SOME FEATURES OF THE CAST STRUCTURE OF ALLOYS OF THE Al–Sc SYSTEM

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Recently considerable attention has been devoted to studying aluminum alloys containing scandium: introduction of small amounts of scandium into aluminum and its alloys promotes a marked improvement in their strength. Strengthening of Al–Sc alloys is connected with precipitation from a solid solution of scandium in aluminum of fine particles of Al₃Sc phase. A high decomposition rate is typical for this solid solution which even affects the cast structure and consequently alloy properties. This article considers features of the cast structure of alloy Al–0.4% Sc–0.01% Fe–0.01% Si.

The favorable effect of small additions of scandium on the properties of aluminum and aluminum alloys was first established by the American researcher Bailey [1]. In 1973 a systematic study started into the nature of the reaction of scandium with aluminum and its effect on the structure and properties of aluminum alloys in our country. It has been shown [2] that scandium forms a eutectic-type diagram with aluminum with a limiting solubility of about 0.4% in the solid state with a eutectic transformation temperature of 655°C. The solubility of scandium in aluminum falls sharply with a reduction in temperature. These results were later confirmed by Japanese researchers [3].

Scandium is inclined to form anomalous supersaturated solid solutions in aluminum during solidification [4]. With subsequent heating the solid solution of scandium in aluminum breaks down with formation of particles of a stable phase Al₃Sc with a cubic structure L1₂. The lattice parameter of the Al₃Sc phase is close to that of aluminum (size nonconformity factor 0.012) as a result of which in the matrix there is ready homogeneous generation of its dispersed particles. With subsequent growth of these particles they retain their coherence with the matrix for a long time. The increase in strength of semifinished products of alloys containing scandium is due both to the strengthening effect of Al₃Sc particles and retention in semifinished products of a stable polygonized structure. The kinetics of this process are studied in [5] by plotting C-shaped curves for the breakdown of a solid solution of scandium in an aluminum ingot. It is shown that a solid solution of scandium in aluminum is much less stable than solid solutions based on aluminum with transition metals such as manganese, chromium, and zirconium. The high decomposition rate for the solid solution of scandium in aluminum is caused by presence of a number of features of the cast granular structure of Al–Sc alloys.

A casting 134 mm in diameter of Al–0.4% Sc–0.01% Fe–0.01% Si alloy was prepared by continuous casting. The structure of the casting was studied by metallographic, electron microprobe, and electron microscope analyses, and also by measuring microhardness. Microsections were electropolished in chloride-acetic electrolyte, etched in Keller's reagent, in 0.5% HF, or stained in 1.8% fluoroboric acid solution. Metallographic analysis was performed in Neophot-2, PMT-3, and Cameca MS-46 instruments, and electron microscope studies were performed on foils prepared by electropolishing in ethanolic chloride electrolyte in a Tesla BS-540 microscope with an accelerating voltage of 120 kV.

The use of electropolishing and various etching reagents made it possible to reveal some structural features of the ingot. Two forms of grains were revealed in the ingot microstructure (Fig. 1a, b): coarse light and fine grains with a well-
differentiated internal structure arranged along boundaries or within large grains. There are often excess phase particles at the center of fine grains (volume fraction ~15%) which are within coarse grains.

A study of ingot structure in polarized light (Fig. 1c) showed that fine grains differ in color from coarse grains (matrix). This indicates different crystallographic orientation and also that there is a large-angle boundary separating them.

The microhardness of fine grains (Fig. 1d) is 4 N higher on average than for coarse grains (the average microhardness for coarse grains from the results of fifteen measurements is 35 N, and for fine grains it is 39 N). After aging at 350°C for 17 min the microhardness for coarse grains is 91 N, and for fine grains it is 68 N.

X-ray microanalysis established that the scandium content of fine grains is higher than for coarse grains (Fig. 2). Particles of excess phases are at the center of fine grains enriched in scandium and they are apparently Al₃Sc phase.

Electron microscope study of foils prepared from an ingot showed that fine grains contain extended particles with a fan-shaped arrangement of excess phases (Fig. 1e). These precipitates are not detected in coarse grains. Diffraction analysis of particles showed that they have a cubic structure L₁₂ and correspond in parameters to stable Al₃Sc phase (Fig. 1f).

Solid solution decomposition similar in nature was observed by Blake and Hopkins [6] and evaluated as discontinuous. The features of discontinuous solid solution decomposition involve the following [7, 8]. With continuous decomposition the concentration of supersaturated solid solution gradually decreases from the original to equilibrium simultaneously throughout the whole volume of the alloy. With discontinuous decomposition local areas form in the alloy structure with equilibrium (or intermediate) solution concentration for a given temperature separated from the original supersaturated solid solution by a high-angle boundary. During discontinuous solution decomposition the proportion of areas with an equilibrium concentration increases, and with the original concentration it decreases. This occurs as a result of the advance of high-angle boundaries; solid solution concentration changes jumpwise from the original to equilibrium. This process is outwardly similar to primary recrystallization. Discontinuous decomposition commences at the original high-angle boundaries or particles of excess phases in areas with a high solution concentration (with maximum supersaturation). Excess phases with discontinuous decomposition precipitate in the form of extended plates or rods.

Consequently, fine grains (see Fig. 1) are regions of discontinuous decomposition of a solid solution of scandium in aluminum which occurs on cooling an ingot from the casting temperature. Considering the very high rate of decomposition for a solid solution of scandium in aluminum and its low stability the possibility of this process occurring is not in question [5].