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Investigation of Electric Characteristics of Contact Assemblages with a Powder Damping Interlayer

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In our work there were investigated thermal electrophysical characteristics of coaxial contact assemblages, made of a steel current carrying rod, steel or cermet sleeve and filled with an iron or nichrome powder. As a result of heating up to 950 ºC the iron powder was shown to be sintered and develop a highly conductive and damping medium that can be used for making contact junctions of materials having very different linear expansion coefficients.

Key words: resistance, contact assemblage, cermet.

Introduction

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

One of the problems of utilizing cermet and ceramic materials as the anodes is the electrical contact between a metal current carrying rod and the anode bulk because materials which they are made of have as a rule different linear expansion coefficients (LECs). Conventional methods of making the contact junction by heating may lead to cracking.

In papers [2-4] different engineering solutions are considered on making high temperature electrical contacts of materials having very diverse linear expansion coefficients. There was suggested to use different discrete conducting mediums such as metal balls, conducting powders and foam metals as compensators of the thermal linear expansion. Quality and high temperature stability of the electric contact greatly depends not only on the degree of interelectrode space filling with the discrete conducting medium, but also on the mutual interaction between the medium and electrode material.

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The aim of our paper is to investigate high temperature electrical characteristics of the contact assemblages with metal powder damper as well as interaction zones between the damping powder and current carrying rod materials.

Experimental

The experimental setup layout is presented in Fig. 1.

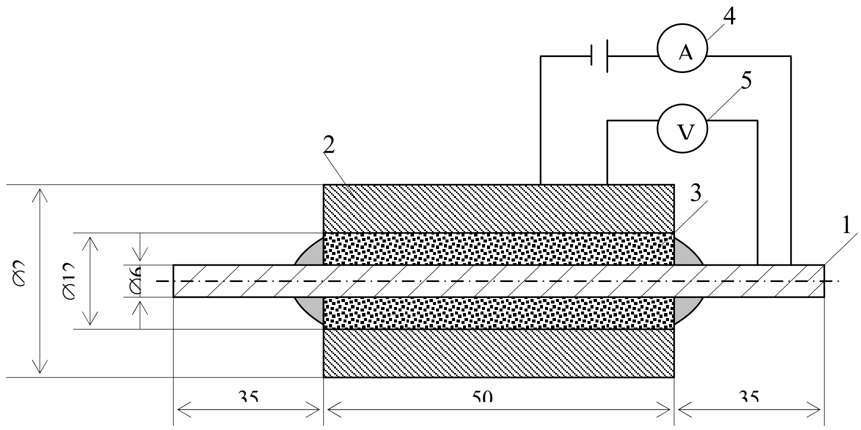


Fig. 1. Experimental setup layout for measuring electric contact properties of materials with very diverse linear expansion coefficients: 1 - cylindrical steel current carrying rod (anode), 2 - cylindrical sleeve (cathode), 3 – iron, nichrome powder, 4 – amperemeter, 5 - microvoltmeter, 6 - sealer. The cylindrical sleeve material is steel, cermet of the composition is $NiFe_2O_4$ – 18%NiO – 17% Cu

Cylindrical steel current carrying rod 1 (anode) was put into the cylindrical steel sleeve 2 (cathode). The space between the sleeve and rod was filled with the iron or nichrome powder. A direct current (DC) between the anode 1 and cathode 2 was applied with a DC source and registered with the amperemeter 4. The voltage drop between them was measured with microvoltmeter 5. The contact assemblage was put into a muffle furnace. Measuring was carried out within a temperature range 20 – 950 ºC.

After the experiments had been finished the contact assemblages were crosscut and contact zones were observed with raster electron microscope.

Results and discussion

The overall contact resistance can be calculated according to the following formula:

$$R = R_1 + R_2 + R_3 , \tag{1}$$

where R_1, R_3 – contact resistances on the rod-medium and medium-sleeve interfaces, respectively, R_2-resistance of the discrete medium layer which in turn can be calculated by the formula:

$$R_2 = \frac{\rho}{2\pi L} \ln \frac{r_1}{r_2} , \tag{2}$$

where ρ – the discrete medium resistivity, r_2, r_1 – external and internal radii of the rod and sleeve, respectively.

Thus, the overall resistance of the contact assemblage can be determined by the following formula:

$$R_1 + R_2 + R_3 = \frac{1}{2\pi L}\left(\frac{1}{\sigma_{R_1} r_1} + \frac{1}{\sigma_{R_3} r_2}\right) + \frac{\rho}{2\pi L}\ln\frac{r_1}{r_2}, \tag{3}$$

where σ_{R1}- a conductivity of the discrete medium-steel contact, σ_{R3} - a conductivity of the discrete medium-sleeve material contact, L- generatrix length of the sleeve.

Conductivities of a contact between the discrete and continuous mediums in a closed volume as well as that of the discrete medium alone depend on a pressure applied to the contact and on an internal pressure inside the medium, respectively. In turn, the both pressures above depend on a degree of the thermal volume change of the material between the sleeve and rod, as well as on the thermal increase degree of a specific volume of the powder.

The volume change between the internal volume of the sleeve and the volume of the rod is determined by the formula:

$$V_2 - V_1 = \pi L \left[r_1^2 - r_2^2 + 2 (T - T_0) \bullet (\alpha_1 r_1^2 - \alpha_2 r_2^2) \right], \tag{4}$$

where α_2 and α_1 – linear expansion coefficients of the rod and sleeve materials, respectively, T – temperature.

From the formula 4 it follows that the discrete medium contraction and therefore the decrease of the contact resistance will take place when $r_2^2/r_1^2 > \alpha_1/\alpha_2$.Otherwise, the discrete medium density will be decreasing with increasing the contact resistance. To the latter there will be proceeding a concurrent process of the volumetric thermal expansion of the medium itself in the confined space which naturally will be leading to increasing the internal pressure and decreasing the resistivity of the medium and contact resistance.

Resistance data of the contact assemblage filled with the iron and nichrome powder versus temperature is presented in Fig. 2. Here the sleeve material was steel.

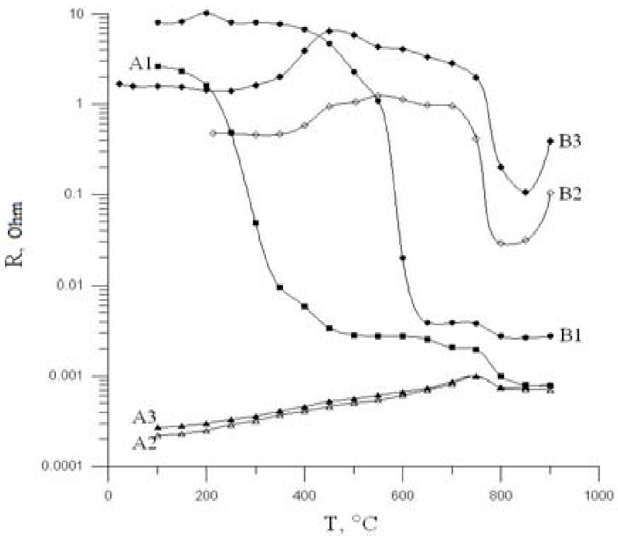


Fig. 2. Resistance data of the steel sleeve contact assemblage filled with the iron (A1- first heating, A2 and A3 – second and third heating) and nichrome powder (B1- first heating, B2 и B3 – second and third heating) versus temperature

As can be seen from the figure the curves can be divided into several parts. Part 1 (up to 250 ºC for Fe powders and 450 ºC for NiCr ones) is characterised with a slight decrease of the resistance that may be associated with a densification of the powder at its thermal expansion. Part 2 (250 - 450 ºC for Fe powders and 450 - 650 ºC for NiCr ones) is characterised with a rapid decrease of the resistance with temperature. Regardless of the volume increase between the rod and internal surface of the sleeve the resistance decrease can be explained with the following reasons:

- further thermal expansion of the powder and increase of the overall contact spot number both between its particles and at the powder-metal interface;
- semiconductor temperature dependence of the oxide film resistance on surfaces of powder particles and current carrying rods.

In case of the assemblage filled with nichrome powder compared to that with the iron powder filling a temperature shift of the beginning of the contact resistance decrease toward a higher temperature region is explained with a higher thermal stability of nichrome oxide films in comparison with those of iron.

Part 3 (450 - 750 ºC for Fe powders and 650 - 900 ºC for NiCr ones) is characterised as a thermal resistance stabilisation that seems to be caused by a deficiency of the internal powder pressure to further increase contact spot areas due to the thermal increase of the internal volume.

For the iron powder there exists one more region at T>750 ºC where the curve has a break and the resistance decreases steadily. This is associated with the beginning of the iron transition from α- to γ-phase.

Further measurements of the iron filler resistance versus temperature (curves A_2 and A_3) exhibited a stable metallic dependence that means sintering of the powder in the assemblage.

As to the nichrome powder at the repeated heating the character of the temperature dependence of the resistance is the same both at first and further treatments (curves B2 and B3). This witnessed to an absence of sintering that was confirmed by the specimen opening.

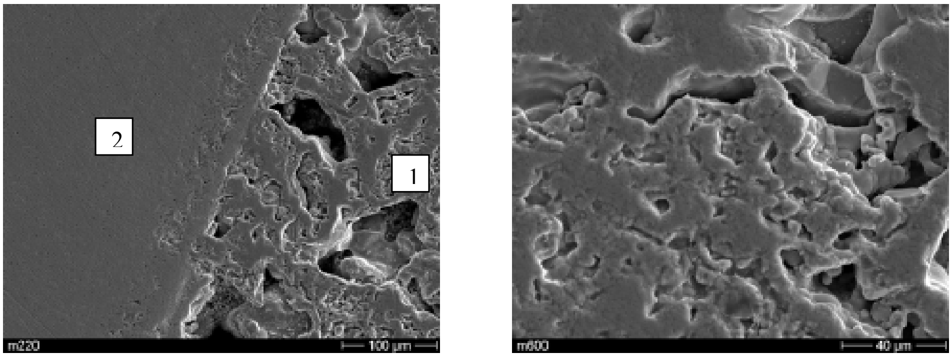
In case of the nichrome powder at repeated heating the feature of the resistance dependence versus temperature is that the initial resistance of the contact assemblage at temperatures up to 550ºC is lower than at first heating. And at higher temperatures it is higher. This can be explained as follows. At cooling after first heating the overall contact spot area in the nichrome powder and at the contact powder-steel interface remains partly unchanged providing hysteresis behaviour of the resistance. The shift of the temperature dependence toward higher temperatures can be caused by the powder being densified enough after first heating. And there are necessary higher temperatures for the pressure to reach a value at which extra contact spots appear.

In Fig. 3 there is presented a SEM image of the contact zone between sintered Fe powder and the central current carrying rod as well as one of the sintered powder region.

As can be seen from the image quite a good contact was created between the sintered Fe powder and the surface of the rod that provides a gradient junction of the solid metal to the damping porous structure.

The porous structure was made as a result of sintering initial Fe particles of several microns in size. There is also seen from Fig. 3 that some corrosion of the rod surface occurred to a depth of 50 μm.

To investigate the interaction of the Fe powder medium with the cermet material at sintering experiments were carried out where as the sleeve material the cermet $NiFe_2O_4$- 18%NiO-17%Cu was



(a) (b)

Fig. 3. a - SEM image of the contact zone between sintered Fe powder (1) and the central current carrying rod (2); b - sintered powder region

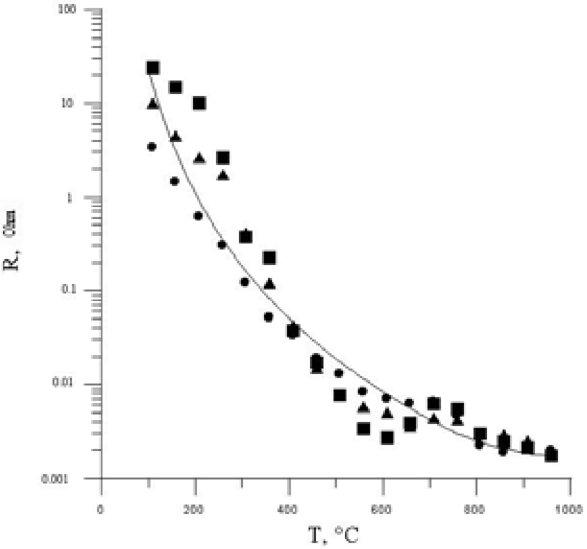
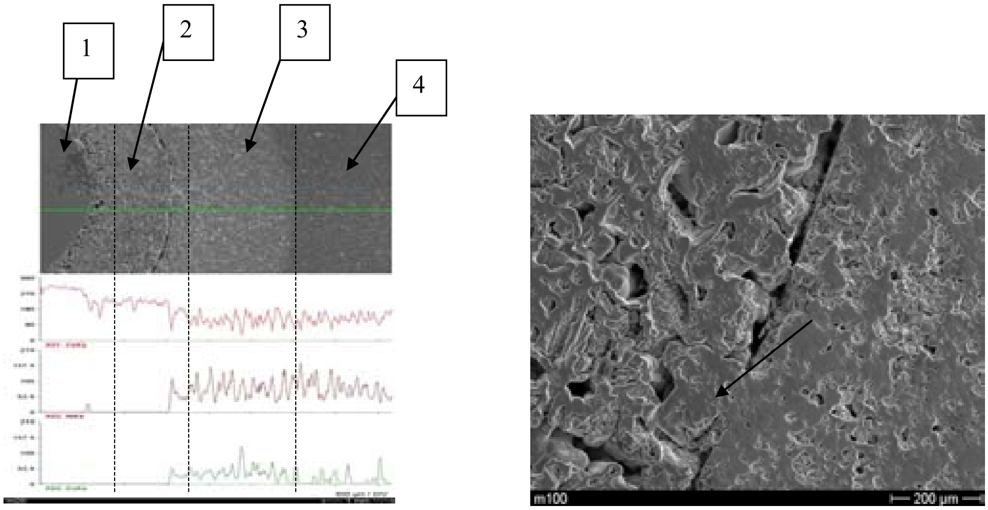


Fig. 4. Temperature dependences of the contact assemblage resistance: 1 – first heating, 2 – second heating, 3 - third heating. The contact assemblage is filled with the Fe powder, the sleeve is made of the cermet $NiFe_2O_4$- 18 % NiO-17 % Cu

used. The linear expansion coefficient of the cermet was $\alpha = 11\text{-}13 \cdot 10^{-6}$ 1/deg, that is, it was equal to the iron's one [5].

Resistance data versus temperature at triple heating and cooling is presented in Fig. 4.

In Fig. 4 the character of the temperature dependence of contact resistance is the same as in case of the Fe sleeve at first heating. Here however the resistance decrease within the temperature range up to 500ºC is associated first of all with decreasing the resistivity of the cermet itself and the contact resistance of the cermet-Fe powder interface. This is confirmed by temperature dependences of the contact assemblage resistance being practically the same both at first and further heat treatments when the Fe powder had sintered. At temperatures higher 600ºC the cermet resistance reaches the value of the sintered powder one that is confirmed with the curve breaks caused by ferromagnetic and α-γ transitions in iron.



(a) (b)

Fig. 5. SEM image of a cross section of the steel rod – Fe powder – cermet contact assemblage (a) and the image of the sintered Fe powder-cermet interface (b). 1 – a region of the rod, 2 – a region of the sintered powder, 3 - transitional cermet zone, 4 - the cermet region

In Fig. 5a there is presented the SEM image of a cross section of the contact assemblage made of the steel current carrying rod, Fe powder and the cermet after the triple heating up to 950 ºC. In Fig. 5a there is also presented the X-ray spectrum analysis data of the element distribution along its radius.

The image of the sintered Fe powder-cermet interface after the triple heat treatment with intermediate coolings is given in Fig. 5b.

In the contact interface image there are areas of the powder that have sintered with the cermet material and also those that haven't. But in spite of triple increase of the internal volume during heating leading to tension cracks were found neither in the sintered powder nor in the cermet. This is evidenced a rather good damping ability of the sintered Fe powder. Moreover a brighter region 3 was found at the sintered Fe powder–cermet interface. It doesn't differ in elemental composition from the cermet itself.

Conclusions

In our work there were investigated thermal electrophysical characteristics of coaxial contact assemblages, made of a steel current carrying rod, steel or cermet sleeve and filled with an iron or nichrome powder. As a result of heating up to 950 ºC the iron powder in the contact assemblage was shown to be sintered and develop a highly conductive and damping medium that can be used for making high temperature and conductivity contact junctions of materials having very different linear expansion coefficients.

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