Peculiarities of Interaction of Electric Arc Plasma and Composite Electrodes' Working Surface

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The aim of this work is complex investigations of interaction between electric arc discharge plasma and Cu-Mo composite electrodes' working surface. The destructions of working layer of such electrodes, caused by discharge plasma influence, were studied. The mutual correlation of plasma properties and destruction behavior of electrodes surface was found.

Keywords: composite materials, electric arc plasma, switching arcs

1 INTRODUCTION

Composite materials on copper base with addition of high-melting metals, particularly molybdenum, have advanced electric and exploitation characteristics. They have applications as materials for switching devices' contacts [1] and sliding contacts for mine slow-speed railway [2]. Arc discharges appear during operation of these devices and interact with electrodes material, so injection of electrode material into discharge gap has place. In the same time, additions of metal affect the plasma properties, particularly lead to decreasing of plasma temperature.

Therefore, investigations of electric arc plasma between such composite electrodes can be useful for further optimization of materials. It would be very useful as well to examine the peculiarities of electric arc plasma and electrodes' working layer interaction. So, the aim of this work is complex investigations of interaction between electric arc discharge plasma and Cu-Mo composite electrodes' surface.

2 EXPERIMENTAL CONDITIONS AND TECHNIQUES

The arc was ignited in argon flow (6.4 slpm) between the end surfaces of Cu-Mo non-cooled electrodes. The discharge gap was 8 mm, arc current was 3.5 and 30 A. With the aim to avoid the metal droplet appearing, a pulsing high current mode was used: the current pulse 30 A was put on the "duty" low-current (3.5 A) discharge. The high-current pulse duration was 30 ms.

Cu-Mo and Cu-Mo-LaB_6 composite electrodes were fabricated by powder metallurgy, particularly, by copper infiltration of the high-melting component. Ratio of copper and molybdenum contents in these electrodes was nearly 50%:50% (mass). Admixture of lanthanum hexaboride in Cu-Mo-LaB_6 electrodes was less than 1 %.

Another type of Cu-Mo composite electrodes [3], fabricated by electron beam evaporation and following condensation in vacuum, was used too. These electrodes have layered structure, content of molybdenum changes from layer to layer in range 1%-20%; average content of molybdenum was 12%.

Plasma of electric arc discharge between abovementioned different types of Cu-Mo composite electrodes were studied by optical emission spectroscopy. Obtained radial profiles of temperature and electron density [4,5] in middle cross-section of discharge gap were used for calculation of plasma compositions for both electrodes' types in assumption of local thermodynamic equilibrium (LTE).

Plasma of electric arc discharge between composite Cu-Mo electrodes in argon flow contains atoms and ions of copper, molybdenum and argon. Plasma in state of LTE can be described by equations set, which consist of Saha equations for copper, molybdenum and argon, equation of electroneutrality and equation of perfect gas law.

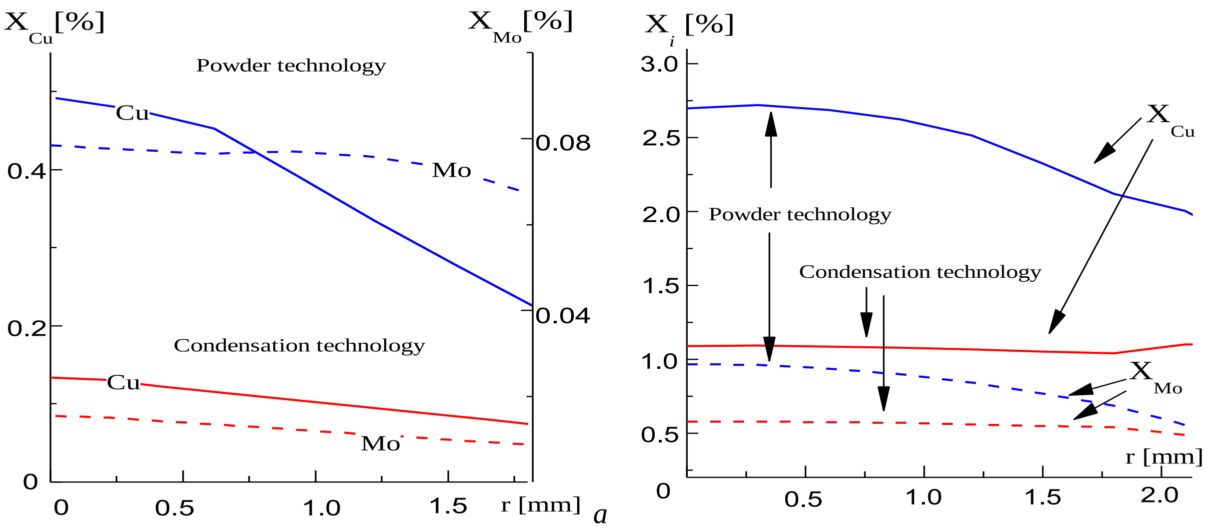


Fig.1: Content of copper and molybdenum in plasma between electrodes fabricated by different technologies at 3,5 (a) and 30 A (b) currents

Additionally, expression for ratio of Cu and Mo atoms' concentrations inside plasma volume were included into equations set. This value can be obtained from ratio of CuI and MoI spectral lines intensities.

3 RESULTS AND DISCUSSIONS

It is reasonable to compare contents of metallic impurities in plasma of electric arc discharge between different electrodes' types. Such content can be evaluated as concentration ratio:

$$X_{Cu} = \left(\frac{n_{Cu} + n_{Cu^+}}{n_{Cu} + n_{Cu^+} + n_{Mo} + n_{Mo^+} + n_{Ar} + n_{Ar^+}} \right) \cdot 100\,\%,$$

$$X_{Mo} = \left(\frac{n_{Mo} + n_{Mo^+}}{n_{Cu} + n_{Cu^+} + n_{Mo} + n_{Mo^+} + n_{Ar} + n_{Ar^+}} \right) \cdot 100\,\%,$$

where n_i are appropriate components concentrations.

One can see (Fig.1) that content of metallic impurity in plasma is two times lower in case of Cu-Mo composite electrodes, fabricated by electron beam evaporation with following condensation in vacuum (condensation technology), in comparison with powder electrodes.

Microscopic investigation of working layer (Fig.2, a) indicates relatively slight destruction of material structure. Rotation of material layers observed only if arc attached to the side zone of working surface (Fig.2, b). Peculiarities of material destruction in this experiment series are close to results obtained in real switching device test (Fig.3, a).

In contrast to previous investigations [6] the layered structure of electrodes were oriented perpendicularly to arc column axis.

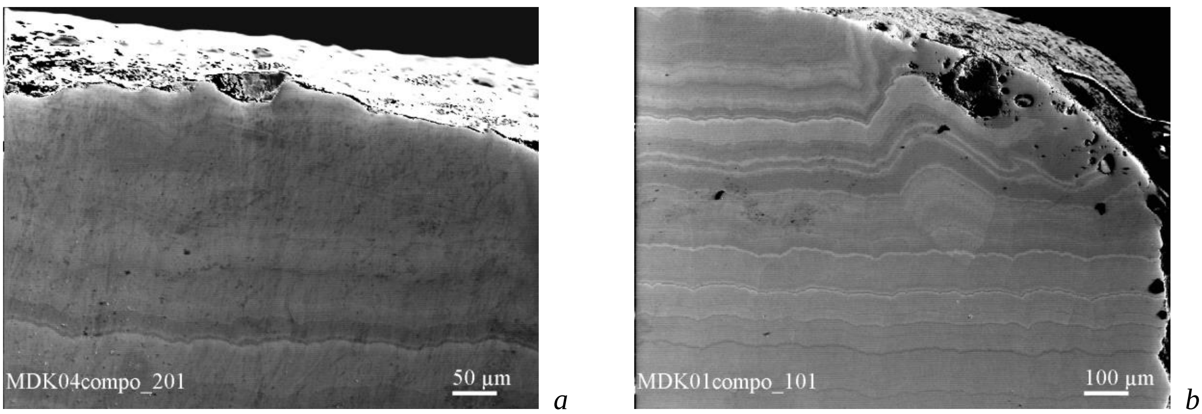
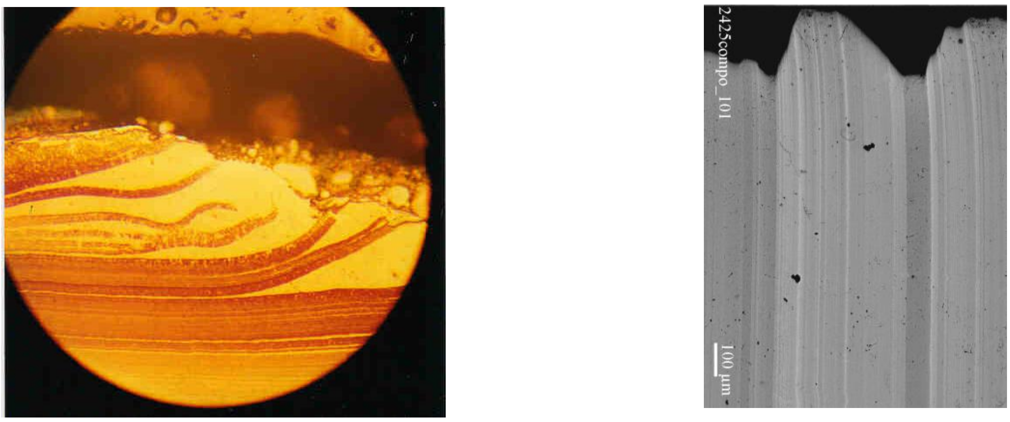


Fig.2: Cross-sections of working layer of Cu-Mo electrodes fabricated by condensation technology



a b

Fig.3: Destruction of layered composite material in real switching device (a) and at longitudinal layer orientation (b) [6]

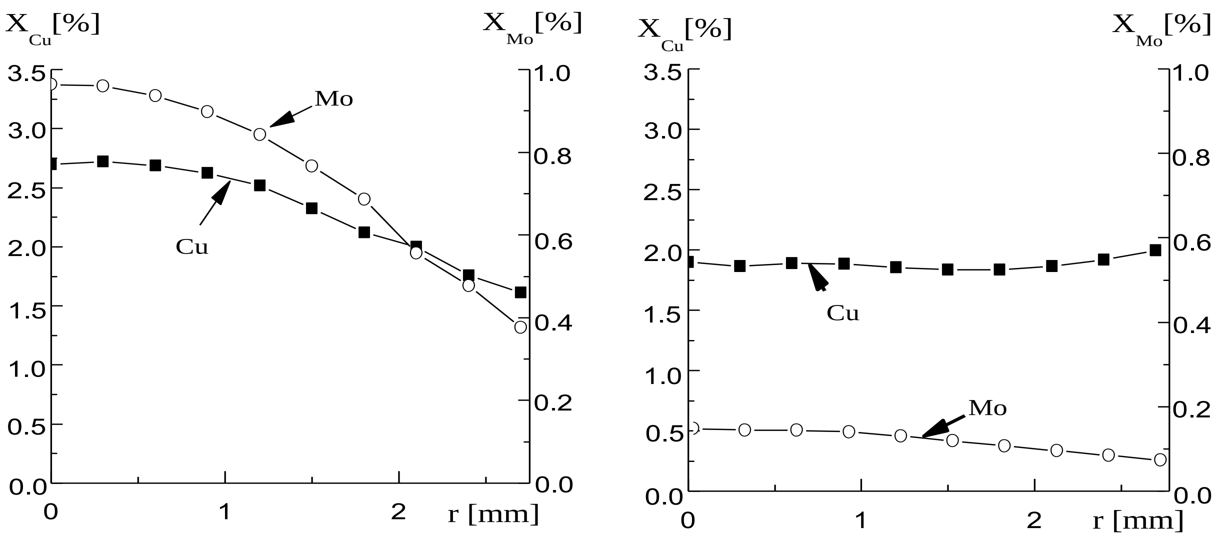
In case of longitudinal orientation of material layers the strong destruction of layers enriched by copper was observed (Fig.3, b).

So, composite Cu-Mo electrodes, fabricated by condensation technology have advanced erosion properties during arcing. In the same time average content of molybdenum in such material was 12% despite 50% in powder Cu-Mo material.

Alternative way for composite materials working properties improvement is addition of lanthanum hexaboride LaB_6. This admixture is widely used as thermionic emitter in vacuum electronics, but its behavior during electric arc discharge is not clear.

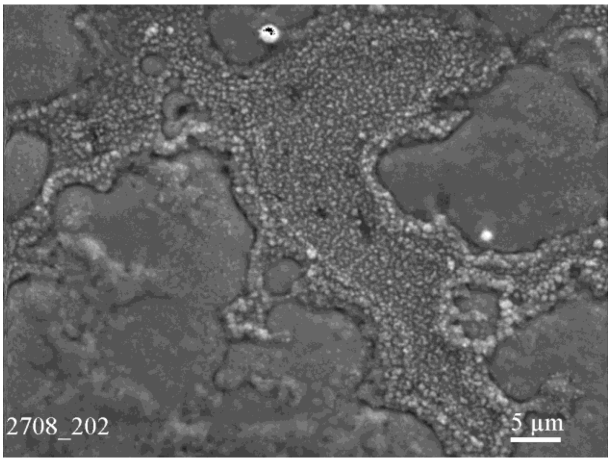
Investigations indicate that addition of ≈ 1% of LaB_6 into composite Cu-Mo material drastically affects processes in plasma and on the electrodes' working surface.

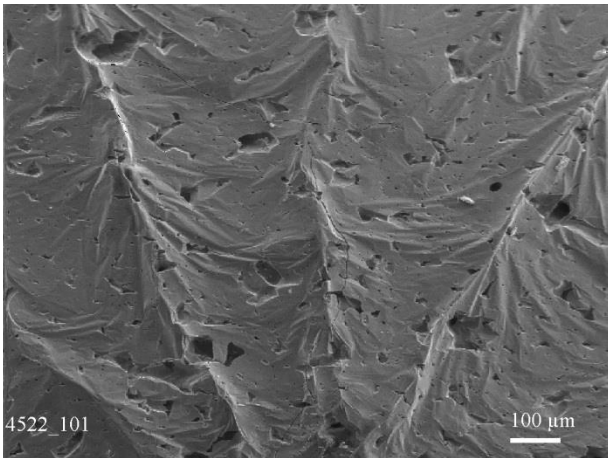
The content of molybdenum impurity in plasma of electric arc discharge (30 A) between Cu-Mo-Lab_6 is significantly lower than for Cu-Mo electrodes (Fig.4). In case Cu-Mo-LaB_6 electrodes, ionization of metallic impurity only can not support conductivity of plasma column. That's why plasma temperature increasing and following significant ionization of argon atoms takes place. So, the plasma temperature at arc axis arise up to 9000 K for Cu-Mo-LaB_6 in comparison with electric arc discharge between Cu-Mo electrodes – 7500 K [5].



a b

Fig.4: Content of copper and molybdenum in plasma between Cu-Mo (a) and Cu-Mo-LaB_6 (b) electrodes at 30 A currents





a *b*

Fig.5: Liquid melt phase on Cu-Mo composite material working surface (a), sintering and tightening of Cu-Mo-LaB_6 composite material working surface (b)

Metallographic investigations indicate significant difference between Cu-Mo and Cu-Mo-LaB_6 working surfaces. Formation of large amount of liquid melt phase was observed at Cu-Mo electrodes surfaces (Fig.5, a). The liquid phase is weakly connected to composite material and easily evaporates during arcing.

The working surface of Cu-Mo-LaB_6 does not contain any peculiarities attributed to liquid phase. In contrast to Cu-Mo electrodes, surface of Cu-Mo-LaB_6 composite material tend to sintering and tightening during arc action. So, investigation of composite material working surface confirm reducing of metallic admixture content in plasma.

4 CONCLUSIONS

The electric arc discharge plasma properties and morphology of electrodes' working surface are strongly depend on composite material fabrication technology and LaB_6 admixture.

The content of metallic impurity in plasma of electric arc discharge between Cu-Mo electrodes, fabricated by electron beam evaporation with following condensation in vacuum is significantly lower than for powder Cu-Mo electrodes. In the same time, destruction of working surface is remarkably depend on orientation of layered structure of material to arc axis.

Addition of lanthanum hexaboride LaB_6 into Cu-Mo electrodes leads to remarkable increasing of electric arc discharge plasma temperature. It can be explained by reducing of metals evaporation, caused by changing of working surface morphology.

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