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Plasma parameters in some industrial vacuum arc deposition systems

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Abstract

The interelectrode plasma generated at the same conditions (discharge atmosphere, pressure, arc current) in two industrial arc devices was studied by optical emission spectroscopy. The devices were operated with titanium cathodes in vacuum, N_2 or a N_2/C_2H_2 mixture. Voltage–current characteristics of the discharges were also investigated. Results of spectral diagnostics indicated on the partial local thermodynamic equilibrium conditions in the sources. From relative emission intensities of the atomic and ionic species, the electron density and the relative concentration of titanium species were evaluated. The coherence of the results derived from the spectroscopic measurements and those obtained earlier by using other techniques was noted.

Keywords: Vacuum arc; Emission spectroscopy; Titanium; Excitation temperature; Ionization temperature; Electron density

1. Introduction

The cathodic vacuum arc coating systems usually utilize an interelectrode plasma that is formed as a result of some interaction of highly ionized plasma of the cathode spots with molecules of a reactive gas being introduced into the discharge reactor. In spite of recognition of the fact that the properties of the interelectrode plasma are of great importance for practical applications of the arc coating system, limited number of experimental studies dealing with the interelectrode plasma characteristics in the presence of a background gas were reported. Most of the works reported in the literature were devoted to a cathodic arc operated with N_2 or O_2 gases and with Ti or Cu cathodes [1–9]. The influence of the gas pressure on the plasma composition and energy distributions of electrons and some ionized

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species was investigated using optical emission spectroscopy [1–7], Langmuir probe [3–5,8], energy analyzing mass spectrometer system [9]. The studies were mainly focused on mechanisms and results of an interaction of the cathode spots plasma with the background gas. The theoretical models to describe spatial profiles of several physical quantities characterizing a vacuum arc operated with background gas were developed by Lepone et al. [10] and Gidalevich et al. [11]. More recently, Kułakowska-Pawlak et al. [12–14] performed spectroscopic investigations of the interelectrode plasma of titanium and zirconium arcs working in vacuum, nitrogen and $N_2+C_2H_2$ atmospheres. They examined relations between optical emission intensities of various plasma species and the arc current for two types of industrial arc devices (arc devices CDS and MZ 383) and have found that the relations are sensitive to the discharge atmosphere, the cathode material and the type of device [12,13]. Results of the investigations of the thermodynamic equilibrium state in the various plasmas generated by using the CDS with Ti or Zr cathodes have demonstrated that the plasmas were in the partial local thermodynamic equilibrium (p-LTE) regime [13,14].

Among the most important parameters of interest to vacuum arc applications are relative density of species (charge-state distribution, CSD) and the electron density and a number of workers have measured and reported proper values for their arc systems. The available data pointed to the high vacuum conditions. For arc current levels of about 100 A, Ti ion fractions with $z=+3$ (from 6% to 14% of the total number of ions), $z=+2$ (67–80%) and $z=+1$ (11–27%) have been found using an ion energy analyzer system or a time-off-flight (TOF) method [9,15,16]. The techniques do not provide information regarding the fraction of neutral atoms in the plasma. Some increase of the mean ion charge with an increase in arc current and magnetic field strength was reported [17].

An electron density (N_e) larger than $10^{20}\,\mathrm{cm}^{-3}$ was determined in the cathode spot region by laser absorption [18,19]. In the interelectrode plasma under vacuum condition, N_e was found to be 4–6 orders of magnitude lower than that obtained in the cathode spot plasma [20] (data for a Cu vacuum arc). In a Cu-arc operated in oxygen, the N_e obtained from the probe-calorimeter system was about $10^{10}\,\mathrm{cm}^{-3}$ [8].

The work presented here was mainly devoted to spectroscopic diagnostics of the plasma generated at the same experimental conditions in two industrial arc systems differing in construction of arc sources. In addition, voltage–current characteristics of the discharges were examined. We considered it important to study how the plasma parameters are affected by the type of the device. The devices were operated with titanium cathodes in reactive (N_2, $N_2+C_2H_2$) or nonreactive conditions. The excitation and ionization temperatures, and the electron density were determined. The relative concentration of titanium species was evaluated. The work has extended our previous studies [12,13] on the interelectrode Ti-arc plasma.

2. Experimental details

Investigations were carried out for two industrial arc deposition reactors—MZ 383 and CDS. The reactors considerably differed in construction of the arc sources. The MZ 383 reactor was a commercial cathodic arc sputtering device (Metaplas Ionon) and had eight sources [21]. The cathodes were fixed to a copper cooler with a central pin and were indirectly cooled. The set had an electrostatic localization of discharge supported by a weak axial magnetic field produced by a permanent magnet attached under the cathode. Direct current discharges were initiated by touching the cathode's frontal surface with a molybdenum starting electrode.

The arc device CDS was constructed by the Institute of Terotechnology (Radom, Poland) and it was a modernized version of the device NNW6,614 [22]. The CDS was supplied with nine arc sources with directly cooled cathodes and high-voltage systems of arc ignition. The sources contained two electromagnetic systems surrounding the cathode. The systems enabled to localize cathode spots on working surface of the cathode and to focus a plasma stream in a deposition zone.