THE POWERFUL PULSED ELECTRON BEAM EFFECT ON THE METALLIC SURFACES

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Experimental results of the influence of powerful pulsed electron beams on the surface structure, hardness and corrosion resistance of the Cr18Ni10Ti steel are presented. The experiments were carried out in the powerful electron accelerators of directional effect VGIK-1 and DIN-2Kwith an energy up to ~300 KeV and a power density of 10^9-10^{11} W/cm^2 for micro- and nanosecond range. The essential influence of the irradiation power density on the material structure was established. Pulsed powerful beam action on metallic surfaces leads to surface melting, modification of the structure and structure–dependent material properties. The gas emission and mass-spectrometer analysis of the beam-surface interaction were defined.
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1 INTRODUCTION

Improvement of mechanical and corrosion-resistant properties of materials and alloys under action of pulsed electromagnetic irradiation and particle beams is intensively investigated now. And while the laser irradiation technology has wide range of applications, the use of charged particles and plasma technology is in frameworks of scientific investigations.

A number of problems on the influence of powerful pulsed electron beams on a solid material surface may be described simply as follows. The thin layer of a substance, where an pulsed energy release of ionization character, fast heats up and partially or completely evaporates towards incident radiation. Thus to the inside of a target the shock wave of pressure moves, and the stream of evaporated particles going towards radiation (providing a recoil momentum) which looks like a “torch” including solid debrises, drops of liquid, separate atoms, molecules and ions of different ionization degree, promotes the processes of evaporation and ionization under irradiation causing plasma heating.

Though the mechanism of structure modifying in both cases is defined by similar physical processes, there are some distinctions in application of the laser radiation techology, powerful pulsed electron and ion beams. In the case of laser and powerful ion beam effect, the features of influence on a material are closer to each other because the electron penetration inside the material is much more stronger in comparison with ion and laser radiation effect. Therefore to obtain the same radiation effect on the material with electron beams it is necessary to increase power density of a beam. But in comparison with the laser technology the later ones have the higher efficiency and allow to process surfaces of larger dimensions. Besides, irradiated surfaces can have a complex configuration.

Comparative analysis of these technologies shows that they have similar features: high power density (~ 10^{10}-10^{12} W/cm^2); energy density (~ 10^2 J/cm^2); high temperature gradients (10^6-10^8 K/cm); heating rate and tempering (10^9-10^{11} K/s) [1].

One of the causes of the strong change of physico-mechanical material properties under powerful pulsed irradiation of a high-density energy can be the creation of amorphous nanocrystal layers.

It is necessary to notice that for a number of the most effective ways of obtaining a homogeneous structure and structure - dependent materials is the use of high-rate heating technique. This provides a rather homogeneous fine-grained structure with a favorable combination of mechanical properties and high corrosion metal resistance. For example, high-rate heating (10^1-10^8 K/s) of elements from Cr18Ni10Ti steel allows simultaneously to increase both hardness and elastic properties (~ 35-40% and 45-55% depending on the grain size from 5 to 10 μm). In practice the techniques of obtaining the homogeneous fine-grained structure with the grain size 3-5 μm and improving the complex of physical-mechanical properties is known for the rate of metal heating equal to 10^2-10^3 K/s. Using magneto-pulsed techniques the rates of metal heating at a level of 10^4-10^6 K/s were realized with the grain size 2-3 μm.

Such kind of structure has a number of positive characteristics: more homogeneous properties along and across the article, higher values of homogeneous tensile properties at rather high hardness of the material. However, low ability of correcting heating parameters, limiting the heating rate, where the processes of recrystallization and phase transformations take place and also large sizes and high power of the setup do not favor a wide range of industrial applications. In this aspect more promizing is the technique of metal processing with the electron beam or with beam-plasma discharge operation at a heating rate of 10^9-10^{11} K/s. Note, that under beam heating the creation of a radiation-resistant amorphous structure is possible. Besides, this technique can have an appropriate technological application for modification of inner and outer surfaces of tubes.

2 EXPERIMENTAL TECHNIQUE

The operating parameters of the electron accelerators VGIK-1 [2] are as follows: beam energy is up to 300 keV, current is 10 kA, current - voltage characteristics are close to sinusoid with a halfcycle of 1.7 μs. The anode - cathode split varied from 10 up to 25 mm by moving the cathode having a diameter of 10 cm. The anode is a plate of the same diameter, from which samples of a necessary form were cut, or it is a special device permitting simultaneously to irradiate about 5 samples with a diameter up to 15 mm. The cathode is grounded.

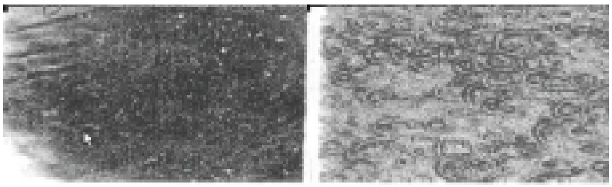
For the accelerator DIN - 2K [3] beam energy is up to 300 KeV, current is 100 kA, pulse duration is 30 ns. The beam diameter could vary from the fractions of millimeters up to 6 cm. [4].

Evacuation was carried out by oil-diffusion pumps. The vacuum chamber of both accelerators has rubber seals and can be heated up to 80°C. The separate assemblies, for example, the cathode and anode can be heated up to 500°C. The pressure in the accelerators was about $2{\cdot}10^{-5}$ Torr.

The heating rate and maximal temperature of the irradiated surface of samples are determined by the power input, pulse duration, material heat capacity, and the cooling rate depends on thermal characteristics and conditions of cooling.

In VGIK-1 and DIN - 2K accelerators the plates of the Cr18Ni10Ti austenitic stainless steel of a width of 0.3 mm were irradiated. The number of radiation pulses varied from 1 up to 30.The residual gas after pulse, in the main (up to 90 %), consists of hydrogen.

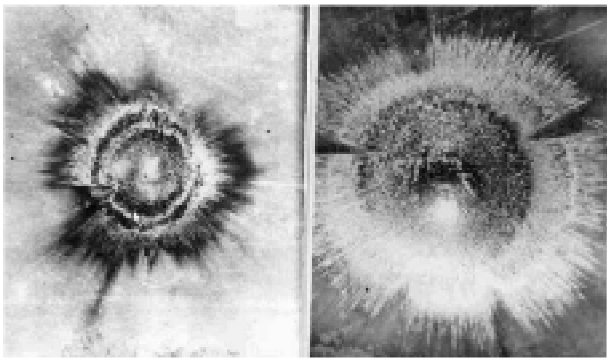
Applying the electron beam with an energy up to 300 keV and a power density up to 10^9 W/cm^2 of the accelerator VGIK-1 it is possible to define two zones at a surface of the irradiated plate: central and peripheral (Fig. 1, a). In the central zone the contour with a legible detection of boundaries which looks like a grain structure (Fig. 1, b) is seen. Inside the grains there are craters, apparently, appropriate to places of local metal evaporation. In a peripheral zone the strips of metal surface oxidizing are observed. The microhardness in the central zone is 240 kg/mm^2, in peripheral it is 210 kg / mm^2, that approximately corresponds to a microhardness of steel in the initial state.



a b

Fig. 1. The Steel Surface Structure after Pulsed Electron Beam Effect with an Energy up to 300 keV and Power Density ~10^9 W/cm^2. Magnification x4 (a) and x100 (b).

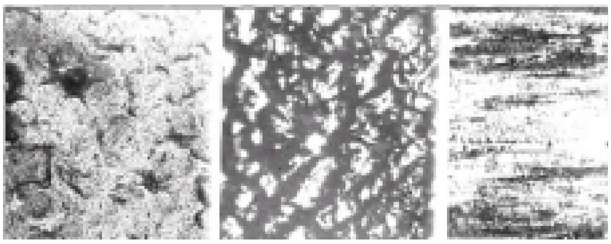
In Fig. 2 the typical microstructures of the steel surface irradiated by electron beams with an energy up to 300 keV and power densities at the central beam zone up to $5{\cdot}10^{11}$ W/cm^2 and on the peripheral zone up to 10^9 W/cm^2 are represented. The irradiated area of the plates is subjected to a strong plastic strain. The epicenter of the irradiated surface of the plates was displaced by 2-3 mm from the initial position. The areas of effect include several concentric zones distinguished by colour and structure, the number of which depends on the parameters of the beam effecting the surface.



a b

Fig. 2. Image of the Cr18Ni10Ti Steel Surface after Irradiation with an Electron Beam of an Energy 300 keV and Power Density ~$5{\cdot}10^{11}$ W/cm^2.

In the central zone the structure typical for cast metal with strong inhomogeneity of chemical composition (Fig. 3a) is observed. For the next-to-central zone the structure with considerable evaporation degree from the metal surface with a high density of craters (Fig. 3b) is characteristic.



a b c

Fig. 3. Microstructure of the Cr18Ni10Ti surface irradiated with electron beam of an energy 300 keV: a – central zone; b- next-to-central zone; c - peripheral zone. (Magnification x200).

The similar structure with craters was observed in the central zone of the zirconium surface [5] by usage of the laser technology. In the next zone the cast columnar dendrite structure being radially directed (Fig. 3c) is observed. And then one can see the initial structure of the strained and annealed stainless steel.

The microhardness of the irradiated surface area in different zones has different values. So for the interaction area shown in Fig. 3 the microhardness in the central zone is 250 kg / mm^2 and, for the next two zones with a fine-grained structure and high density of craters it increases up to 312 kg / mm^2, then in the direction far from the centre the microhardness is reduced to initial value. Thus, in radial direction from the centre of beam - surface interaction area the microhardness in the beginning rises, and then it is reduced to initial value. The dependence of the microhardness in a radial direction has an oscillating character.

Using the sample with an interaction area shown in Fig. 3a, the structure and microhardness vs. depth (width) of the irradiated plate were studied. For this purpose using the electrospark discharge machine the sample was cut on two halves in the central area, from which the transversal microsections along the width of the plate were obtained. In Fig. 4 the microstructure of the central zone crosscut is represented. The microstructure was studied and microhardness measurements vs. width of the plate in the central beam-surface interaction area, and also along the width in the directions from the central zone were performed (Fig. 5). The grain sizes in the middle of the plate is larger approximately by a factor of two than the grain sizes of surface layers. It specifies a distinction of the temperature along the width of the plate and different cooling rates of a surface and volume of irradiated sample. After microsection etching the slip lines are visible inside grains.

Fig. 4. Microstructure of the Crosscut of the Sample in the Central Zone (Magnification x400).

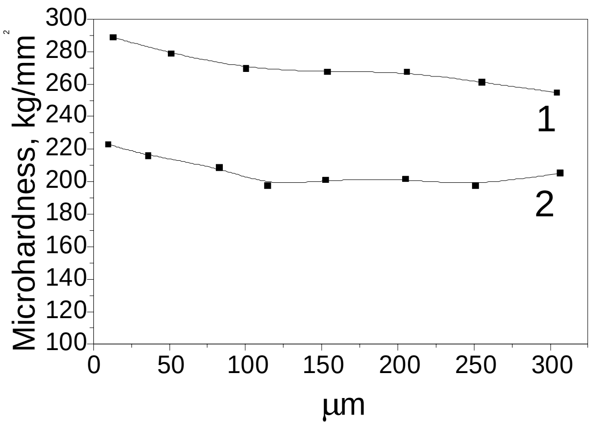


Fig. 5. Microhardness vs. Width of the Sample in Central (1) and in Peripheral (2) zones of Beam-Surface Interaction.

3 CONCLUSIONS

The obtained microhardness values vs. width of the irradiated plate testify that the microhardness along the whole width of the sample (~300 microns) in the central zone of beam-surface interaction is about 30 % higher than the mean microhardness in the peripheral zone.

Thus, the results of these researches show a significant influence of pulsed electron beam effect on a surface structure of the steel under consideration. It is determined by values of power density, beam energy and pulse duration. Creation of the devices with controlled radiation parameters will allow directionally modify the surface-volume properties of materials and articles from them.

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