THE ELECTRICAL RESISTIVITY OF ALUMINUM OXIDE APPLIED TO A BACKING BY PLASMA AND GAS-FLAME DEPOSITION

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We present the results from experimental investigations of the determination of the electrical resistivity of aluminum oxide applied to a backing by plasma and gas-flame deposition, with the resistivity a function of the backing material.

The use of aluminum oxide applied by plasma and gas-flame deposition onto a backing as insulation in coaxial or plane systems has gained widespread acceptance in the electrical engineering industry. The structure of the oxide produced by the deposition differs substantially from the baked oxide, exhibiting an α modification, and it is made up of a mixture of corundum and alumina (the γ modification) with predominance of the latter (as high as 80-90%). As is well known [1], to obtain pure corundum the oxide has to be heated to high temperatures (1200-1400°C) under specific conditions, but since certain backing materials exhibit a lower melting point (copper, steel) it is difficult to produce pure corundum.

We tested the electrical resistivity of Al_2O_3 insulation applied by plasma and gas-flame deposition for various thicknesses of the deposited layer, as well as for various metal backings: copper, steel (St. 20 and Kh18N10T in addition to niobium.

Reagent-grade anhydrous aluminum oxide powder with a granulation 20-100 μm is used in the plasma and gas-flame deposition. The equipment and deposition regimes are the following:

a) gas-flame deposition, UPN-5-61 units: 1) the working pressure for the oxygen ahead of the injector is 5.5 kg/cm^2; 2) the oxygen pressure for the power feed is 0.3 kg/cm^2; 3) the overall oxygen flow rate is 5000 liters/h; 4) the acetylene working pressure is 0.4 kg/cm^2; 5) the acetylene flow rate is 1500 liters /h); 6) the compressed-air flow rate (for $P = 3$ kg/cm^2) is 0.4 m^3/min; 7) the distance from the gun (burner) to the coated surface is 250 mm;

b) plasma deposition, UPU-2M unit, GN-5R burner: 1) power-circuit current, 420 A; 2) operating voltage, 65 V; 3) working gas pressure, 3.5 kg/cm^2; 4) working gas flow rate in mixture: argon, 70 liters /min; hydrogen, 4.5 liters/min; 5) argon flow rate for power feed, 7.5 liters/min; 6) distance from burner to coated surface, 200 mm.

The specimen was prepared in the following manner: a layer of the test aluminum oxide is applied to a metallic tubular backing, and this coating is then machined (polished) to the required dimensions, subsequently covered with a metal layer (also by deposition), into which electrodes are inserted (wires 0.5 mm in size) to measure the electrical resistance, and thermocouples were attached. A second pair of electrodes were spot-welded to the backing.

The electrical resistance was measured with an EK6.7 tetraohmeter for resistances above $10^7\ \Omega$, and with a megohmmeter for resistances that were lower.

The temperatures were measured with the Chromel–Alumel thermocouples mounted in the deposited metal layer. The emf of the thermocouples was measured with a dc R330 potentiometer. Tubular heaters made of refractory metal were used to heat the specimens, and the heaters were insulated from the specimen by means of 22 DhS ceramic rings.

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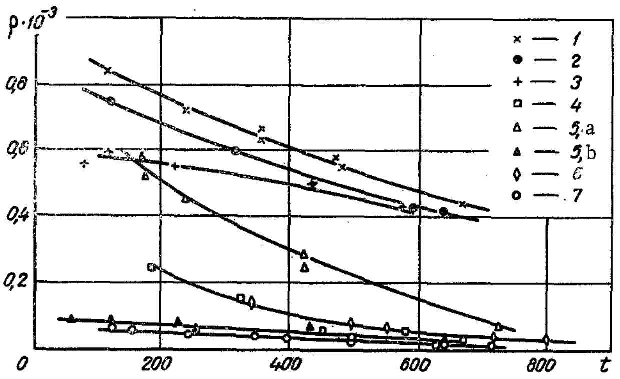

Fig. 1. Electrical resistivity (Ω . cm) for various Al_2O_3 thicknesses, the aluminum oxide applied to the backing by plasma and gas-flame deposition: 1) niobium backing, 1.3 mm thick; 2) the same, with a thickness of 0.87 mm; 3) the same, with a thickness of 0.8 mm; 4) the same, 0.5 mm in thickness; 5a) copper backing with a deposition thickness of 0.3-0.32 mm for the Al_2O_3; initial data (gas-flame deposition); 5b) the same, after a stay time of 100 h at a temperature of 750°C (gas-flame deposition); 6) backing made of Kh18N10T steel at a thickness of 0.27-0.28 mm (gas-flame deposition); 7) backing of St. 20 steel at a deposition thickness of 0.2 mm (gas-flame deposition).

The experiments were carried out in a cooled vacuum chamber evacuated to 10^{-4}-10^{-5} mm Hg, with a capacity of about 70 liters; the thermocouples and electrode leads from the chamber passed through windows insulated from the chamber by means of Textolite and rubber rings to provide for hermetic sealing.

The measurement accuracy ranged from 3 to 6%, depending on the thickness of the deposited layer.

Figure 1 (curves 1-4) shows the electrical resistivity as a function of temperature for various thicknesses of layers applied by plasma deposition onto a niobium backing. The characteristic feature of these tests is the rise in the electrical resistance with an increase in the thickness of the installation layer, but only up to certain thicknesses, beyond which there is a substantially slower increase in ρ. Thus, for example, from a thickness of 0.8 to 1.5 mm the electrical resistivity increases only slightly. We note that a thermocouple was imbedded into a layer with a thickness of 0.5 mm, and this had the effect of reducing ρ (curve 4), with the wire diameter of the thermocouple 0.2 mm. The figure (curves 5a and 5b) shows the results from the measurements of the electrical resistance of the aluminum oxide, applied by gas-flame deposition to a copper backing (the thickness of the deposited layer is 0.32 mm). The investigations were carried out for various temperatures, and for various durations. It is interesting to note that with an increase in the test time, there is a constant but slow change in the electrical resistance. Microstructural analyses demonstrated that the copper diffused into the aluminum oxide layer. The separation boundary formed a wavy line with peaks in the direction of the aluminum oxide. In addition, in the preparation of the specimen we noted separation of the aluminum oxide from the copper backing, together with the copper "crust" on the "peeling" surface. The copper penetrated to a depth of 20-30 μm.

Figure 1 (curves 6 and 7) shows the results for experiments with aluminum oxide applied by gas-flame deposition to a backing of Kh18N10T steel (curve 6), with the thickness of the deposited layer 0.27-0.28 mm, and a backing of St. 20 steel (curve 7), the thickness of the deposited layer in this case 0.2 mm.

We noted separation of the Al_2O_3 from the backing of St. 20 steel in the preparation of the specimens (maximum backing heating, 800°C), and the Kh18N10T steel separated at temperatures of 950-1000°C. The separation of the aluminum oxide from the backings can be explained by the substantial difference in the thermal coefficients of linear expansion for the materials of the backing and for the deposited aluminum oxide.

It should be stressed that the electrical resistances were measured after the specimens were kept in a vacuum at temperatures from 800 to 1100°C, depending on the type of backing.

The tests therefore demonstrated the following:

1. The magnitude of the electrical resistivity for deposited aluminum oxide depends strongly on the thickness of the layer. It can be assumed that this is a consequence of the penetration of metal particles from the original material into the deposited layer; the penetration of metal particles into the deposited layer as a consequence of emission and erosion removal in the burner; as a consequence of metal-particle diffusion during the heating process, particularly when the particle size is commensurate with the thickness of the deposited layer.

2. The electrical resistivity was markedly affected by the material of the backing.

The backing material is selected on the basis of the thermal expansion and the diffusion properties of the backing, the range of temperatures within which the system will operate, the ambient medium, etc.

For example, the use of a copper backing at temperatures in excess of 700°C will cause the copper to diffuse into a layer of Al_2O_3, and this will result in a constant reduction in the electrical resistivity. In addition, copper and steel backings exhibit α_t (the coefficient of thermal expansion) that are substantially greater than for Al_2O_3 [2], which at certain temperatures leads to separation of the deposited layer from the backing. Thus, in the case of Kh18N10T steel the deposited aluminum oxide layer separates from the backing at t $\simeq$ 1000°C and higher (the thickness of the layer is less than 0.5 mm).

LITERATURE CITED

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