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PLASMA PECULARITIES OF ARC DISCHARGE BETWEEN CARBON-COPPER ELECTRODES

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Abstract. The experimental investigations of plasma parameters of electric arc discharge between composite carbon-copper electrodes are carried out by optical emission spectroscopy. It was shown, that arc channel width of electric arc between C-Cu composite electrodes tends to be wider in comparison with those between one-component copper electrodes. The experimentally obtained radial profiles of electron density in plasma channel of investigated arc discharges confirm such conclusion.

Keywords: Plasma, electron density, carbon-copper composite.

1. Introduction

The transfer of electrical signals and power between two components of electric circuits that are in relative motion to each other, is usually realized through sliding electrical contacts [1].

Nowadays, composite materials on carbon base are usually used as pantograph contact inserts, in particular, in high-speed railway [1–3]. On the one hand, these composites have advanced electric and exploitation characteristics. On the other hand, erosion properties of such materials are still under careful examination in developing processes of this composite. The matter is that the arc discharges appear during pantograph lowering process in pantograph-catenary system, so injection of contact material into discharge gap has place. Therefore, investigations of electric arc plasma between such composite electrodes can be useful for further optimization of materials.

It is well-known, that graphite, coke, copper-graphite or copper alloys, as materials in producing of inserts, have some advantages and disadvantages [4].

In particular, in spite of good lubricating properties of graphite and coke inserts, they have a comparatively high electrical resistivity. So, deterioration of tribological parameters of copper trolley wire or catenary takes place due to annealing in a result of significant Joule heating [5]. Moreover, such inserts have a sufficiently low hardness, so their service life is reduced.

The metal contact inserts on a base of copper alloys are characterized by a significantly less resistivity and a longer life. However, as a result of their affinity with the copper wire, the last one is significantly abraded by such inserts. Additionally, it must be noted that cost of copper wire is significantly higher in comparison with the cost of inserts.

Therefore, design engineers of such inserts usually recommend a copper-graphite composite as an optimal material for their produce [4]. Such composite has good lubricating properties due to its graphite component. The additions of copper in these materials provide the much higher electrical conductivity in comparison with graphite inserts. To avoid an affinity of these composite inserts with a conducting wire, the copper content in such material is insignificant.

The aim of this work is a study of plasma peculiarities of model electric arc ignited in air atmosphere between C-Cu composite electrodes. Namely, this paper is focused on the experimental investigations of parameters of thermal plasma mixture and calculations of electrical conductivity as well as electron density in discharge column.

2. Experimental investigations

2.1. Arc discharge arrangement

The free burning electric arc was operated in air between the end surfaces of C-Cu composite non-cooled vertically arranged electrodes.

The diameter of the rod electrodes was 6 mm, the discharge gap was 8 mm, arc current was 3.5 or 30 A. To avoid the metal droplet appearing, a pulsing high current mode was used: namely, the rectangular current pulse of 30 A was put on the "duty" low-current (3.5 A) discharge. The high-current pulse duration was of 30 ms.

2.2. Experimental techniques

2.2.1. Temperature measurement

Boltzmann plot techniques was used for plasma temperature determination. The one-pass tomographic recording of the spatial distribution of spectral line intensities was proceeded [6–8]. Copper spectral lines Cu I 510.5, 515.3, 521.8, 570.0 and 578.2 nm were used for plasma diagnostics in this study. Monochromator MDR-12 with 3000-pixels CCD linear image sensor (B/W) Sony ILX526A accomplished fast scanning of spatial distribution of radial intensity. The registration of arc plasma emission was performed at 7 ms after current pulse rise when a steady-state mode of electric arc discharge was realized. Due to the instability of the discharge, statistical averaging

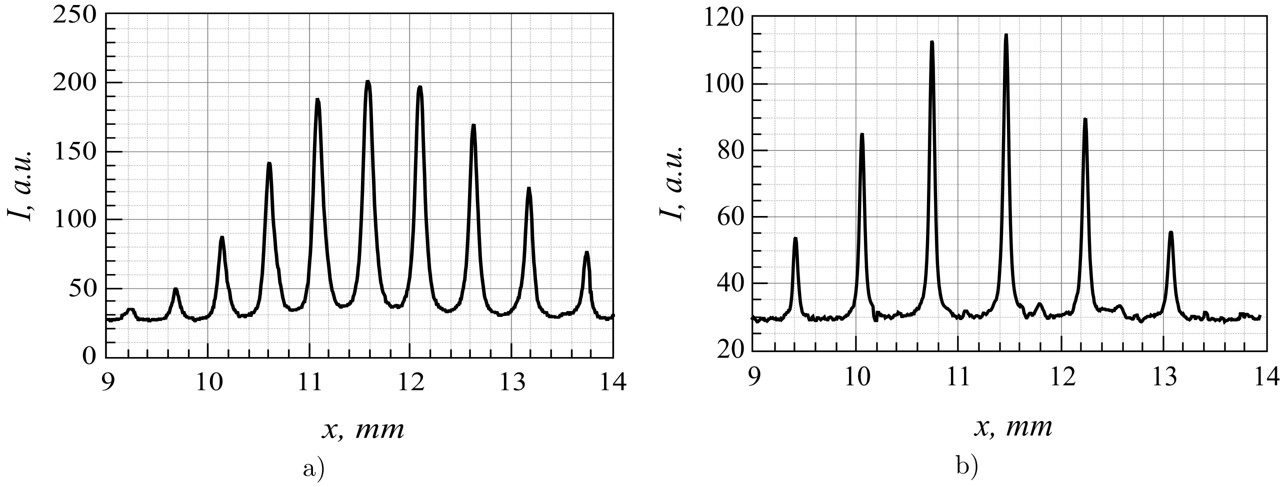


Figure 1. Interferograms of the Cu I 515.3 nm spectral line radiated by plasma of arc discharges of 30 A current between copper (a) and C-Cu (b) electrodes.

of the recorded spatial distributions of the radiation characteristics was carried out.

2.2.2. Electron density measurement

Radial profiles of electron density were obtained from half-width of spectral line Cu I 515.3 nm in assumption of dominating quadratic Stark effect. The spectral device combined with Fabry-Perot interferometer in etalon mode was used for registration of spectral line profiles at 30 A [9].

As it was turned out, such Fabry-Perot interferometer can't be used for half-width measurements at arc of 3.5 A. So, electron density in this case was calculated by algorithm based on previously obtained plasma parameters, namely: temperature distributions for 3.5 and 30 A, electron density for 30 A, intensities ratio of Cu I spectral lines. Comprehensive description of this algorithm is proposed in paper [8].

In addition, the electron density was obtained by solving of the energy balance equation in an arc discharge positive column. The preliminary determination of the temperature radial distribution and electric field strength was carried out [9]. A more detail description of experimental setup and measurement procedure one can find in [10, 11].

3. Results and Discussions

The electron density in the arc discharge plasma by 30 A current between pure copper electrodes was determined from the half-width of the spectral line Cu I 515.3 nm at each local point, which corresponds to the maximum on the interferogram (Fig. 1a). Unfortunately, the electron density in the arc plasma by 30 A current between the copper-graphite electrodes can not be determined in this way, since the width of the spectral line Cu I 515.3 nm is comparable with the instrumental function of the Fabry-Perot interferometer (Fig. 1b).

Therefore, the electron density of arc discharge plasma between C-Cu electrodes of current of 30 and 3.5 A was determined from the electric field strength of the positive column. For this, the energy balance equation was solved using a predetermined plasma temperature distribution, in assumption that the thermal conductivity of the plasma mixture corresponds to the thermal conductivity of the pure air in the given temperature range. The electron density of arc discharge plasma of current of 3.5 A between pure copper electrodes was determined from the ratio of Cu I lines for currents of 3.5 A and 30 A, as it was mentioned above. The results of the electron density determination are shown in Fig. 2.

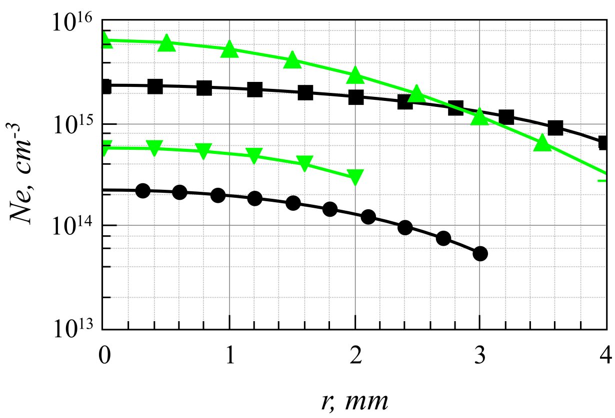


Figure 2. Radial distribution of electron density in arc discharge plasma between copper (3.5 A: "▼"; 30 A: "▲") and C-Cu (3.5 A: "●"; 30 A: "■") electrodes.

It follows from of the electron density distributions, that its absolute value between C-Cu electrodes is less than between pure copper electrodes, but it has less gradient, which suggests a greater width of the discharge column. To test of this assumption, the visualization of arc discharge is performed by CCD camera (1/8000 s) from the same solid angle for each electrodes composition.

From the comparison of figures 3 one can conclude that the increase of the current from 3.5 A to 30 A

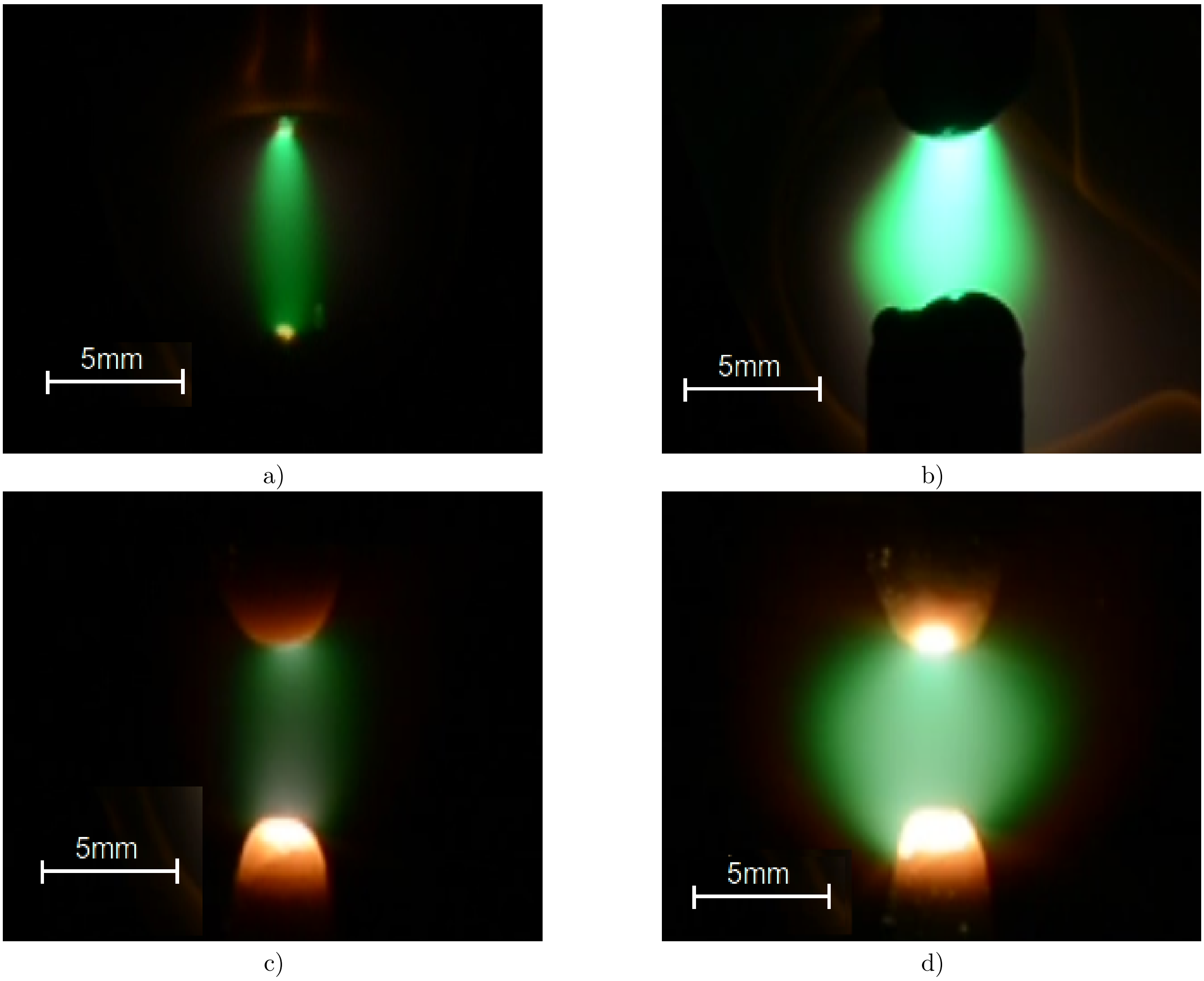


Figure 3. The images of arc discharge channels between copper (3.5 A - (a), 30 A - (b)) and C-Cu (3.5 A - (c), 30 A - (d)) electrodes.

leads to the expansion of the arc channel in the case of copper (Fig. 3a and 3b) and composite C-Cu (Fig. 3c and 3d) electrodes as well. At the same time, the discharge channel between the composite C-Cu electrodes is wider than between of copper electrodes. It must be stressed that this difference is more obviously observed for the current of 30 A (see, Fig. 3b – Cu and 3d – C-Cu). Such behaviour of arc channel is not observed so clearly for the current of 3.5 A.

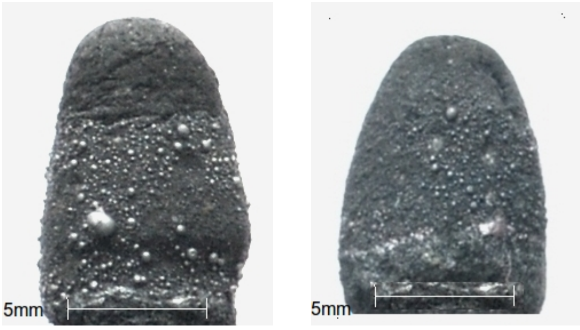
To explain the reason of this phenomenon, namely, the growth of the channel width of discharge between C-Cu electrodes, the working surface of electrodes was carefully analyzed after extinction of the arc discharge (Fig. 4). In the arc impact on composite C-Cu electrodes they much more heated than copper electrodes, because of their relatively low thermal conductivity. Since the sublimation temperature of graphite (4073 K) is much higher than the melting and boiling temperatures of copper (1357 K and 2848 K, respectively), then the superheated copper is percolated through the pores of the graphite matrix. So, the hardened copper droplets are clearly observed on the electrode surface after switch-off of the arc discharge. Therefore, the emission of copper vapor occurs at the discharge operation not only within the narrow molten area the arc spots, as in the case of copper electrodes, but within the much larger surface area of composite electrodes.

Consequently, composite C-Cu electrodes have a much higher effective copper vapor emission area than Cu electrodes, which is the reason of the expansion of the discharge channel of the arc between this type contacts due to the effective thermal ionization of these vapors.

One can conclude, finally, the total arc current in case of composite C-Cu electrodes is provided by the according electrical conductivity of discharge gap because of natural realization of the wider radial profile of electron density of relative low value in comparison with copper electrodes.

4. Conclusions

Plasma peculiarities of model source of electric arc ignited in air atmosphere between C-Cu composite



a) b)

Figure 4. The images of composite C-Cu electrodes treated by arc discharge plasma: (a) - anode, (b) - cathode.

electrodes were studied. The experimental investigations of parameters of thermal plasma mixture and calculations of electrical conductivity as well as electron density in discharge column are carried out.

It was found, that arc channel width of electric arc between C-Cu composite electrodes tends to be wider in comparison with those between one-component copper electrodes. In fact, the experimentally obtained radial profiles of electron density in plasma channel of investigated arc discharges confirm such conclusion.

The additional visualization of discharge gap and electrodes during arcs operation was used to clarify this phenomenon. It turned out, the composite C-Cu electrodes have a much larger effective copper vapor emission area than Cu electrodes. It is the reason of the expansion of the discharge channel of the arc between this type contacts due to the effective thermal ionization of these vapors. So, the total arc current in case of composite C-Cu electrodes is provided by the according electrical conductivity of discharge gap because of natural realization of the wider radial profile of electron density of relative low value in comparison with one-component copper electrodes.

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