ANISOTROPY OF THE ELECTRICAL CONDUCTIVITY AND MECHANICAL PROPERTIES OF EXTRUDED ALUMINUM ALLOYS

N. M. Naumov, P. G. Miklyaev, and I. I. Novikov

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The anisotropy of the electrical conductivity of extruded semifinished products of aluminum alloys is of interest due to the anisotropy of the mechanical properties and the relationship between the mechanical properties and the electrical conductivity [1].

We investigated rods 22 mm in diameter of Al–Cu, Al–Mg, Al–Zn, and Al–Mn alloys (92% deformation, extruded at 400°C), rods 22 mm in diameter and strips with a section of 40 × 350 mm of alloys D16, V95, and AD31 (94% deformation and 84 and 98% in separate cases, extruded at 450, 400, and 500°C respectively).

The anisotropy was calculated from the difference between the maximum and minimum values of the properties in different directions in relation to the minimal value and expressed as per cent. The electrical conductivity was measured by the eddy current method with a galvanometer connected to the electrical conductivity pickup. The sensitivity of the method is 0.01 mΩ·mm², i.e., around 0.05%. The surface of the samples on which the sensor was placed had a finish of at least grade V7; the strain hardened surface layer was removed by etching. It was calculated that with the sensor placed on the plane normal or parallel to the extrusion direction the electrical conductivity of the part was determined respectively in the longitudinal (l) and transverse (t) directions. Thus, if the electrical conductivity γ in the longitudinal direction amounts to 19.5 mΩ·mm² and 20 mΩ·mm² in the transverse direction then the anisotropy of the conductivity

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A_{t(l)} = \frac{20-19.5}{19.5} \times 100 = 2.6\%.
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The mechanical properties were determined in tension on rods of alloys D16, V95, and AD31. Miniature samples with reduced sections 1.5 and 10 mm in diameter and length respectively were tested.

The anisotropy of the electrical conductivity of freshly quenched (from 500°C) rods of the binary alloys was 1.3% (Al + 0.72% Mn), 1.3% (Al + 4.23% Cu), 0.7% (Al + 1.56% Mg), and around 0.5% (Al + 6.3% Zn).

In the first two alloys with a large anisotropy of the electrical conductivity the fibrous structure was the most pronounced (examined in an optical microscope) and also the texture (observed by means of x-ray analysis).

In the process of zone aging at 20°C an increase in the anisotropy of the electrical conductivity by 0.6% was observed only for Al + 4.23% Cu among the binary alloys.

The anisotropy of the electrical conductivity of alloys V95, D16, and AD31 in the freshly quenched condition (after quenching from the optimal temperature) amounted to 2.3, 1.9, and 0.5% respectively. None of the alloys was recrystallized and all had a deformation texture. The structure was most fibrous in alloy V95 and least fibrous in alloy AD31. Recrystallization of alloy D16 after heating at 500°C for 20 days led to disappearance of the fibrous structure and texture (Fig. 1), and the anisotropy of the electrical conductivity was eliminated.

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Fig. 1. Microstructure and x-ray patterns of unrecrystallized (a) and recrystallized (b) rods of alloy D16 (x300).

Fig. 2. Variation of the anisotropies of electrical conductivity $A_\gamma(t - t)$, ultimate strength $A_{ob}(l - t)$, and elongation $A_\delta(l - t)$ with natural aging time for rods of alloys D16 (1), V95 (2), and AD31 (3).

Zone aging of unrecrystallized rods with a fibrous structure at room temperature increases the anisotropy of the electrical conductivity and improves the mechanical properties (Fig. 2). The anisotropy of the electrical conductivity for alloy D16 with disc-shaped zones and alloy AD31 with needle-shaped zones was larger than for alloy V95 with spherical GP zones [2].

No anisotropy of the electrical conductivity was noted in recrystallized rods of alloy D16 after quenching. Aging at room temperature of recrystallized alloy AD31 with negligible anisotropy of the electrical conductivity due to the slight fibrousness of the structure increases the anisotropy of the electrical conductivity by 0.6%. With a distinct deformation texture, needle-shaped zones are formed in the extrusion direction within the grains, as the result of which the anisotropy of electrical conductivity of the texturized alloy increases by 2.4%.

Rods of alloy D16 extruded with 98% deformation are more fibrous than rods with 84% deformation. The anisotropy of the electrical conductivity of such rods in the freshly quenched condition amounted to 2.1 and 1.7% respectively, and increased by 1.9 and 1.6% respectively after natural aging, which indicates that the anisotropy of the electrical conductivity varies with the structure and with the direction of GP zones. In alloy V95 with spherical GP zones natural aging of rods extruded with 84 and 98% deformation increased the anisotropy of the electrical conductivity by 0.6% in both cases.

Intensive phase aging of alloy D16 (100 h at 250°C), during which stringers of the second phase are formed, causes an increase in the anisotropy of the electrical conductivity by 0.2% as compared with the freshly quenched condition. Thus, the anisotropy of the electrical conductivity of alloy D16 in the unrecrystallized condition increased by 1.9% because of the fibrousness of the structure, by 1.8% because of the directional GP zones, and by 0.2% due to stringers of the second phase.

The anisotropy of the mechanical properties is larger and of the opposite sign, although it depends on the same factors as the anisotropy of the electrical conductivity. This explains the correlation between the anisotropy of the electrical conductivity and the anisotropy of the ultimate strength for parts of the same