STRUCTURAL CHANGES IN INGOTS OF ALUMINUM ALLOYS DURING HOMOGENIZATION

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Numerous studies of the processes accompanying homogenizing annealing of ingots of alloys AK6, AK8, AK4-1, AMG6, V95, D16, and AD31 have revealed the basic principles governing the workability of the alloys during subsequent extrusion and the level of the properties.

The ingots generally have a cellular structure. In small ingots the cells of dendrites are free of secondary precipitation products after casting, while finely dispersed decomposition products of the supersaturated solid solution of manganese and iron in aluminum are observed in the peripheral areas of cells in large ingots. The concentration of most components increases from the center to the edge of the cells. During preparation of microsections one observes monolithic stringers between cells of dendrites surrounded by distinct boundaries on both sides (Fig. 1a). In cellular stringers there are inclusions of soluble and insoluble phase components, gas bubbles and shrinkage cavities, oxide films, etc. (Fig. 1). Decomposition products are almost never precipitated from the solid solution in the stringers during homogenization, and therefore it can be assumed that the composition is near equilibrium.

Different processes may occur in aluminum alloys during homogenization of ingots, depending on the composition and the melting and casting procedures.

Solution of Phase Components in Stringers with Subsequent Transfer of Alloying Components into the Cells. As the ingots cool from homogenization temperature, the phase components are precipitated as needles and platelets throughout the bulk of the dendrites. The particle size of these precipitates increases toward the center of the cells as the bulk of the cells increases, as the concentration of alloying components in the alloy decreases, and as the cooling rate after homogenization decreases.

The solution rate of the phase components in the process of homogenizing heat-treatable alloys is determined from the change in the ultimate tensile strength of samples quenched from homogenization temperatures [1]. The solution rate varies with the composition of the alloy, the homogenization temperature, and the nature and size of the phase components. With decreasing crystallization rates and increasing diameter of the ingots, the time to complete solution of the phase increases because of the larger particle size of the primary precipitates. Metallographic analysis indicates that the phases dissolve within 6, 8, and 12 h, at 500° in AMG6 ingots with diameters of 127, 367, and 500 mm, respectively.

Alloys AD31 and V93 are well suited for studying the solution processes during homogenization, since they contain only soluble alloying elements. Solution of the phases in ingots of alloy AD31 at 560-570°C is completed in 1-3 h, depending on the diameter, and in 3-12 h at 460-480° for alloy V93. Iron impurities have a negative effect on the combination of properties of these alloys. Iron forms a supersaturated solid solution during crystallization and results in finely dispersed decomposition products, which lead to reduced workability of the ingots during deformation [2] and laminations in semifinished products.

The effect of the homogenizing conditions, including the cooling rate, on the technological and mechanical properties was reported in [3]. The reliability of these data was confirmed in the development of the manufacturing technique for sections of alloy AD31 quenched in a press providing rapid cooling of ingots from the homogenization temperature in special chambers with air cooling, which promotes more complete solution of the precipitated phase in the center of deformation during extrusion, improves the surface quality [4], and increases the anticorrosion characteristics of the sections.

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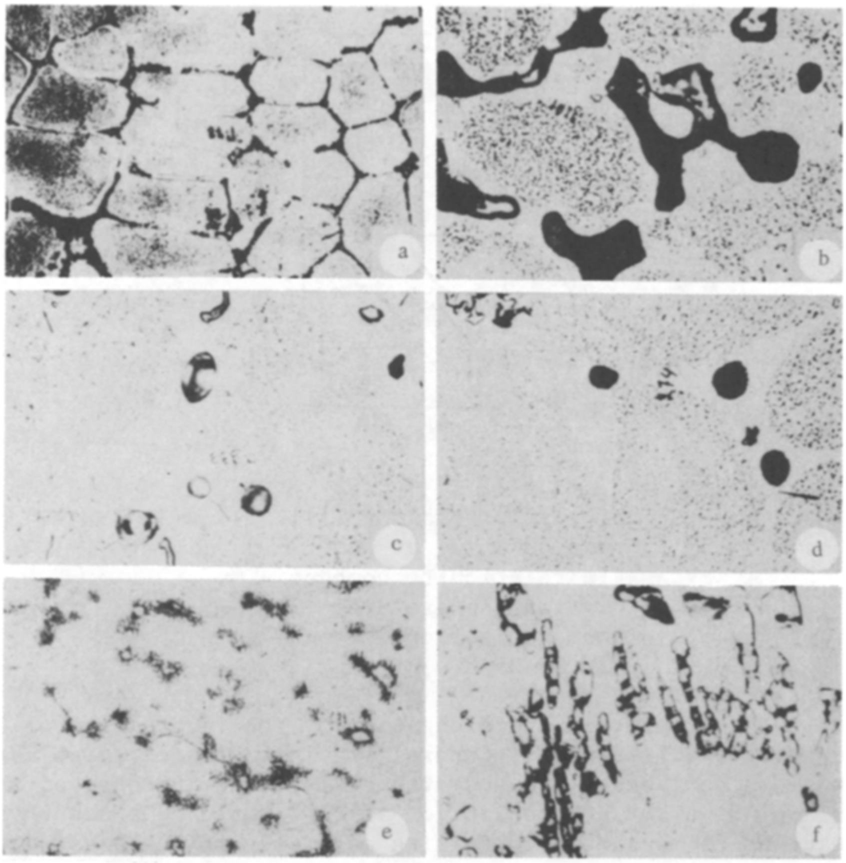

Fig. 1. Microstructure of aluminum alloys AK6 (a, d) and AMG6 (b, c, e, f) in relation to homogenization conditions: a) not homogenized; b) homogenization at 500° for 6 h; c, d) 520° for 6 h; e) 300° for 24 h; f) 560° for 24 h.

Decomposition of the Supersaturated Solid Solution of Manganese and Iron in Aluminum with Coalescence of the Decomposition Products. In continuous casting of aluminum alloys the supersaturation with manganese and iron of peripheral areas of cells and dendrites may be several times higher than the average concentration in the alloy [5]. In the process of homogenization the supersaturated solid solution decomposes, the extent depending on the homogenization conditions and also on the type of alloy and concentration of alloying elements. The rate of decomposition and coalescence of precipitation products is 50-100% higher in alloy AMG6 than in alloys AK6, D16, and V95 (Figs. 1c, d), evidently due to the larger lattice constant of the solid solution in the presence of manganese, the diameter of which is much larger than that of aluminum and the other alloying elements.

Decomposition of the supersaturated solid solution of manganese in aluminum begins at 200-300° in Al—Mg alloys. Precipitation occurs primarily around phases (Fig. 1e). In other aluminum alloys precipitation of manganese phases occurs at 350°. In this case the decomposition of the solid solution varies with the temperature and holding time. Finely dispersed particles with diameters up to 0.2 μm are first precipitated in the peripheral areas of cells, and then in the bulk of the cells. With a large quantity of finely dispersed particles of manganese phase, the technological properties of ingots first decrease and then increase again when these particles coalesce to a size of 0.5-1.5 μm.

Figure 2 shows the ductility of ingots from three alloys (two of which are models) at 400° in relation to the homogenization conditions. The ductility of the binary alloy of Al + 8% Mn increases sharply at a homogenization temperature above 500°. After homogenization at 540° for 24 h, the relative elongation of the ingots doubles.

The variation of the ductility of the binary alloy of Al + 6.5% Mg, containing 0.14% Mn and Fe, in relation to the homogenization conditions shows three peaks at 300, 460, and 540°C. The higher ductility at 300° is due to the smaller negative effect of large particles precipitated during crystallization because of finely dispersed particles precipitating

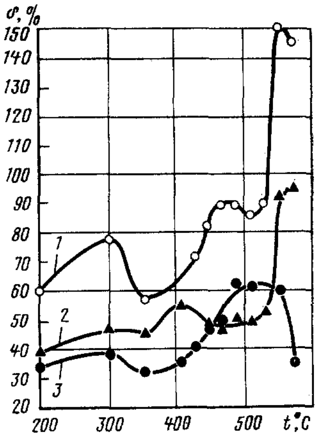

Fig. 2. Relative elongation of Al + 0.8% Mn (2), Al + 6.5% Mg (1), and AMG6 (3) at 400° in relation to homogenization temperature: 1) homogenization for 6 h; 2, 3) 24 h.

around them (Fig. 1e). The lower relative elongation of the ingots from all three alloys after homogenization at 350-440° is due to general precipitation of large numbers of particles of manganese phase in peripheral areas of the cells. The increase of the relative elongation of the ingots to 150% after homogenization at 540° for 6 h is due to acclerated precipitation and coalescence of manganese-containing particles in the presence of magnesium.

Only one peak of ductility is observed for alloy AMG6 after homogenization at 480-540°. The solution of newly formed precipitates and precipitation and coalescence of excess manganese phases are observed at the same time.

Liberation of Hydrogen from the Supersaturated Solid Solution with Development of Secondary Porosity. The liberation of excess hydrogen during homogenization occurs preferentially in the boundaries of dendrites and in stringers between cells (see Fig. 1c); disk-shaped pores are formed in this case, and spherical pores in the second case. Secondary porosity occurs more often in alloy AMG6, which is capable of retaining as much as 0.9-1.0 cm^3 of hydrogen per 100 g of metal during crystallization. Fine pores 2-3 μm in diameter are observed at 350-400°. With rising temperatures and increasing holding times, the pore size increases several times and pores join together to form voids consisting of 2-4 pores. The porosity of the ingots increases with homogenization at temperatures up to 480-520°, then decreases. The effect of degassing is evident when the ingots contain more than 0.5 cm^3 of hydrogen per 100 g of metal. In unhomogenized ingots of alloy AMG6 containing 0.9 cm^3 of hydrogen per 100 g of metal, the quantity of hydrogen drops to 0.38 cm^3/100 g after homogenization at 490° for 24 h, to 0.63 cm^3/100 g after homogenization at 540° for 6 h, and to 0.1 cm^3/100 g after homogenization at 540° for 24 h.

Thus, the effect of secondary porosity on the technological and mechanical properties of semifinished products is due to the hydrogen content of the ingots, the homogenization conditions, the nature of the alloy, and the nature of the changes in the structure during homogenization. Obviously, the effect of secondary pores as a notch would increase at high partial pressures of hydrogen in them and with the given structure of the surrounding matrix. The most dangerous pores are those located along the boundaries of grains and the cells of dendrites.

Change in the Shape of the Particles of Insoluble Phases. The insoluble intermetallic compounds containing iron, in the form of skeletons and hieroglyphics, may change their shape in the process of homogenization at high temperatures (≥ 520°C) by way of recrystallization via the liquid part of low-melting components [6] or by coalescence of particles to a more compact shape (Fig. 1f). A change in shape by recrystallization is observed in alloys AMG2 and AMG6 homogenized at temperatures around 560°, and a change in shape by coalescence in alloy AK4-1 at 540°. Since the intermetallic phases greatly reduce the workability of the ingots, the change in the shape of the precipitated phase has a positive effect on the structure of the ingot.

Boundary Movements in Grains and Cells of Dendrites. Homogenization of ingots with some quantity of nonequilibrium liquid phase at temperatures of 520° and higher may be accompanied by boundary movements in grains and cells. In the process of boundary movement the bulk of the grain is purified of decomposition products, which are forced into new boundaries. Such changes in the structure of the ingots occur only in sections with the most favorable combination of crystallographic orientations and in the presence of nonequilibrium components. These sections of the grain have high ductility even though the boundaries are very brittle. For this reason, the ductility of ingots of hard-to-work alloys may increase, and that of easily worked alloys may decrease somewhat.

It can be concluded on the basis of our results that each change in the structure accompanying homogenization annealing of the ingot may have a decisive effect on the workability and on the mechanical and operating characteristics of semifinished products. The properties of heat-treatable alloys are affected mainly by the solution of phase components and decomposition of the supersaturated solid solution of manganese and iron in aluminum in the case where homogenization of the ingot is not accompanied by formation of some quantity of liquid phase. In addition to these changes in the structure, a change in the shape of particles of insoluble phases and boundary movements of grains in cells of dendrites occur during high-temperature homogenization. The workability of non-heat-treatable alloys can be increased considerably by a combination of the structural changes that occur during homogenization of the ingots and exclusion of the conditions for the formation of secondary porosity or reduction of its negative effect due to degassing of the alloy during heat treatment of the ingot.

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