

# LOW TEMPERATURE PLASMA AND PLASMA TECHNOLOGIES

## PLASMA OF ELECTRIC ARC BETWEEN ELECTRODES FROM COMPOSITE MATERIALS

I.L. Babich<sup>1</sup>, V.F. Boretskij<sup>1</sup>, R.V. Minakova<sup>2</sup>, A.N. Veklich<sup>1</sup>

<sup>1</sup> Taras Shevchenko Kyiv National University, Kyiv, Ukraine, e-mail: [van@univ.kiev.ua](mailto:van@univ.kiev.ua);

<sup>2</sup> Institute of Materials Technology Problems NAS of Ukraine, lab.29

The investigations of the processes of the mass transfer in a discharge gap of electric arc and peculiarity of interactions of composite electrode surface with discharge plasma were carried out. The optical spectroscopy and metallographic techniques were used. The unique secondary structure of electrode surface was formed by plasma of an electric arc discharge in air at arc current under 100 A.

PACS: 52.25.Os, 52.70.-m, 52.80.Mg

### 1. INTRODUCTION

The component optimization of electrodes remains in electric industry still an important problem in developing of composite materials with predetermined properties. It was found in our previous investigations [1] that the plasma temperature strongly depends on the electrode composition and the state of its surface as well. Therefore it is necessary to investigate the correlation of plasma parameters and electrode surface state or its erosion properties.

The main aim of this paper is the detailed study of the efficiency of the mass transfer processes in a discharge gap of electric arc and peculiarity of interactions of electrode surface with discharge plasma.

Namely, we studied the influence of plasma of a free burning in air electric arc on the surface state of composite materials on the copper base: *Cu-Mo* or *Cu-W*.

These materials are obtained by the copper infiltration of the high-melting component. The last one is a porous framework which is prepared from *Mo-Co* or *W-Co* powder with additions of copper powder. Cobalt (up to ~2%) is added to decrease the angle of contact of copper liquid and molybdenum or tungsten. Furthermore because of peculiarities of the process technology the iron is always present in such composite materials as an addition. The matter is that a grinding and a mixing of powders is carried out in steel ball mills. So, composite materials *Cu-Mo-Co-Fe* or *Cu-W-Co-Fe* in fact were used.

### 2. EXPERIMENT

The arc was ignited in air between the end surfaces of the non-cooled electrodes. The diameter of the rod electrodes was 6 mm, the discharge gap was 2...8mm, and the arc current was 3.5 and 30 A. To avoid the metal droplet appearing a pulsing high current mode was used: the current pulse up to 100 A was put on the "duty" weak-current (3.5A) discharge. The pulse duration ranged up to 30 ms.

The structural changes in the working layer of electrodes were investigated by the optical microscope "Neophot-2" and the scanning electron microscope (SEM) with the X-ray microanalyzer "JSM Super Probe-733", JEOL.

The spatial distribution of metal vapours in a discharge gap we measured by techniques of optical emission spectroscopy (OES) [2] and laser absorption spectroscopy (LAS) [3] as well. So, the efficiency of mass transfer in an electric arc can be evaluated in such manner.

### 3. RESULTS AND DISCUSSIONS

#### 3.1. MASS TRANSFER IN A DISCHARGE GAP

Two independent spectroscopy techniques in a study of the spatial distribution of metal vapours were used. In OES

the temperature profiles  $T(r)$  in electric arc between composite electrodes were obtained from relative intensities of spectral lines *CuI* 521.8 and 510.5 nm. The radial profiles of electron densities  $N_e(r)$  are obtained from width of spectral line *CuI* 515.3 nm in a case of prevail quadratic Stark broadening. The ratio of atom concentrations *Cu* and *Mo* or *W* in plasma was calculated from radial profiles of intensities of spectral lines *CuI* 521.8 and *MoI* 603.1 nm [2] or *WI* 589.1 [4] nm in the assumption of the equilibrium of the energy level population.

The obtained electron density and the temperature in plasma as initial parameters were used in the calculation of the plasma composition in LTE assumption. As an additional experimentally obtained parameter we used the ratio of atom concentrations *Cu* and *Mo* [2] or *W* [4].

So, it can be possible to calculate the concentration of any considered plasma particle in a discharge gap and the content of any kind of metal vapours as well.

One another technique of copper vapours visualization is LAS.

The absorption coefficient at the centre of the spectral line 510.5 nm in arc plasma volume was measured. We used the copper vapour laser at this wavelength. The image of the discharge gap in a parallel laser beam was recorded sequentially on the CCD matrix with arc and without it.

From the measured coefficient of absorption at the centre of the spectral line  $\kappa_0$  we can calculate the population of the lower level of this line  $N_m \sim \kappa_0 \delta \lambda$ . So, in such manner we could realize the copper vapours visualization in a discharge gap.

In Fig.1 (a-c) the spatial distributions of  $\kappa_0$  in arc discharge between *Cu-Mo* (a) and *Cu-W* (b, c) electrodes are shown. We found that the spatial and time profile of  $\kappa_0$  as well as copper vapours in arc between *Cu-Mo* electrodes, more or less, is stable. In contrast to this case such profile in discharge gap between *Cu-W* electrodes is unstable. In Fig.1 (b-c) two samples copper profiles are shown.

To clarify the proper cause of this phenomenon we investigated the behavior of arc discharge between two different kinds of electrodes. In Fig.2 (a-c) the images of arc discharges between *Cu-Mo* (a) and *Cu-W* (b, c) electrodes are shown.

As one can see the drop mass transfer of metal (Fig.2, c) as well as a gas (vapour) phase transfer (Fig.2, b) is realized in discharge gap between *Cu-W* electrodes. The dominated gas (vapour) phase mass transfer of metal (Fig.2, a) is realized in discharge gap between *Cu-Mo* electrodes.

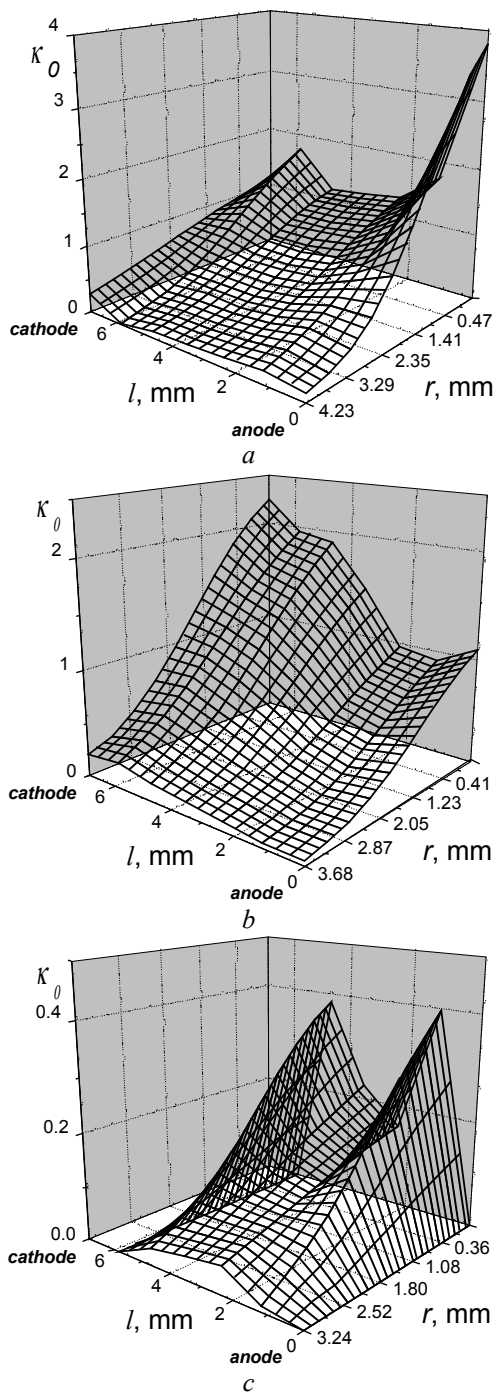


Fig.1. Spatial profiles of copper vapours between composite Cu-Mo (a) and Cu-W (b, c) electrodes

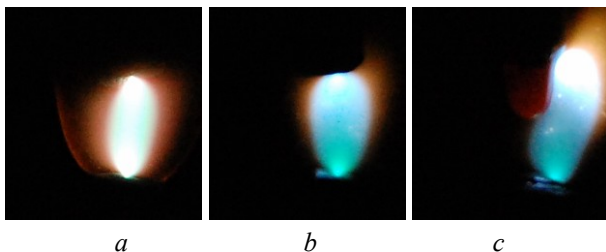


Fig.2. Images of arc discharges between composite Cu-Mo (a) and Cu-W (b, c) electrodes

In Fig.3 radial distributions of copper atom concentration in average cross section of discharge gap between copper

(1), composite Cu-Mo (2) and Cu-W (3, 4) electrodes are shown.

One can conclude that in Fig.1 (c) and in Fig.3 (curve 4) the results of investigation in case of drop mass transfer of metal in the arc gap between Cu-W electrodes are shown. Fig.1 (b) and in Fig.3 (curve 3) correspond to gas (vapour) phase transfer in a gap between such electrodes.

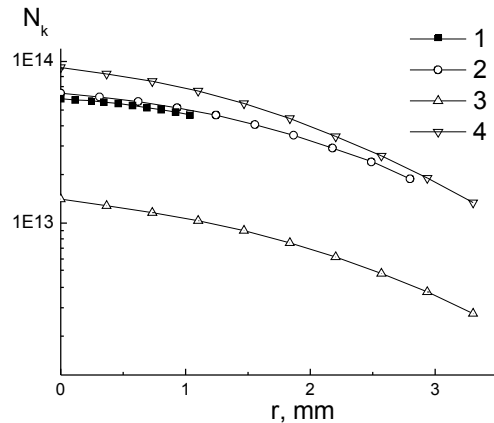


Fig.3. Radial distributions of copper atom concentration in discharge gap between copper (1), composite Cu-Mo (2) and Cu-W (3, 4) electrodes

To clarify the efficiency of the mass transfer processes in a discharge gap and peculiarity of interactions of electrode surface with arc plasma we carried out additional surface investigations by metallographic technique.

### 3.2. PLASMA-SURFACE INTERACTIONS

The structural changes in a working layer of electrode were studied by metallographic analysis of microvolumes of a working layer.

Such secondary modified surface of electrode has a complicated structure on the surface of the composite electrode on a copper base under effect of plasma of a high current arc discharge (1...100 kA) in air [1].

Another kind of unique secondary structure formation is observed on the surface of the composite materials Cu-Mo or Cu-W at a discharge current under 100 A (3.5 or 30 A). The input power in this case is less than in previous one.

In Fig.4 (a) the secondary structure on the surface of Cu-Mo electrode treated by a single pulse current of 30 A and duration of 30 ms is shown. Surface fragments in more detailed scales are shown in Fig.4 (b, c).

The similar formation of the secondary structure is observed in the Cu-W composite electrodes [see Fig.5].

The directional crystallization of eutectics colonies takes place on the above mentioned component electrodes surface in the investigated modes of electric arc discharge. Between these colonies the solid solution on the oxides of the composition, which depends on element components in a solution under an arc spot, is formed. Then the oxides, which have a high saturation pressure, are vaporized. The hollow spaces are realized in the tungstates (molybdates). These low-melting eutectics probably form the walls of the observed boxes on the electrodes surface (Fig.4 b, c and Fig.5, b). As a result of the directional crystallization the unique boxes walls are formed on the electrodes surface in the investigated modes of electric arc operation.

Except particles and their conglomeration which are formed in the liquid melt crystallization the clear facet crystals are observed on the electrodes surface (Fig.5,a). Such crystals can be formed in the process of condensation from the vapour phase of erosion products which are contained in the discharge gap.

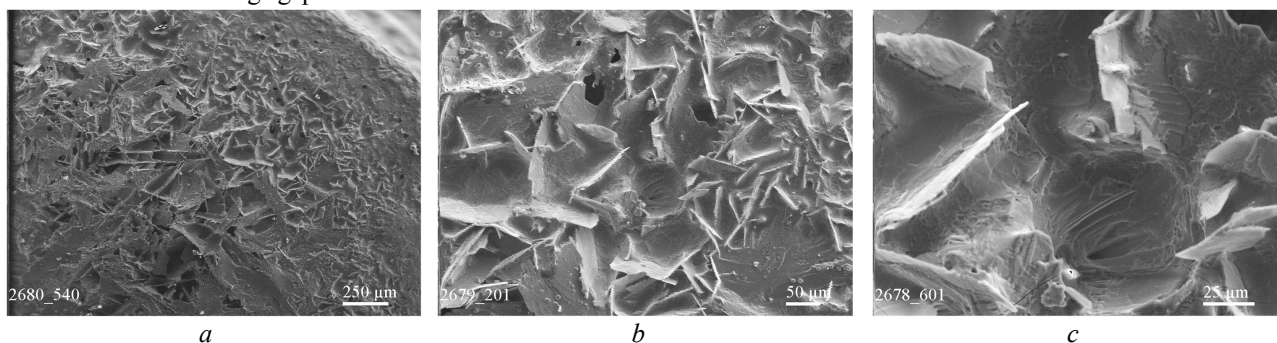


Fig. 4.

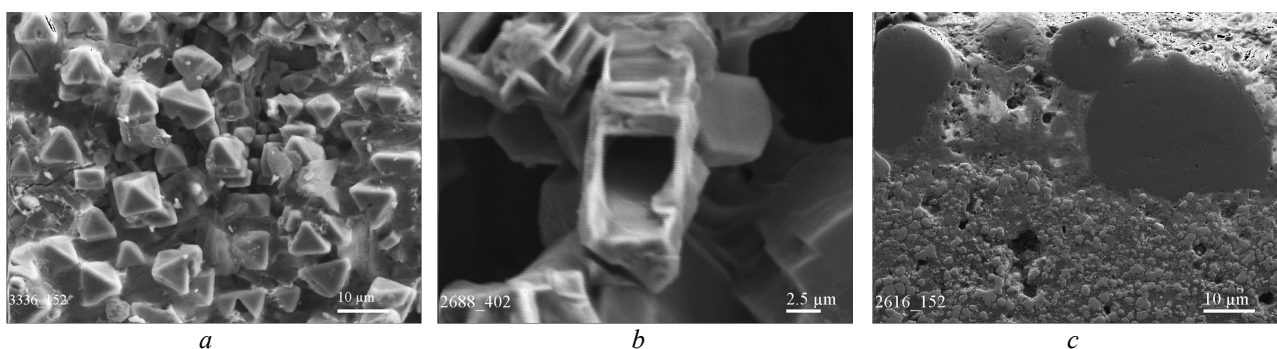


Fig. 5.

The carried out analysis testified that the electrical erosion of the tungsten-copper electrodes under influence of the free burning in air electric arc occurs mainly in a liquid phase. The formation of spheroid particles is observed in the electrode (cathode) section confirms the drop mass transfer in discharge gap (Fig.5, c).

#### 4. CONCLUSIONS

The gas (vapour) phase mass transfer of metal is realized in discharge gap between composite *Cu-Mo* and *Cu-W* electrodes of electric arc in air. The drop mass transfer mechanism plays significant role in a gap between *Cu-W* electrodes as well.

The unique secondary structure formation is realized on the surface of the composite materials *Cu-Mo* or *Cu-W* at a discharge current under 100 A (3.5 or 30 A).

#### ПЛАЗМА ЭЛЕКТРИЧЕСКОЙ ДУГИ МЕЖДУ ЭЛЕКТРОДАМИ ИЗ КОМПОЗИЦИОННЫХ МАТЕРИАЛОВ

*И.Л. Бабич, В.Ф. Борецкий, Р.В. Минакова, А.Н. Веклич*

Металлографическими методами и методами оптической спектроскопии исследованы процессы массопереноса в разрядном промежутке электрической дуги. Изучена особенность взаимодействия поверхности композиционных электродов с разрядной плазмой. Обнаружена уникальная вторичная структура поверхности электродов под влиянием дугового разряда в воздухе при силе тока до 100 А.

#### ПЛАЗМА ЕЛЕКТРИЧНОЇ ДУГИ МІЖ ЕЛЕКТРОДАМИ З КОМПОЗИЦІЙНИХ МАТЕРІАЛІВ

*І.Л. Бабіч, В.Ф. Борецький, Р.В. Мінакова, А.М. Веклич*

Металографічними методами та методами оптичної спектроскопії досліджені процеси масопереносу у розрядному проміжку електричної дуги. Вивчена особливість взаємодії поверхні композиційних електродів з розрядною плазмою. Виявлена унікальна вторинна структура поверхні електродів під впливом дугового розряду в повітрі при силі струму до 100 А.

#### REFERENCES

1. A.N. Veklich, I.L. Babich, L.A. Kryachko et al. The influence of the secondary structure of the working layer of composition electrodes on the temperature of electric arc plasma // *Electric Contacts and Electrodes*, Kiev: IPM

2. I.L. Babich, D.V. Chukhalenko, N.I.Grechanyuk et al. Plasma of electric arc discharge between *Cu-Mo* electrodes // *Problems of Atomic Science and Technology. Series "Plasma Physics" (11)*. 2007, N 1, p.139-141.
3. I.L. Babich, V.F. Boretskij, A.N. Veklich. Plasma of electric arc discharge between copper electrodes // *Contr. papers of the XVII<sup>th</sup> Symp. on Phys. of Switching Arc (FSO 2007) Brno 10-13 Sept. 2007 / Univ. of Techn., Brno*. 2007, v. I, p.13 – 16.
4. I.L. Babich, A.N. Veklich, V.Ye Osidach. Investigation of the electric arc discharge plasma between composition electrodes on the copper base // *Bull. of the Univ. of Kiev. Series "Phys.&Math"*. 2006, N.4, p.265-268.

Article received 22.09.08.