Energy density values achieved 30, 23 and 11 J/cm^2 for helium nitrogen and krypton, accordingly.

Measurements of radial distribution (Fig. 4) of energy density in the plasma flow were performed by means of movable local calorimeters. The maximum value of energy density registered in the axial part of the plasma stream. The slight decrease of energy density observed from the central part of the plasma stream till to a distance of 3…4 cm for all types gases. Energy density decreases significantly for large distances from the the stream axis. Based on these data, it can be argued that the effective diameter of the plasma stream is 6...8 cm. Therefore, for plasma impact with uniform energy density the target size should not exceed the effective diameter of the plasma stream.

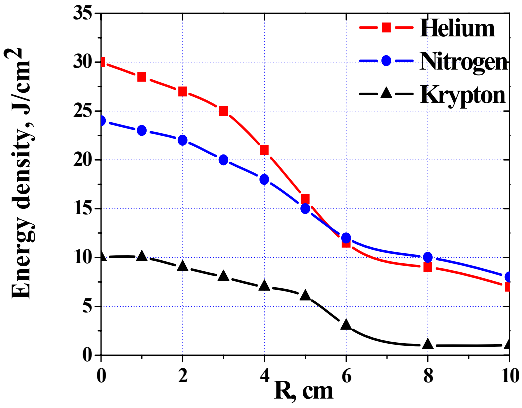

Fig. 4. Radial distribution of plasma energy density on the distance 35 cm from the accelerator output

Plasma stream velocity was evaluated by time-of-flight method. It was found that helium plasma streams have higher value of velocity – 2×10^7 cm/s, krypton and nitrogen plasma streams propagated with velocity of 7.5×10^6 and 1.1×10^7 cm/s accordingly. Such a substantial variation in the velocity of plasma flows is due to the difference in atomic mass of the mentioned working gases. The obtained velocity values of plasma streams allowed us to estimate the energy of ions for different gases. Krypton plasma streams have the highest energy ions that achieves 2.3 keV. Average ion energies for helium and nitrogen plasma flows are 500 and 750 eV, respectively.

3.2. ALLOYING OF SURFACE LAYERS BY MIXING IN LIQUID PHASE

The performed experiments have shown that pulsed plasma treatment leads to improvement of physical and mechanical properties of exposed cast iron and steel materials. These materials were used as substrate for coating deposition in consecutive studies. Essential increase of microhardness in result of pulsed plasma treatment was achieved for both cases: exposures of samples with and without previously deposited coatings.

Modification of thin (0.5…2 μm) PVD coatings of MoN, C+W, TiN, TiC, Cr, Cr+CrN and others with the pulsed plasma processing is investigated for varied parameters of impacting nitrogen plasma streams. It is shown that pulsed plasma treatment results in coating mixing with substrate providing material alloying.

The Table below shows the results of wear resistance tests for the samples subjected to coating deposition and following pulsed plasma exposures in different combinations. It should be noted that smallest friction coefficient (from 1.5 to 3 times decrease) is measured in wear resistance tests for samples with previously deposited Cr and CrN coatings, especially for those treated with powerful plasma pulses. Increasing wear resistance is achieved for samples with coatings TIC, C + W, Cr + CrN and Cr with subsequent pulsed plasma treatment. It is interesting to note that TiN coatings without following pulsed plasma processing demonstrate the worst result due to essentially increased indenter wear, which is accompanied by transport and sticking of indenter material to the sample during the friction.

Results of tribological tests,
(*) – transport and sticking of indenter material to the sample

Type of sample	Indenter wear, 10^{-4} g	Sample wear, 10^{-4} g	Friction Coefficient p=1 кN	Microhardness kg/mm²	
				area of contact	outside of contact
initial	26,5	2,5	0,084	893	785
Nitrogen plasma	32,0	4,0	0,088	1013	1013
Cr + nitrogen plasma	24,0	3,0	0,074	1100	1630
Cr + CrN	57,0	0	0,076	962 (*)	1420
TiN	655,5	5,5	0,085	695 (*)	2575
MoN	25,5	4,5	0,080	1100	1079
TiC	79,0	2,0	0,084	550 (*)	2232
C + W	23	1,0	0,084	1100 (*)	2232

Experiments with different substrate materials reveal possibility for essential improvement of wear resistance in the course of applied combination of coatings deposition with pulsed plasma processing. Alloying of surface layer in result of the coating-substrate mixing in liquid stage allows achievement of desirable chemical composition in surface layers being most loaded in all machine components. In particular, combined plasma processing is found to be prospective for modification of piston rings and other machine parts operating in conditions of bearing or dry friction.

4. CONCLUSIONS

Characteristics of helium, nitrogen and krypton plasma streams generated by pulsed plasma accelerator are investigated. Krypton plasma streams have the highest energy ions that achieves 2.3 keV. Average ion energies for helium and nitrogen plasma flows are 500 and 750 eV, respectively.Effective diameter of the PPA plasma streams was found to be (6...8 cm) for different gases.

Features of surface layers alloying from gas and metallic plasma as well as previously deposited coating mixing with the steel substrate in liquid phase are analyzed also. In particular, modification of thin (0.5…2 μm) PVD coatings of MoN, C+W, TiN, TiC, Cr, Cr+CrN and others in result of pulsed plasma processing has been studied. Alloying of surface layer in result of the coating-substrate mixing allows achievement of desirable chemical composition in surface layers being most loaded in all machine components. Thus, combined plasma processing is found to be prospective for modification of piston rings and other machine parts operating in conditions of bearing or dry friction. Increasing wear resistance is achieved for samples with coatings TiC, C + W, Cr + CrN and Cr with subsequent pulsed plasma treatment.

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ВЛИЯНИЕ ПАРАМЕТРОВ ПЛАЗМЕННЫХ ПОТОКОВ, ГЕНЕРИРУЕМЫХ ИМПУЛЬСНЫМ ПЛАЗМЕННЫМ УСКОРИТЕЛЕМ, НА ПРОЦЕССЫ МОДИФИКАЦИИ КОНСТРУКЦИОННЫХ МАТЕРИАЛОВ

О.В. Бырка, А.Н. Бандура, В.В. Чеботарев, И.Е. Гаркуша, В.В. Гаркуша, В.А. Махлай, В.И. Терешин

Анализируются параметры гелиевых, азотных и криптоновых плазменных потоков, генерируемых импульсным плазменным ускорителем (ИПУ). Основной задачей данных исследований является оптимизация режимов плазменной обработки различных материалов. Такая оптимизация позволяет добиться однородной толщины модифицированного слоя и минимального значения шероховатости поверхности. Также обсуждаются особенности легирования материалов в результате перемешивания в жидкой фазе тонкой пленки с материалом подложки.

ВПЛИВ ПАРАМЕТРІВ ПЛАЗМОВИХ ПОТОКІВ, ЯКІ ГЕНЕРУЮТЬСЯ ІМПУЛЬСНИМ ПЛАЗМОВИМ ПРИСКОРЮВАЧЕМ, НА ПРОЦЕСИ МОДИФІКАЦІЇ КОНСТРУКЦІЙНИХ МАТЕРІАЛІВ

О.В. Бирка, А.М. Бандура, В.В. Чеботарьов, І.Є. Гаркуша, В.В. Гаркуша, В.О. Махлай, В.І. Терешин

Проведено аналіз параметрів гелієвих, азотних і криптонових плазмових потоків, що генеруються імпульсним плазмовим прискорювачем (ІПУ). Основним завданням цих досліджень є оптимізація режимів плазмової обробки різних матеріалів. Така оптимізація дозволяє домогтися однорідної товщини модифікованого шару та мінімального значення шорсткості поверхні. Також обговорюються особливості легування матеріалів в результаті перемішування в рідкій фазі тонкої поверхневої плівки з матеріалом.