

MODIFICATION OF MULTI-PROFILE SURFACES BY COMPRESSION PLASMA FLOWS ACTION OF QUASISTATIONARY HIGH-CURRENT PLASMA ACCELERATOR

S.I. Ananin, V.M. Astashynski, V.V. Astashynski,
Yu.A. Chivel, E.A. Kostyukevich, L.Ya. Min'ko*

*Institute of Molecular and Atomic Physics
National Academy of Sciences of Belarus, Minsk, Belarus*

E-mail: ast@imaph.bas-net.by

**Belarusian State University, Minsk, Belarus*

The results of investigations into the action of compression plasma flows generated by the gas-discharge two-stage quasistationary high-current plasma accelerator (QHPA) on multi-profile details are presented. Efficiency of the QHPA application to hardening treatment of samples from low- and medium-carbon steels with sufficient for practical purposes depth and microhardness of modified surface layer is shown.

INTRODUCTION

Reliability and durability of details of various mechanisms are determined largely by surface properties of used materials rather than their volumetric characteristics. As the possibilities of traditional thermochemical methods of surface hardening are practically exhausted, intensively investigated now are new methods of processing. Broad opportunities for increase of hardness, durability and wear resistance of a surface layer are opened up by plasma methods based on the exposure of various details to the action of plasma flows. The power parameters of plasma flows should ensure the preheating of a treated detail surface and maintaining of necessary temperature levels until completion of physical-chemical transformations in a surface layer without both warming the underlying bulk and disturbing its structure and properties. Meeting all of these demands are high-energy compression plasma flows generated by a gas-discharge two-stage quasistationary high-current plasma accelerator (QHPA) [1-4].

Amongst major factors governing the changes in properties of surfaces treated by the QHPA compression plasma flows are rapid heat of a material (even the most refractory one) above melting points due to thermalization of a plasma flow kinetic energy, shock-wave processes accompanying the supersonic flow incidence on a specimen surface, and ionic implantation as well.

EXPERIMENTAL

The experiments were carried out on the two-stage P-50M type QHPA [2,4]. The Fig. 1 schematically shows an accelerator discharge device. The passive anode transformer is formed by 36 copper rods each measuring 120 cm in length, symmetrically located along a circle 50 cm in diam. The input ionization block (IIB) consists of four input ionization chambers (IIC). A construction of the IIC is developed on a basis of a magnetoplasma compressor of a compact geometry with a valvular working gas admission. A semi-active cathode transformer is seated at the axis of the P50M discharge device. It consists of two coaxial cylinders separated by insulators and connected by 16 copper pipes forming an ellipsoid of revolution. Copper needles, lo-

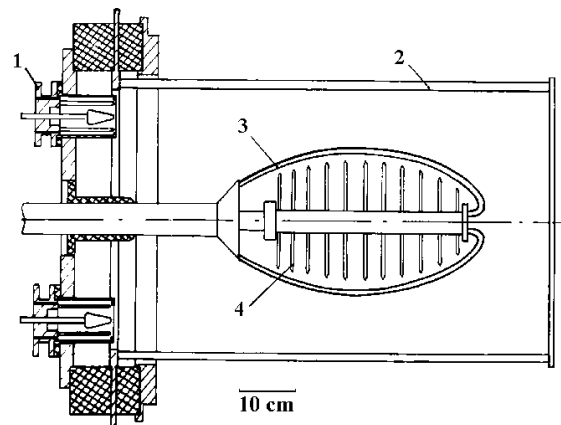


Fig. 1. Diagram of the discharge device of the QHPA: 1 — input ionization chamber, 2 — cathode transformer, 3 — anode transformer, 4 — copper needles

cated in a gap between pipes on the inner cylinder, act as current collectors or, in other words, as emitters of electrons neutralizing current-carrying ions. To begin with, the construction of the cathode transformer enables its shifts relative to the IIB, thereby changing a length of the drift channel, and in the second place, the ellipsoid size alterations, thereby changing a profile of the main accelerating channel.

Three sectioned capacitor banks served as energy storages feeding the accelerator main stage ($W_0 = 150$ kJ), the IIB ($W_0 = 60$ kJ), and valves ($W_0 = 5$ kJ) providing delivery of a working gas into the IIB. The nitrogen was used as working gas. Mass rate of the IIB varied from ~ 20 up to ~ 50 g/s. Voltage on the capacitor bank of the 2nd (main) stage was varied between 3 and 5 kV, causing an increase in the discharge current (in maximum) from 250 to 400 kA. Downstream of a tip of an inner electrode of such an accelerator the compression plasma flow ~ 50 cm long is formed, the latter ranging in diameter from ~ 3 cm in the area of the peak compression to ~ 40 cm at the QHPA outlet. The plasma velocity in a compression flow under the experiment conditions ranges from $\sim 3 \cdot 10^6$ to $\sim 8 \cdot 10^6$ cm/s at total duration of the discharge of ~ 450 μ s. The multi-

profile steel targets (either under floating potential, or under potential of the anode) were mounted at a distance of 30÷55 cm from a tip of an inner electrode (cathode). The action was accomplished either by single pulses, or by a series of pulses, following each other at intervals of 30–40 s. The number N of pulses in a series varied from 2 up to 10.

The QHPA compression plasma flow effected on annular details (material — steel 45) featuring an internal spherical (working) profile, and on spools of hydro-pumps (steel 40X). The action of a compression flow on a target causes in the vicinity of its surface the emergence of a shock-compressed plasma layer formed from a target material and appreciably differing in parameters from a plasma flow. Observed between shock-compressed plasma layer and incident compression flow is distinct border exhibiting noticeable oscillations throughout the discharge with frequency of ~1 MHz, during which process the width of the layer varies from ~ 0,5 up to ~ 2 cm. However, as the studies conducted imply, the shock-compressed layer formation results in the shielding of a processed surface. In order to eliminate the shielding effect, the operating conditions were chosen so that the shock-wave patterns formed near the target surface were driven away downstream the flow.

The conducted experimental studies enable conclusions as follow. The physical-chemical properties of a modified layer formed on treated details depend on parameters of an impacting plasma flow — with an increase in both velocity and power density of an incident flow the operational capabilities of constructional materials are improved. In modes of treatment with the surface melting the hardened layer forms (Fig. 2). Such a

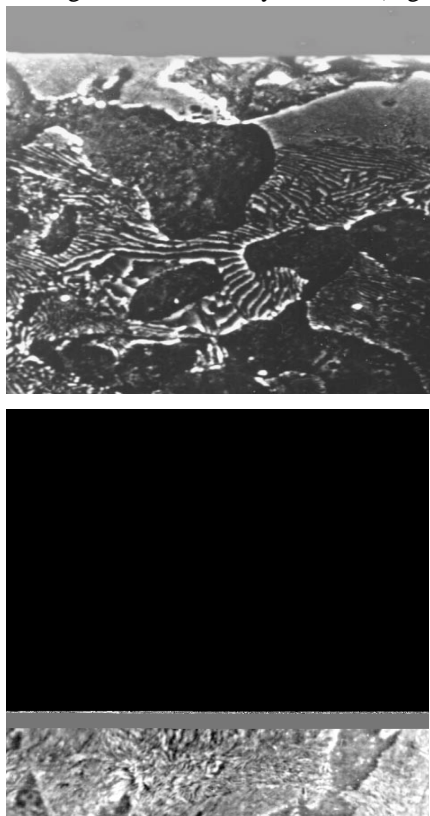


Fig. 2 The specimen surface structure before (a) and after (b) the action of a high-energy plasma flow. Magnification 500X

layer, like those observed after laser hardening of details [5], features the availability of three zones: non-etchable melted layer; non-doped heat-hardened layer (the solid-phase hardening zone), and the thermal influence zone. It is worth noting that, unlike laser treatment, the weak doping is observed in the first zone.

As the studies show (Fig.3), on exposure to single

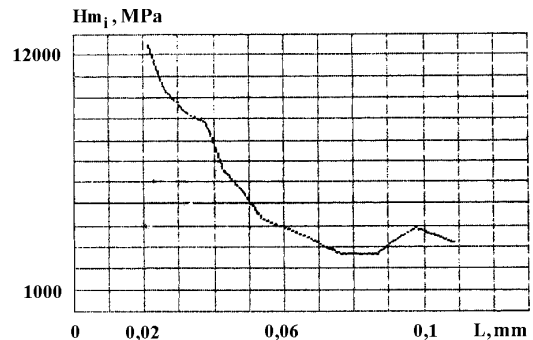


Fig. 3. Distribution of microhardness over the depth of a detail after a single action of a plasma flow

pulses the surface microhardness of treated details reaching a maximum ~ 12000 MPa in a zone of melting, is 5 - 6 times as high as that of a basic metal due to effects of both hardening from liquid state and doping. Average microhardness in the solid-phase hardening zone amounts to $(5\div7)\cdot 10^3$ MPa, and the hardening depth (0,05-0,06 mm) correlates with a warm-up thickness at $\tau = 400 \mu\text{sec}$. Observed in an upper area of this zone are martensite structures.

Two modes of repeated exposure of samples to a compressed flow differing in number of influencing pulses were investigated. In a mode of strong action ($U_0 = 5 \text{ kV}$, $L = 55 \text{ cm}$, $N = 7$) the formation of two hardening zones — hardening from molten state and that from solid state — takes place. The hardened zone thickness increases with growth of number of the influencing discharges, i.e. the effect of "accumulation of hardening depth" is observed. Testings of treated samples for wear resistance under conditions of dry friction have shown its increase 5 to 8 times due to rise in the uniformity of a surface texture and its hardness.

In a mode of weak action ($U_0 = 3,5 \text{ kV}$, $L = 55 \text{ cm}$, $N = 2$) the thickness of a hardening zone decreases to ~ 0,08 mm. Note that in a mode of strong action the microhardness makes ~ 8000 MPa (Fig. 4a), whereas in that of weak action it amounts to ~ 9500 MPa (Fig. 4b). Such a difference in values of microhardness derives from the fact that in a mode of strong action the plasma flow "blows off" an upper area of a molten surface layer.

Primary factors ensuring modification of properties of surfaces exposed to the action of high-energy plasma flows, are alternating high-speed processes of heating and cooling of a treated material layer. On thermal treatment accompanied by a surface melting the resulting structure is formed at the stage of the molten metal cooling. Here the possibility of reaching high and superhigh velocities of the molten metal cooling is of greatest interest, as in this case hardening from a liquid phase takes place.

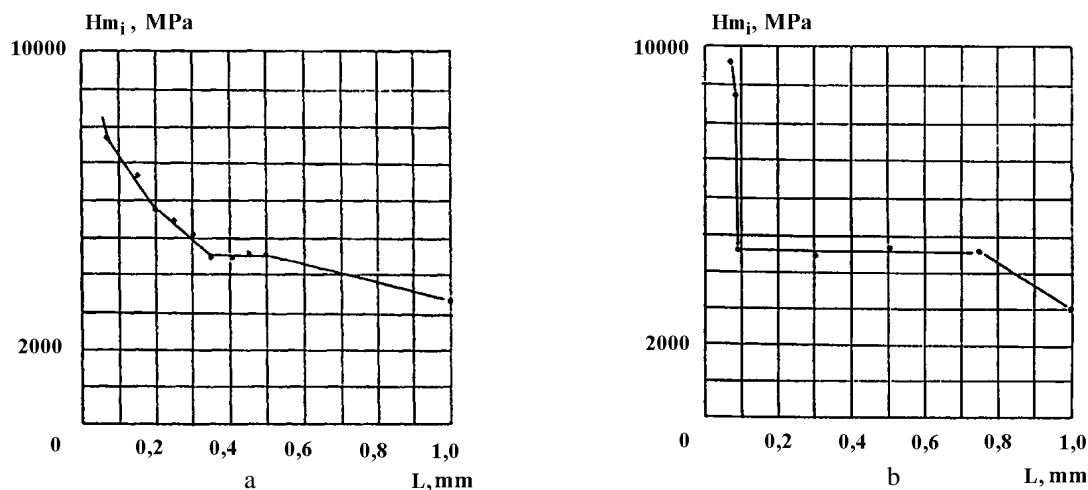


Fig. 4 distribution of microhardness over the depth of a detail: a — in a mode of strong action; b — in a mode of weak action

The X-ray diffraction analysis of phase structure of a surface layer of samples was carried out prior to and after exposing them to the action of compression plasma flows. The pre-treatment X-ray photograph recorded five diffraction maxima pertaining to α -phase of iron (Fig. 5a).

phase of iron.

Broadening of diffraction lines observed on the post-treatment X-ray photographs (as compared to those on the X-ray photographs obtained prior to exposure of the sample surface to the plasma flow) indicates a decrease

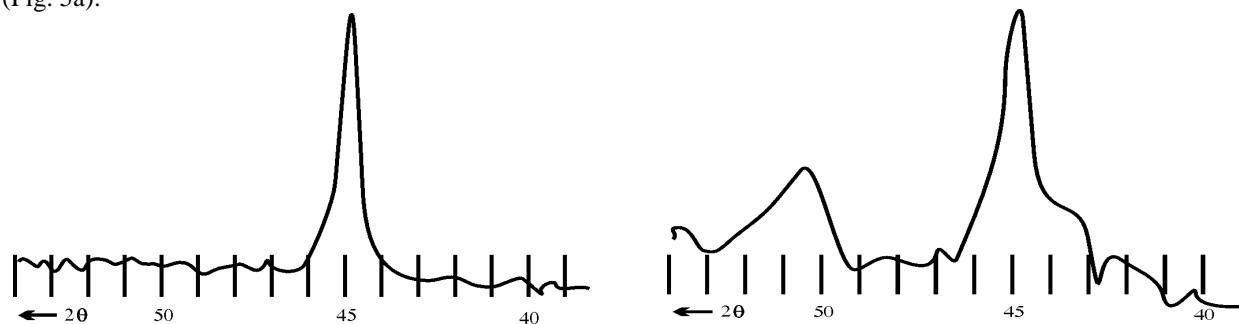


Fig. 5. Intensity curves on X-ray photographs of samples: a — before processing; b — after processing

The development of "arms" on the diffraction maxima along with emergence of additional maxima after the compression plasma flow action on a sample (Fig. 5b) is indicative of the availability of a new phase in the hardened layer. A comparison of interfacial spacings calculated from these lines, with the tabular data [6] makes it possible to conclude, that the new one is γ -

of blocks in size.

Thus, the conducted studies have shown reasonably high efficiency of the QHPA application to hardening treatment of samples from low- and medium-carbon steels yielding sufficient for practical purposes depth ($\sim 0,1 \pm 0,3$ mm) and microhardness (~ 10000 MPa) of modified surface layer.

REFERENCES

1. A.I.Morozov. Principles of coaxial (quasi) stationary plasma accelerators // *Fizika Plazmy*. 1990, v. 16, № 2, p. 131-146.
2. V.M.Astashinskii, A.A.Man'kovskii, L.Ya. Min'ko, A.I.Morozov. Physical processes responsible for the different operating regimes of quasistationary high-current plasma accelerators // *Sov J.Plasma Phys.* 1992, v. 18, № 1, p. 47-51.
3. A.I.Morozov, D.G.Soliakov, V.I.Tereshin, V.V.Chebotaev. Control of a radial profile of plasma density at the inlet of the accelerating channel of the complete-block QHPA X-50 // *Sov. J. Plasma Phys.* 1994, v. 20, № 10, p. 891-895.
4. S.I.Ananin, V.M.Astashynski, E.A.Kostyukevich, A.A.Man'kovskii, L.Ya. Min'ko. Interferometric studies of the processes occurring in a quasi-steady high-current plasma accelerator // *Plasma Physics Report (translated from Fizika Plazmy)*. 1998, v. 24, № 11, p.936-942.
5. A.G.Grigoriants, A.N.Safonov. *Methods of surface laser processing*. M.: "Higher school", 1987, 191 p.
6. L.I.Mirkin. *The directory on the X-ray diffraction analysis of polycrystals*. M.: " Physical and mathematical literature ", 1961, 864 p.