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ROLE OF METALLURGICAL FACTORS IN STRUCTURE AND PROPERTY FORMATION FOR THICK PLATES OF ALLOYS OF THE Al–Cu–Mg–Mn SYSTEM

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The role of chemical composition is studied in thick plate structure and property formation for alloys of the Al–Cu–Mg–Mn system. It is shown that in order to correct the chemical composition of aluminum alloys it is necessary to consider the alloying element compatible solubility limit within an aluminum matrix at the heating temperature for hardening and the proportion of alloying elements participating in forming almost insoluble phases with impurity elements. An important role is also played by alloying elements formed with reaction of excess phases, although they are soluble but cannot be dissolved during heating for hardening due to saturation of α-solid solution with alloying elements.

Keywords: *aluminum alloy, phase composition, thermogram; plate, mechanical properties.*

Contemporary metallurgical production of large semifinished products (plate, forgings, pressed panels) of aluminum alloys is an energy-intensive production process. Each stage of this process is accompanied by an unfavorable effect on environmental surrounding conditions. For example, preparation of aluminum alloy weighing 30–60 tons in a flame furnace unavoidably leads to an increase in concentration of carbon dioxide within the surroundings, and refining of molten aluminum alloys with a mixture of inert and active gases causes discharge of chlorine into the atmosphere.

Manufacturing experience shows that large semifinished products often do not correspond to standard documents with respect to mechanical, anticorrosion, and structural properties. As a result of this, semifinished products are scrapped and directed for remelting, and this again gives rise to the unfavorable ecological phenomena mentioned above. In view of this, the task of preparing semifinished products of aluminum alloys with a required combination of mechanical, corrosion, and structural properties in the first production cycle is very important.

In order to resolve this important task, extensive research has been carried for establishing rational regimes for homogenization and hot rolling of large ingots, and also for studying the effect of heat treatment of thick plates on their structure and properties. It has been revealed that as a result of these production operations alone it is impossible to obtain plates with the required property combination. Therefore, in this work the main attention has been devoted to studying the role of the aluminum alloy chemical composition in thick plate structure and property formation.

One of the most extensively used aluminum alloys for producing thick plates is alloy D16 (2024 according to the designation of the Aluminum Association of the USA) of the Al–Cu–Mg–Mn system [1]. It is well known [2–5] that chemical composition of multicomponent aluminum alloys of this system, intended for manufacturing semifinished products with the required structure and properties, is very important. One approach to resolving the question of optimizing alloy chemical composition is based on minimizing the volume fraction and reducing inhomogeneity of excess phases in semifinished products [3]. This approach does not consider composition of alloy phases and matrix, and this makes it impossible to optimize

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TABLE 1. Mechanical Properties of Alloy 2124 Plate 139.7 mm Thick Prepared by Regime T851 of Standard and Corrected Chemical Composition

Specimen cutting direction	σ_u, MPa			$\sigma_{0.2}$, MPa			δ, %		
	serial	corrected	SD specification	serial	corrected	SD specification	serial	corrected	SD specification
Longitudinal (*L*)	445–463	460–472	442	385–409	395–414	379	7.5–8.5	8.4–9.5	5
Transverse (*ST*)	440–457	450–460	442	380–403	390–406	379	5.6–6.3	6.6–7.5	4
Over height (*ST*)	**420–435**	426–440	421	360–388	375–390	366	1.4–1.8	2.3–2.6	1.5

entirely the alloy composition with respect to alloying and impurity element content. In order to optimize chemical composition of multicomponent aluminum alloys D16 and D16ch an approach is suggested based on the results of thermal and x-ray microanalysis of alloy specimens in a quenched or aged condition.

The objects for study were commercial aluminum alloys D16 and D16ch, cut from cast flat ingots with a cross section of 300 × 1100 and 400 × 1320 mm, and also from heat treated plates 60–150 mm thick.

A JSM-5900LV scanning electron microscope was used for studying the structure with an electron probe microanalyzer attachment with detection for 1–2 μm. In order to establish phase transformation temperature (nonequilibrium solidus, equilibrium solidus and liquidus) of specimens from aluminum alloy castings and plates, a modernized thermal analysis (TA) method was used followed by numerical differentiation of heating and cooling curves. In order to determine mechanical properties of semifinished products, an Instron 5585H universal instrument was used, fitted with a digital high-resolution extensometer.

Plates manufactured from alloys D16 and D16ch of different melts, often have mechanical properties below specified values, particularly in the direction through the thickness. In some cases, although it has been possible to prepare with properties answering the standard document (SD) specifications, mechanical properties of plates have considerable scatter (see Table 1).

All attempts to provide preparation of plates of alloy D16 with the required mechanical property values as a result of changing ingot homogenization regime, heating temperature of plate for hardening, and soaking duration at the hardening temperature were unsuccessful. A complicating situation was the basis for revealing the role of chemical composition of alloys D16 and D16ch in forming plate structure and properties.

In order to determine the combined solubility limit of magnesium and copper in an aluminum matrix of alloy D16, x-ray microanalysis (XRMA) was performed for specimens cut from plates of this alloy quenched (heating temperature for hardening 497°C) and aged by regime T351. It was revealed that within the structure of a plate particles of insoluble Al_2CuMg phase are retained. The content of the main alloying elements within grains of α-solid solution is (wt.%): Mg 1.3–1.42, Cu 3.77–3.88, and Mn 0.16–0.59. According to the SD, the copper, magnesium, and manganese content in alloys D16 and D16ch may be varied within the following limits (wt.%): Cu 3.80–4.90, Mg 1.20–1.80, and Mn 0.30–0.90.

On the basis of the established combined solubility of copper an magnesium in an aluminum matrix at 497°C, it was proposed to adopt as a lower alloying limit the content of these elements corresponding to their solubility limit, and the upper limit at 0.1–0.2 wt.% above it.

Thermograms are presented in Fig. 1 for heating specimens of cast ingots from alloys D16 and D16ch prepared taking account of recommendations for chemical composition correction. In heating thermograms for the alloys there are clearly expressed endothermic peaks in the range 500–511°C, pointing to eutectic melting. Consequently, the homogenization temperature for alloy D16 and D16ch ingots should not exceed 500°C. Proceeding from this a heating regime has been proposed for ingot homogenization at 485–495°C.

Comparison of mechanical properties of plates manufactured from ingots of serial chemical composition and that proposed, and homogenized by the heating regime of 485–495°C, 12 h, showed that the mechanical properties of alloy plates of the recommended chemical composition were higher (see Table 1).

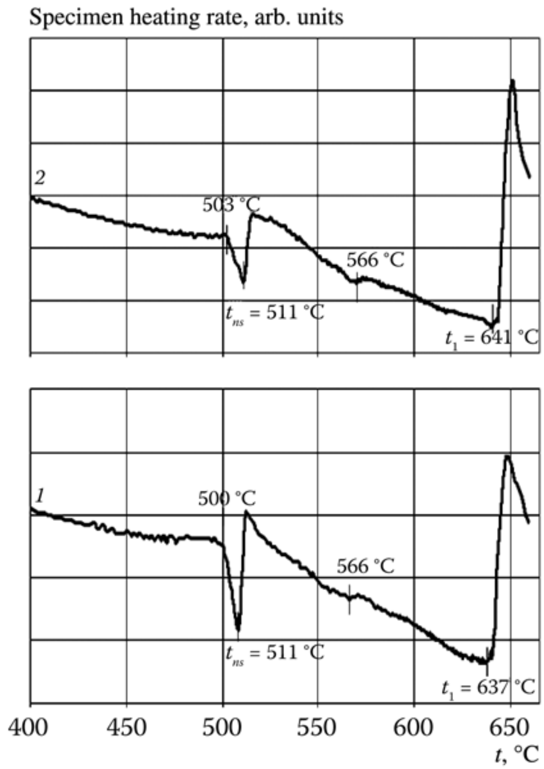

Fig. 1. Thermograms for specimens from industrial ingots of aluminum alloys in heating regime: *1*) D16; *2*) D16ch.

Conclusion. In order to correct the chemical composition of aluminum alloys based on the Al–Cu–Mg–Mn system, it is necessary to consider that limiting compatibility of alloying element solubility in an aluminum matrix of alloys at the heating temperature for hardening and proportion of alloying elements participating in forming almost insoluble phases during reaction with impurity elements. An important role is also played by the proportion of alloying element forming excess phases during reaction, which although soluble, cannot be dissolved during heating for hardening due to α-solid solution alloying element saturation achieved.

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