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Investigation of Electrical Characteristics of High Temperature Ceramic-Metal Contact Assemblages

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There was carried out research work on electrical technical characteristics of contact assemblages made of materials with very diverse linear expansion coefficients (LECs) at temperatures up to 900°C and current loads of long-durations up to 100 hours. Foam nickel was employed as a conductive damping material. After being subjected to long current and heat loads contact junctions between the foam nickel and contact assemblage materials were studied by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis.

Keywords: electrical contact, ceramic, metal.

Introduction

Nickel ferrite-based cermets and SnO_2-based ceramics are perspective materials to be utilised as non-consumable anodes for aluminium production [1]. Such materials possess a high electrical conductivity at electrolysis temperatures (900-1000 °C), sufficient thermal shock resistance as well as rather high chemical resistance to the electrolyte.

One of the problems of the cermet and ceramic materials application is the electrical contact between a metal current carrying rod and the anode bulk since the materials they are made of have diverse linear expansion coefficients (LECs). And usual methods of their connection by heating the contact assemblage can lead to its destruction.

Technologies for the high temperature electrical contact formation between materials having very different LECs are reported in papers [2-5, 7]. There are suggested such discrete conducting media as metal balls, powders and foam metals to be used as dampers. Electrical contact quality and its high temperature stability are determined not only by an extent of interelectrode space filling with a discrete conducting medium but also by an interaction of the medium with electrode materials.

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Electrical characteristics of high temperature coaxial contact assemblages of materials with close LECs are reported in paper [5] where a steel current carrying rod is used as an anode and a cermet of the following composition $NiFe_2O_4$ – 18 %NiO – 17 % Cu as a cathode.

An iron powder was chosen to be the damping conducting medium between the anode and cathode that sintered at high temperature and formed rather good damping and conducting medium, ensuring a stable operation of the contact assemblage at multiple heating and cooling cycles without destruction.

In some cases, however, iron and some other powders sintering at the contact assemblage operation temperature can not be used as high temperature damping media. This takes place when the contact materials have very different LECs or the damping medium material interacts with cathode or anode materials (e.g., iron from a Fe-SnO_2 contact reduces SnO_2 to a non-conductive SnO).

The objectives of the present paper are:

1) the investigation of high temperature electrical characteristics of coaxial contact assemblages where anode LEC was 2 times greater than that of the current carrying rod and foam nickel was used as the conducting damper;
2) the investigation of the contact assemblage stability versus time at long-duration and intensive current loads;
3) the investigation of the damping material interaction with the rod and anode ones.

Experiment

The experimental assembly layout is presented in Fig. 1.

Cylindrical steel current carrying rod 1 was coaxially put into the blind hole of the cathode sleeve 2. The space between the sleeve and rod was filled with foam nickel 3 having porosity PPI 60. The blind hole of the sleeve after being filled with the foam nickel was sealed with a bonding fireproof mastic ZVMK “KOM” 4. The anode material is steel 12X18H10T with a LEC ~$10{\cdot}10^{-6}$ 1/deg. The cathode sleeve was made of conductive ceramics SnO_2 - 1,5 % Sb_2O_3 - 1,5 % CuO*. Its density, porosity and strength were 6200-6460 kg/m^3, 1.8-2.7 %, 445-457 MPa, respectively [6, 7]. The ceramics LEC changed linearly with temperature from 3 to $6{\cdot}10^{-6}$ 1/deg within the range 20-900 ºC [7].

To prevent the interaction between the foam nickel and anode and cathode materials the internal surface of the ceramic sleeve 2 and the rod were covered with silver paste of PP-17C grade.

A direct current between the rod 1 (anode) and cathode sleeve 2 was supplied with a DC source 7 and measured with amperemeter 6. The voltage drop between the rod and sleeve was registered with the microvoltmeter 8. The contact assemblage was situated in a muffle furnace. The measurements were carried out at the current load of 20 A for up to 100 hours at 900 ºC.

After the high temperature experiments had been finished the contact assemblage was crosscut at the right angle to its axis. Contact junctions between the foam nickel and contact assemblage materials were studied by scanning electron microscopy (SEM) and X-ray diffraction (XRD) analysis.

Results and discussion

In Fig. 2 there are presented the results of measuring contact assemblage resistance vs. temperature when heating and vs. waiting time at 900 ºC.

As seen in Fig. 2 there takes place an exponential decrease of the contact assemblage resistance from 4 Ohm to $6{\cdot}10^{-3}$ Ohm at 2 hours heating within the temperature range 200-900 ºC. Then, during 100 h

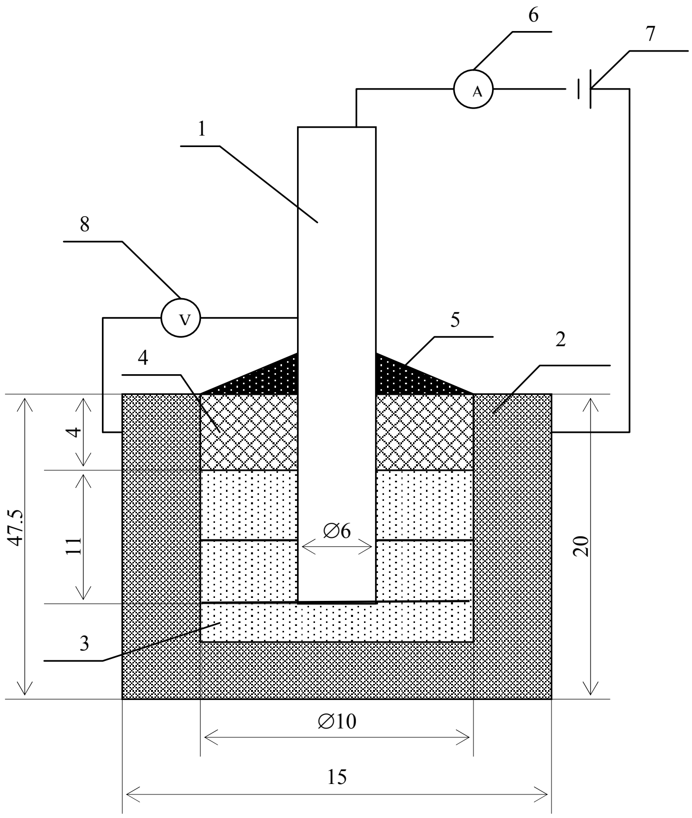


Fig.1. The experimental assembly layout to study electrical technical characteristics of contact assemblages of materials with very different LECs: 1 – cylindrical steel current carrying rod (anode); 2 – blind-holed cathode sleeve of a rectangular cross section; 3 - foam nickel; 4 – air stopper; 5 – high temperature sealing enamel; 6 – amperemeter; 7 - dc source; 8 - microvoltmeter

holding at 900 ºC the contact resistance slightly increases to $8 \cdot 10^{-3}$Ohm. This implies operational stability of the contact assemblage during long-term exposure to high temperatures at simultaneous current load.

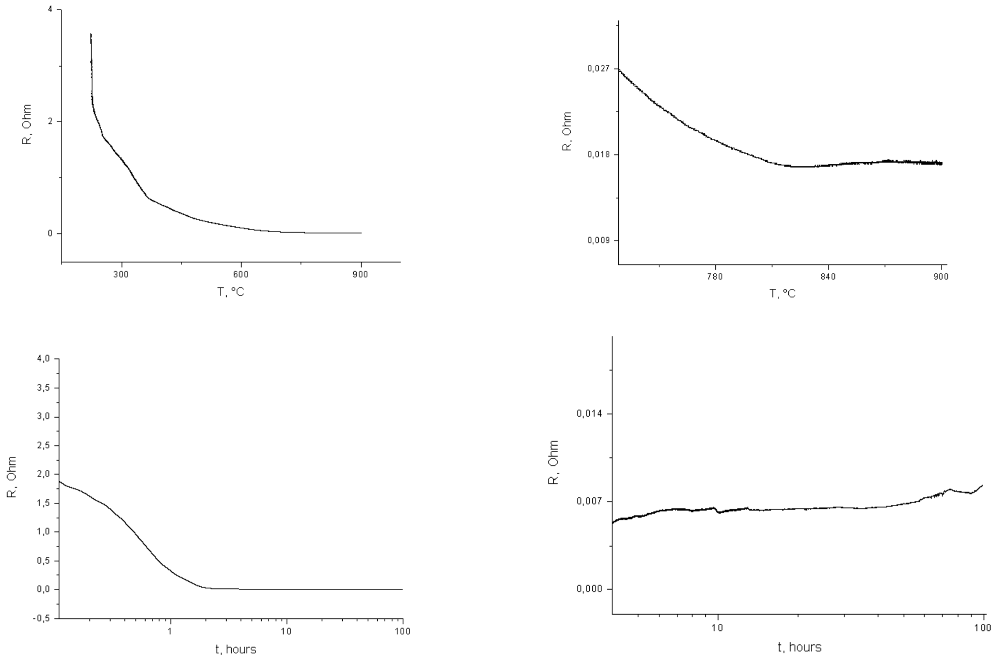
In Fig. 3 there are presented the pictures of the appearance of contact assemblages after 10 and 100h holdings at 900 ºC and 20A load.

As seen in the picture after the 100h experiment the appearance of the contact assemblage has not practically changed. The only change was found in the region of the nichrome rod connection to the current carrying rod (anode) where a significant steel corrosion took place (Fig. 3, pointed to with arrow). Such a great corrosion seems to be caused by an intensive ionic transfer as the result of current load and high temperature.

In Fig. 4 SEM-images of foam nickel – steel anode and foam nickel – ceramic cathode contact interfaces are presented after 100h experiments at 900 ºC.

In Fig. 4 the foam nickel (region A) is practically unchanged in structure. And it formed with the silver paste a transitional heterostructural region B consisting of a foam nickel network (pointed to with arrows in the figure) filled with silver. The region B seems to ensure a stable contact of the foam nickel layer with the steel and ceramics.

SEM and XRD analyses have shown the adjacent regions D and B did not change their chemical composition. On the contrary, the region A contains up to 25 % iron and up to 30 % oxygen. The



(a) (b)

Fig. 2. Results of measuring contact assemblage resistance vs. temperature when heating (a) and vs. holding time at 900 ºC (b)

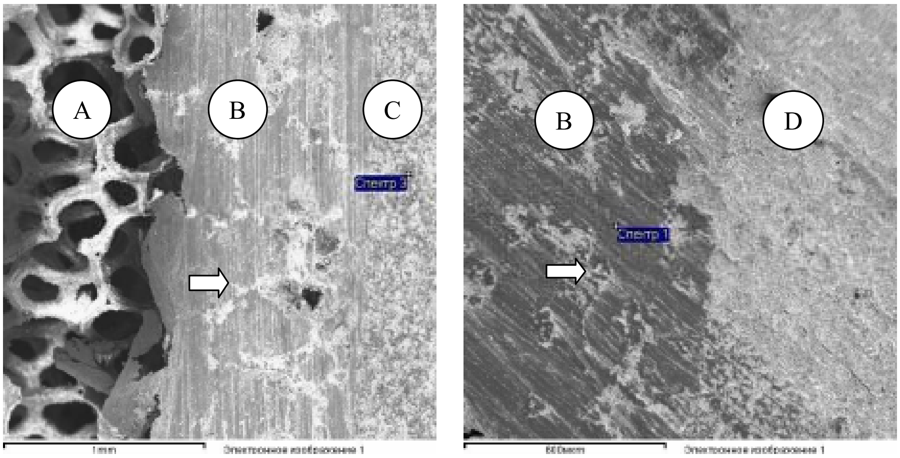
(a) (b)

Fig. 3. The appearance of contact assemblages after 10 (a) and 100h (b) holdings at 900 ºC and 20A load

adjacent region B also contains iron (5 at. %) and oxygen (30 at. %). The region C contains up to 64 at. % oxygen. This implies a strong oxidation of the steel rod surface. The presence of a rather large amount of iron in regions B and C adjacent to the steel rod confirms the ion transfer in the contact assemblage at the current load and high temperature. The phenomenon has to be taken into account when making high temperature contact assemblages.

Conclusions

The research work on high temperature electrical characteristics of coaxial contact assemblages made of steel (anode) and SnO_2-based ceramics (cathode) with foam nickel as conductive damper has shown the following:



(a) (b)

Fig. 4. SEM-images of foam nickel – steel anode and foam nickel – ceramic cathode contact interfaces after 100h experiments at 900 ºC. A – a foam nickel zone; B – a heterostructural foam nickel region filled with silver; C – a region of the steel current carrying rod; D – a ceramic cathode region (SnO_2 - 1,5 % Sb_2O_3 - 1,5 % CuO)

1) the contact assemblage resistance decreases exponentially vs. temperature. And at temperatures up to 600 °C it is determined by the ceramics resistance;

2) operational stability of the assemblages at long-duration intensive current loads at up to 900 °C.

SEM of contact regions has shown that transitional heterostructural foam nickel ones filled with silver form at the foam metal-steel and foam metal-ceramics interfaces. This ensures a good electrical and mechanical contact between materials with very diverse LECs.

In the heterostructural steel-foam nickel region there was found a high concentration of iron which implies an intensive ion transfer between anode and cathode.

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