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Optimization of Technology for Production of Bimetallic Compounds by High-current Relativistic Electron Beam Hardfacing of Nanostructured Coatings

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The mechanism of remote application of nanostructured coatings on metallic substrates is considered in the article. Spectroscopic studies of gas-plasma torch produced when the number of materials used in coatings is irradiated by the high-current relativistic electron beam have been carried out. The differences in the spectra for solid and tubular beams are determined. Measurements of the brightness temperature of gas plasma torch and the position of its maximum are obtained. Prospects of using high-current relativistic electron beams sources with pulse duration ~ (1 ... 2)·10^{-6} s for the modification of the structure and properties of metallic materials are proved.

Keywords: High-current relativistic electron beam, Gas plasma torch, Nanostructured coatings.

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INTRODUCTION

Applied significance of the interaction between high-current relativistic electron beams (HREB) with metals and alloys becomes possible with the advent of solid-state and air high-current switches, that allow the pulse repetition frequency modes and, consequently, to realize high-throughput processes based on them. In this context it is interesting to study in detail the possibility of obtaining bimetallic compounds using remote welding by HREB irradiation [1, 2]. The principle of such a hardfacing is HREB foil material irradiation coating and subsequent deposition of the molten material on the substrate surface. At the same experimentally determined [3] that the adhesive strength of the resulting compound and dispersion of the deposited material [4] depends greatly on the distance between the foil and the substrate and the foil thickness obviously determined by the temperature of the melt and solidification dynamics. In order to obtain data of the molten target material temperature gas plasma torch, formed by irradiation of materials that are used for coating, spectroscopic studies were carried.

1. SPECTROSCOPY OF GAS PLASMA TORCH

Integrated emission spectra in the visible range of the gas plasma torch (GPT) were recorded using a spectrograph STE-1 in different modes of accelerator operation (solid cylindrical and tubular beams).

In the case of a solid cylindrical HREB emission spectrum of the target GPT of different materials is linear. The radiation intensity is maximum at the target surface ($l \le 0.5$ cm) and decreases with the distance $1/l$ (up to $l \approx 5$ cm). The glow is almost uniformly across the beam. For steel target 12Cr18Ni10T the most intense lines are FeI, CrI, NiI. Ionic lines are practically absent. Qualitatively spectra are similar to arcs discharges commonly used in spectroscopy.

When using a tubular beam GPT radiation is significantly different as the topography and the nature of the spectrum. Near the target ($l \le 2$ cm) are clearly distinguished two emission region - the central part of diameter $d \approx 0.5$ cm, giving an intense continuous spectrum with the individual absorption lines, and peripheral (in the fall of HREB on target) with a linear spectrum similar to the spectrum of a continuous cylindrical HREB. This picture is most clearly seen when used a steel 12Cr18Ni10T band target of wide less than 1 cm, oriented perpendicular to the axis of observation. The absorption lines of the central region of the GPT are represented by the most intense lines of FeI and CrI. With increasing distance from the target, the intensity of the continuous spectrum decreases and at a distance of $l \ge 2$ cm emission lines appear. As the line absorption and emission lines widened significantly ($\Delta\lambda = 1$ ... 2 Å), which may be explained by a very high density of the central education GPT.

For determine the temperature of the GPT the method of relative intensities of the spectral lines is used. Spectrograms glow processing of targets and analysis of the GPT line intensity showed that the temperature of the GPT under the influence of a solid cylindrical beam with a steel 12Cr18Ni10T target at a distance of (0.5 ... 2) cm from the target was $T \approx 0.5$ eV. The temperature of the peripheral (in radius) of the target GPT region and the central GPT formation of the remote HREB is $T \approx (0.6 \ldots 0.7)$ eV. Measurements of the three pairs of lines gave well matching results, indicating that the conditions of LTE. The assessment of the of ionization of GPF by the Saha equation in thermodynamic equilibrium given $\delta = (0.35 \ldots 0.4)$ %.

2. MEASURING THE BRIGHTNESS TEMPERATURE AT THE TARGET SURFACE

In order to measure brightness temperature at the target surface of different materials the method of pulse pyrometry with a photographic registration of target and GPT optical radiation at a wavelength of

6600 ± 20 Å was used. The glow of GPT was measured at distances of (0 ... 20) mm from the target surface when the gas-plasma formation remained optically opaque. Transparency of GPT was determined by the method of the flyback radiation. Since emissivity GPT is unknown, the value of the actual temperature was estimated from the experimentally obtained brightness temperature of GPF. The target temperature within (2 ... 3) ms increases to maximum values and then decreases gradually over a few tens of microseconds.

The temperatures at the maxima are boiling points of the respective metals. Temperature maximum during the HREB current flow is achieved faster for materials with higher atomic weights, due to different volume energy deposition in the target associated with a different mean free path of electrons in the target material.

Large depth of maximum HREB energy release for lighter elements leads to the maximum temperature on the surface of the target over time is recorded with a great delay in comparison with the materials of the heavy components. It is related to the fact that the heat output from the depth of the target surface due to heat transfer mechanisms take some time.

The temperature maximum is reached at distances (3 ... 5) mm from the target surface and is (8 ... 5.5)·103 K. Location of the maximum GPT temperature at some distance from the target surface caused by the heating of the front of dispersing GPT dense layers vapor by electron beam with current value which at that time is still quite high.

3. REMOTE APPLICATION OF COATINGS

With the requirements of ultrafast cooling of metal materials a remote surfacing method of metals and alloys on the surface of constructional products as applied layer (foil), located at a distance from the substrate was exposed by HREB partially melted and vaporized was developed. The gap presence between the inflicted layer and substrate enables beam energy input substantially only at inflicted material. By subjecting beam destruction in the gap between the inflicted layer and substrate the substrate heating can be controlled, which greatly expands technological possibilities of the described application of coatings method. The power density (q) of the electron beam irradiating the layer is selected in the range of ($5\cdot10^{10}$ … $5\cdot10^{12}$) W/m^2. The power density of $q < 5\cdot10^{10}$ W/m^2 is insufficient for intensive evaporation from the surface layer, and to bring it to the accelerated movement toward the substrate. For $q > 5\cdot10^{12}$ W/m^2 comes unacceptable coating ablation regime, when the beam vaporizes a layer without melting the material and carries it to the opposite side of the substrate due to the formation of GPT. Material evaporation from the surface of the molten foil irradiated by the electron beam results to its rapid movement towards the substrate. During this movement, the molten layer continues to be electron irradiation exposed, and it accumulates negative charge. In the liquid melt under the action of surface tension, develops hydrodynamic instability of the Rayleigh-Teylers type instability. In the event of small perturbation surface electrostatic repulsion forces increase the disturbances to break up into droplets of the liquid layer, which leads to discontinuities deposited coating.

CONCLUSIONS

Using optical diagnostic techniques carried out a comprehensive study of the interaction of HREB with the solid surface. The thermodynamic parameters of mass transfer - the propagation velocity, density and temperature of GPT are determined. Longitudinal and transverse expansion velocities GPF of steel 12Cr18Ni10T are respectively (0.8 ... 4.0)·10^5 cm/s and (1.25 ... 2.15)·10^5 cm/s.

The mechanism of generation and propagation of GPT at action of tubular HREB (power density of ~ (10^8 ... 10^{10}) W/cm^2) on the surface of a solid target is associated with ablation of the irradiated surface with its super-fast heating, melting and evaporation and the formation of strong cylindrical shock wave fronts converge on the axis of the drift chamber and form a gas-plasma focus.

The glow that is logged is strongly heated gas and plasma with excited and partially ionized atoms of the target material. The focus of GPT is also a gas-heated plasma but with higher density and temperature than near target GPT. The maximum density of GPT focus since the formation of the 8th ms and of all time (up to $1.5\cdot10^{-5}$ s) did not change its position, and is at a distance (2 ... 3) mm from the surface of the irradiated target (12Cr18Ni10T) until the beginning of expansion at ~ 4·10^5 cm/s. The brightest glow occurs on the axis of the drift chamber, wherein the beam having the shape of a cylinder is not.

Proved prospects of using HREB sources with pulse duration ~ (1 ... 2)·10^{-6} s for the modification of the structure and properties of metallic materials. The features of hardening and structural transformations of structural steels (steel 45, CVH, VC-8, P-18) irradiated by HREB with a power density of ~ (10^6 ... 10^9) W/cm^2. It is shown that in combination with traditional forms of treatment, such beams can effectively solve the technological problems associated with improved strength and wear resistant characteristics as well as corrosion and erosion resistance of materials and products.

REFERENCES

1. V.F. Klepikov, A.V. Pashchenko, A.G. Ponomarev, V.V. Uvarov, V.T. Uvarov, V.I. Sheremet, *Phys. Chem. Mater. Treat.* **3**, 24 (2006).
2. V.F. Klepikov, Yu.F. Lonin, V.V. Lytvynenko, A.V. Pashenko, A.G. Ponomarev, V.V. Uvarov, V.T. Uvarov, V.I. Sheremet, *Probl. Atom. Sci. Tech.* **5** (50), 91 (2008).
3. U.F. Lonin, A.G. Ponomarev, V.V. Uvarov, V.T. Uvarov, M.I. Bazaleev, S.E. Donets, V.F. Klepikov, V.V. Lytvynenko, E.M. Prokhorenko, *Phys. Surf. Eng.* **8** No 4, 326 (2010).
4. S.E. Donets, V.F. Kivshik, V.F. Klepikov, V.V. Lytvynenko, A.G. Ponomarev, V.T. Uvarov, *Phys. Chem. Mater. Treat.* **2**, 18 (2010).