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Effect of Superheat Melt Treatment on Microstructure and Mechanical Properties of Aluminum Alloys Produced by Lost Foam Casting

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Abstract. The resource-saving technology for producing of thin-walled castings from A356.1, A413.1 and A360.0 aluminum alloys by the lost foam casting method, as well as the results of this technology implementation in production conditions are considered in the paper. The technology involves thermo-speed treatment of the melt with the predominance of secondary materials in charge (85...90 wt.%), including isothermal holding and subsequent rapid cooling of the melt for fixation the high-temperature state. It is shown that the use of thermo-speed treatment promotes the production of aluminum castings with fine-grained microstructure and the enhanced level of mechanical properties without the addition of costly modifying additives, and makes it possible to use an increased amount of secondary charge materials during smelting.

Introduction

The method of lost-foam casting (LFC) is a promising technology for obtaining thin-walled cast products of aluminum alloys [1-5]. One of the ways to reduce the manufacturing cost of castings made by LFC-process is the application of resource-saving technologies based on the use of increased amount of secondary charge materials [6-8]. However, use of secondary materials in the melting charge can lead to various casting defects and, as a result, to rejection of castings [9, 10]. The perspective direction of works for maintenance of the desired quality of castings made from low-grade charge is the melt superheat treatment, including rational temperature-time parameters of melting and pouring [11-14].

It is known that the high-temperature type of the structure of short-range order of the melt, obtained by superheat treatment, can be fixed by rapid cooling of the melt by thermo-speed treatment (TST) before pouring [15-17]. Rapid melt cooling is achieved by addition of solid charge, having the same chemical composition as the resulting alloy. These additives create a grain refining effect, introducing microinhomogeneities of smaller scales and activated insoluble impurities, which are potential centers of crystallization [18, 19]. The effect of TST is related to the fact that the rate of structural transformations in the liquid phase is sufficiently low, despite the relatively high rates of diffusion processes, so rapid melt cooling can greatly suppress the transformation of clusters.

The purpose of this paper is an investigation of the effect of thermo-speed melt treatment on the microstructure and mechanical properties of aluminum alloy castings obtained by LFC-process.

Experimental Procedure

An industrial aluminum alloys A356.1, A413.1 and A360.0 have been used as the objects of research. Component composition of charge materials included 10…15 wt.% of primary alloys and 85…90 wt.% of secondary materials in the form of returns and production waste. The secondary materials in all variants contained ~50 vol.% of fine scrap and alloy waste, ~50 vol.% of compacted turnings. The experiments have been carried out in an induction furnace IF-0.06. For the thermo-speed treatment, the melt has been superheated to a temperature 980…1000°C and held at this temperature for a predetermined time varying from 0 to 15 min. Optimal temperature modes of TST has been previously determined experimentally [20]. In all series of experiments, the pouring temperature was 820…830 °C. The melt has been cooled to a pouring temperature by introducing a pre-crushed primary alloy (10…15 wt.%). The pouring has been carried out through the fiberglass mesh filter with a cell size of 0.6 mm.

For the production of casting molds, the quartz sand with an average grain size of 0.2 mm has been used. In the manufacture of gasified models, polystyrene with an average granules diameter of 400 μm has been used. The density of the obtained models was 0.022-0.024 g/cm^3. Finished model blocks have been placed vertically in a suspended state into a molding box of 700 x 700 x 700 mm in size and covered with molding sand at vibration with frequency of ~36 Hz. The mold has been vacuumed before melt pouring. Investigations have been carried out on box-type castings with a wall thickness of 5…10 mm.

Metallographic studies have been carried out using an inverted optical microscope Olympus GX-51. Mechanical properties have been determined on the universal testing machine WDW-100E on standard samples with diameter of working part of 10 mm obtained by LFC-process.

Results and Discussion

Metallographic images of thin-walled castings made of alloy A356.1 depending on the melt holding time at the superheat temperature 1000 °C are shown in Fig. 1. The structure of alloys in the as-cast state is represented by crystals of α-solid solution and eutectics (α + Si). In comparison with other TST time modes, the melt holding time of 4…5 min (Fig. 1, c) and 8…10 min (Fig. 1, d) at superheating has the greatest grain refining effect observed by decreasing of average grain size of α-Al.

Experimental data on influence of the proposed technology for the production of aluminum alloys using TST on the mechanical properties of experimental castings are shown in Fig. 2. For comparison, the mechanical properties of castings obtained by standard melting technology (with content of no more than 35...40% of secondary materials in the charge) without high-temperature superheating of the melt are given, thus the melt has been cooled to the pouring temperature (820... 830 °C) together with the furnace.

According to the data obtained, the mechanical properties of castings after TST compared to castings manufactured by standard technology have increased (on average): for castings made of A356.1 alloy, the ultimate tensile strength (UTS) by 13 ... 16%, the elongation by 35 ... 50%; for A413.1 alloy, the UTS by 15 ... 18%, the elongation by 60 ... 63%; for alloy A360.0, the UTS by 12 ... 14%, the elongation by 28 ... 40%.

The observed increase in the mechanical properties of castings is achieved by refinement the alloy structure during overheating and subsequent rapid cooling of the melt. The obtained results show that the method of TST realized by introducing into the melt of fine-grained solid charge, which corresponds to the composition of the obtained alloy, allows to solve the problem of fixation the achieved effect of high-temperature superheating due to accelerated cooling of the melt to the pouring temperature. Additives of fine-grained charge materials act as melted microcoolers that increases the cooling rate of the melt. Besides that, the addition of solid charge creates inoculating effect, introducing a large number of potential crystallization centers in the form of activated insoluble impurities and microinhomogeneities of smaller scales.

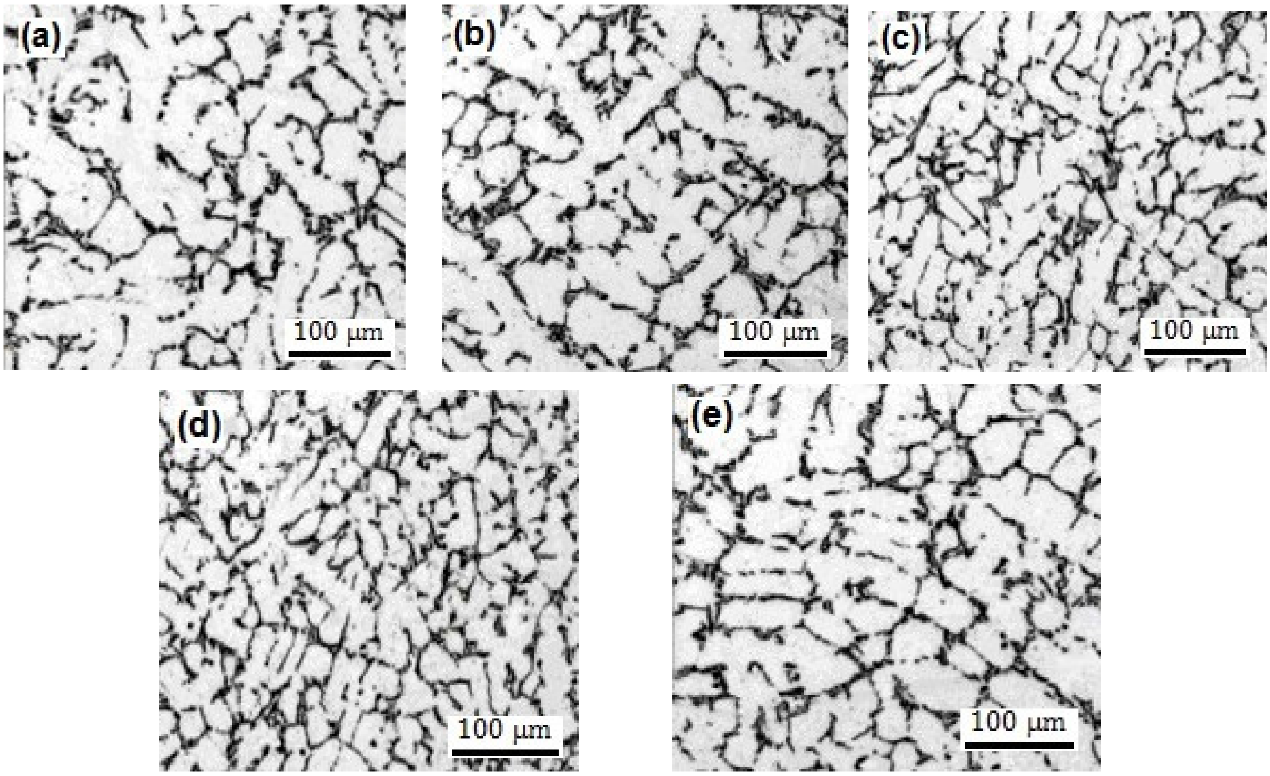

Fig. 1. Influence of the melt holding time during TST (τ) on the microstructure of castings from A356.1 alloy, obtained by LFC-process: *a)* initial alloy; *b)* τ = 0…1 min; *c)* τ = 4…5 min; *d)* τ = 8…10 min; *e)* τ = 12…15 min

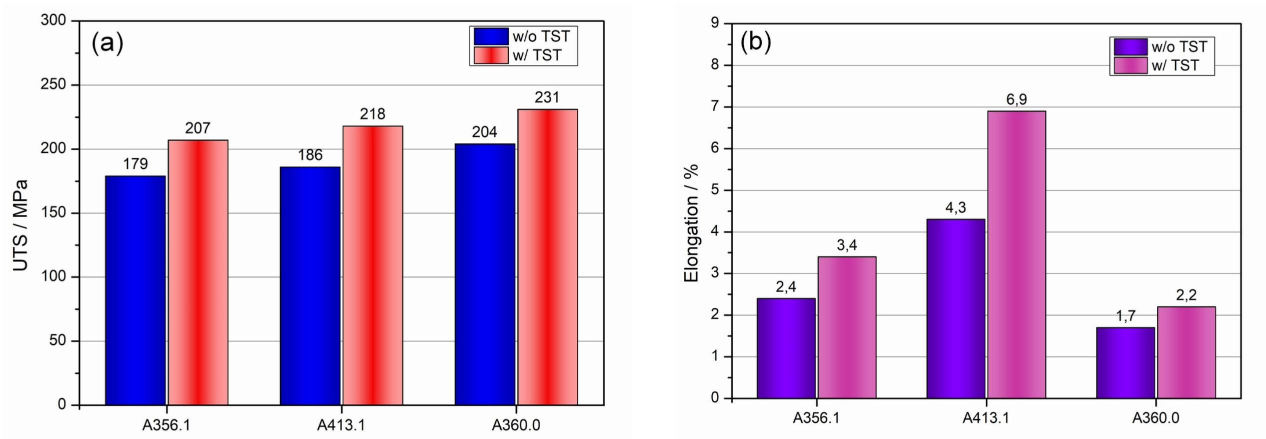

Fig. 2. Average values of ultimate tensile strength (*a*) and elongation (*b*) of aluminum alloys obtained by LFC-process with and without of TST

A significant advantage of the proposed technology is high resource efficiency, because expensive grain refining additives (Al-Ti-B, Al-Sr, etc.) are not used in the melting and casting processes, and fine-crystalline wastes of own production can be used as additives of solid charge. The obtained results can be used in the conditions of existing foundry and metallurgical enterprises at production of casting from secondary aluminum alloys by LFC-process.

Summary

It is shown that using of the TST method enhances the mechanical properties of castings by refining the alloy structure during superheating and subsequent rapid cooling of the melt for fixation the high-temperature state. Implementation of resource-saving technological processes at smelting A356.1, A413.1 and A360.0 alloys with application of TST for the production of high-quality thin-walled castings by the LFC-process will allow to obtain significant economic effect by increasing the amount of secondary materials in charge up to 85... 90 wt.%.

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