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FOUNDRY

Influence of Melting Conditions of Aluminum Alloys on the Properties and Quality of Castings Obtained by Lost Foam Casting

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Abstract—The development of modern foundry production is characterized by a constant increase in requirements for the quality of fabricated casting and rational use of material resources, which determines the search for new technical and process solutions, making it possible to acquire the required properties of cast wares along with resource saving. Herewith, the question of revelation and investigation into the regularities of the influence of thermal-temporal parameters of smelting and pouring of aluminum alloys into the casting mold during the lost foam casting on tightness and mechanical and qualitative characteristics of thin-wall castings remain poorly known and complex for implementation, especially allowing for the performance of resource-saving measures. In this publication, the influence of process parameters of smelting on the strength, tightness, and content of nonmetallic inclusions in castings of the gas-analyzer case made of AK7 alloy during the lost foam casting is considered. The data set acquired based on the experimental investigations has been subjected to statistical processing. The use of statistic models makes it possible to acquire the results of the influence of the holding time and content of secondary materials in the charge on strength and tightness of mentioned castings. The results of an investigation into the influence of holding the AK7 melt at the overheating temperature of 880–890°C on the content of nonmetallic inclusions in castings show that it can be regulated varying the holding time. This procedure decreases the melt microinhomogeneity and provides the acquisition of numerous castings with a minimal content of nonmetallic inclusions.

Keywords: casting, aluminum alloy, melt overheating, lost foam models, strength, tightness, melt, holding time, secondary materials, nonmetallic inclusions

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INTRODUCTION

Lost foam casting (LFC) is currently one efficient and promising method of fabrication of high-quality thin-wall castings possessing the specified precision, required surface fineness, and other useful properties [1–7]. This technology becomes increasingly widespread when fabricating aluminum wares [8–23].

A decrease in the prime cost of production of cast wares is possible only when using resource-saving technologies. For example, an increased amount of secondary materials in the charge is used for aluminum casting by the LFC method. Meanwhile, their prevalence in the charge even for a stable run of the LFC production process can lead to porosity, solders, and other types of casting defects and rejects, which considerably lowers the mechanical and operational properties of castings.

The casting technology should include efficient procedures of melt treatment in this case, for example, such as thermal-temporal treatment according to optimal temperature modes and refining [24–28], as well as the possibility of providing the optimal pouring temperature into casting molds. Unfortunately, these measures and factors are determined individually in each concrete case and depend on the production type, smelting aggregate, grade of fabricated alloy, sizes and weight of the future casting, casting mold "complexity," etc. We should recognize that all listed factors result in the fabrication process of required quality wares being complicated from the engineering viewpoint. Nevertheless, the development of the efficient smelting technology of aluminum alloys with LFC is reasonable.

It should be noted that other methods of melt treatment during smelting and crystallization, which can be used allowing for the possibilities of production and applied casting method, are also promising [29–34].

It was previously shown [4, 35] that the overheating (t_{over}) and pouring (t_{pour}) temperatures affect the qualitative characteristics of castings including AK7 alloy fabricated according to the LFC technology, and optimal values of overheating were recommended. In addition to the t_{over} of the melt, the holding time (τ) of this temperature can also substantially affect the casting quality.

In this article, we present the results of studying the influence of the duration of melt holding of the AK7 composition (at optimal values t_{over} = 880–890°C and t_{pour} = 820–830°C) on the strength, tightness, and content of nonmetallic inclusions (γ-Al_2O_3) in castings fabricated using the LFC method under conditions of OOO NPP Vektor Mashinostroeniya (Novokuznetsk). The charge composition included an increased amount of secondary materials.

EXPERIMENTAL

The object of the investigation was AK7 industrial aluminum alloy (*GOST* (State Standard) *1583–93*). AK7 pig alloy and secondary feedstock of the same alloy, notably, scrap of parts and wastes of foundry and mechanical shops, were used for its preparation. Secondary materials in all experiments contained 50–55 vol % of small scrap and alloy wastes and 45–50 vol % of briquetted shavings. All wastes were preliminarily cleaned and treated according to standard requirements.

Experimental smeltings were performed in industrial conditions in an IST-0.06 furnace. The melt holding time at overheating temperature t_{over} = 880–890°C was varied during the process. Pouring into casting molds was performed at t_{pour} = 820–830°C through an SSF-0.6 filtering glass mesh.

The $2K_1O_302$ silica sand was applied for forming, and polysterene produced by Styrochem (Canada) was applied to fabricate lost foam models. A GK-100-3M autoclave was used to foam polysterene and prepare the models. Ready foam polysterene models were treated with a Polytop AL2 coating. Model blocks were placed vertically in a suspended state into a casting box 700 × 700 × 700 mm in size. Sand was poured into a casting box simultaneously with its vibration (f ~ 36 Hz), which was performed by means of two electric vibrators fastened on it (ν = 3000 rpm). Then the casting box was coated with a film, the pouring facility was arranged, the casting mold was evacuated, and the melt was poured. After cooling, we performed the knocking out of the castings, sawing, and sand blasting. Investigations were performed for thin-wall castings of the cap of the gas analyzer case [4] included into nomenclature of OOO NPP Vektor Mashinostroeniya.

The chemical composition of alloys and content of nonmetallic inclusions was monitored using an XRF-1800 X-ray fluorescent wave-dispersion sequential action spectrometer (Shimadzu, Japan).

Mechanical properties and porosity were determined for standard samples fabricated by LFC according to *GOST 1583–93*. Tightness was investigated by the pneumatic strength criterion using a special installation [24] for the sampling glasses with a wall thickness of 4 mm fabricated by the LFC method.

Our results were processed using Microsoft Excel and STATISTICA 6.0 and SPSS 13.0 software packages, as well as with the help of the Delphi 2007 for Win32 incl UPDATE 1 program application specially developed in the visual programming method.

RESULTS AND DISCUSSION

Based on our experimental data on the influence of the holding time of the melt (τ) and content of secondary materials in the charge composition (C_{sec}, %) on strength (σ_u) and tightness (Γ) on the pneumatic strength criterion of castings of the cap of the gas analyzer case, fabricated by the LFC method, we performed the statistic treatment of revealed dependences with the purpose of a mathematical description of observed phenomena.

The adequacy of formed regression models was evaluated by the Fischer criterion (F_r corresponds to the error of 5%, F_{tab} = 3.49). For each regression equation, we additionally presented the significance level (p), approximation reliability R^2, and ranges of varying dependent variables, for which this expression was derived.

Variations in strength (σ_u) and tightness (Γ) of the alloy depending on the holding time in the furnace (τ) and charge composition (C_{sec}) are described by regression equations in the form of the second-order polynomial:

$$\sigma_u = 192.99484 + 3.55098\tau - 0.20094\tau^2 - 0.42970C_{sec} - 0.00250C_{sec}^2 \quad (1)$$
$$\left(F_p = 45.3;\ p = 0.01;\ R^2 = 0.941;\ 0 \le \tau \le 15;\ 0 \le C_{sec} \le 80\right),$$

$$\Gamma = 11.90527 + 0.42071\tau - 0.02466\tau^2 - 0.03007C_{sec} - 0.00011C_{sec}^2 \quad (2)$$
$$\left(F_p = 75.8;\ p = 0.01;\ R^2 = 0.903;\ 0 \le \tau \le 15;\ 0 \le C_{sec} \le 80\right).$$

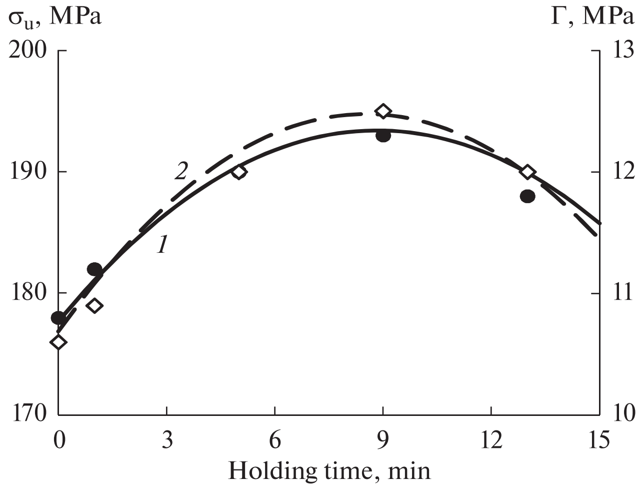

Fig. 1. Influence of the melt holding time on (*1*) strength and (*2*) tightness of castings of the cap of the gas analyzer case with the content in the charge of 50% of pig and 50% of secondary materials. Points correspond to the experiment and curves correspond to calculation according to formulas (1) and (2).

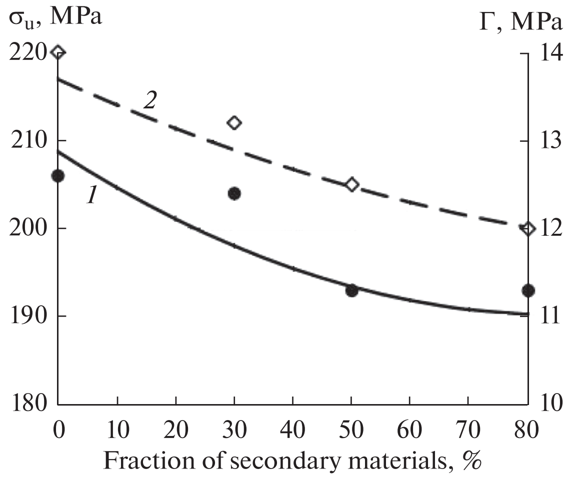

Fig. 2. Influence of the content of pig and secondary materials in the charge on (*1*) strength and (*2*) tightness of castings of the cap of the gas analyzer case with the holding time of the melt in the furnace of 8–10 min. Points correspond to the experiment and curves correspond to calculation according to formulas (1) and (2).

Figure 1 shows the data calculated by Eqs. (1) and (2) and experimental data on the determination of properties of castings for various holding times in the furnace found with the content of 50% pig and 50% secondary materials in the charge, overheating temperatures of 880–890°C, and temperatures of pouring the melt into the casting mold of 820–830°C. It is seen that for the holding time of the melt in the furnace of about 8–10 min, the strength and tightness of castings have an inflection point of the regression curve, or the point of maximum of studied parameters, which can be explained by the homogeneous fine-grain structure of castings and is associated with the more homogeneous melt state before the crystallization. Magnitude $\tau < 5$ min does not significantly affect the strength level and tightness of castings, while $\tau > 12$ min leads to an increased content of gases in the melt, which promotes the formation of porosity during the crystallization and lowering of the strength and tightness of castings.

Figure 2 shows the calculated and experimental data at various contents of pig and secondary materials in the charge acquired at $\tau = 8$–10 min, $t_{over} = 880$–890°C, and $t_{pour} = 820$–830°C. An increase in the fraction of secondary materials in the charge causes the nonlinear decrease in alloy strength and tightness in the casting. Herewith, an increase in Csec from 0 to 50% leads to a drop in the value of σ_u by 15–16 MPa, and the strength increases only by 2–3 MPa with a further increase in their fraction from 50 to 80%. A similar pattern is observed for tightness: 1–2 and 0.5–1.0 MPa, respectively.

Thus, for the process mode, which provides the duration of melt holding in the furnace of about 8–10 min, an increase in the content of secondary materials in the charge from 50 to 80% does not lead to an abrupt decrease in strength and tightness of castings or an increase in the fraction of rejects due to the fault of metal.

Figure 3 shows the results of the investigation of the content of nonmetallic inclusions in castings on the cap of the gas analyzer case (192 pieces total; 6 series by 32 castings in each variant) depending on the holding time at overheating temperature $t_{over} = 880$–890°C and a content of secondary materials in the charge of 50–55%. The analysis of these data shows that the variation in the holding duration during overheating makes it possible to control the content of nonmetallic inclusions in castings. The optimal time of melt holding is the overheating duration of 5–10 min, during which the melt microinhomogeneity decreases and numerous casings with a minimal content of nonmetallic inclusions (γ-Al_2O_3) are formed.

It follows from Fig. 3a that a holding time of 0–1 min is insufficient to decrease the fraction of nonmetallic inclusions in castings: a very large number of castings with γ-$Al_2O_3 \geq 0.40\%$ is formed. These results are explained by the fact that the content of secondary materials in a charge higher than 50% requires sufficient melt molding at overheating temperature $t_{over} = 880$–890°C with the purpose of lowering the melt microinhomogeneity level.

It is also noteworthy that the duration of 12–13 min (Fig. 3d) is excessive and leads to substantial gas absorption by the melt and an increased content of nonmetallic and gas inclusions in both liquid and solid states of alloy.

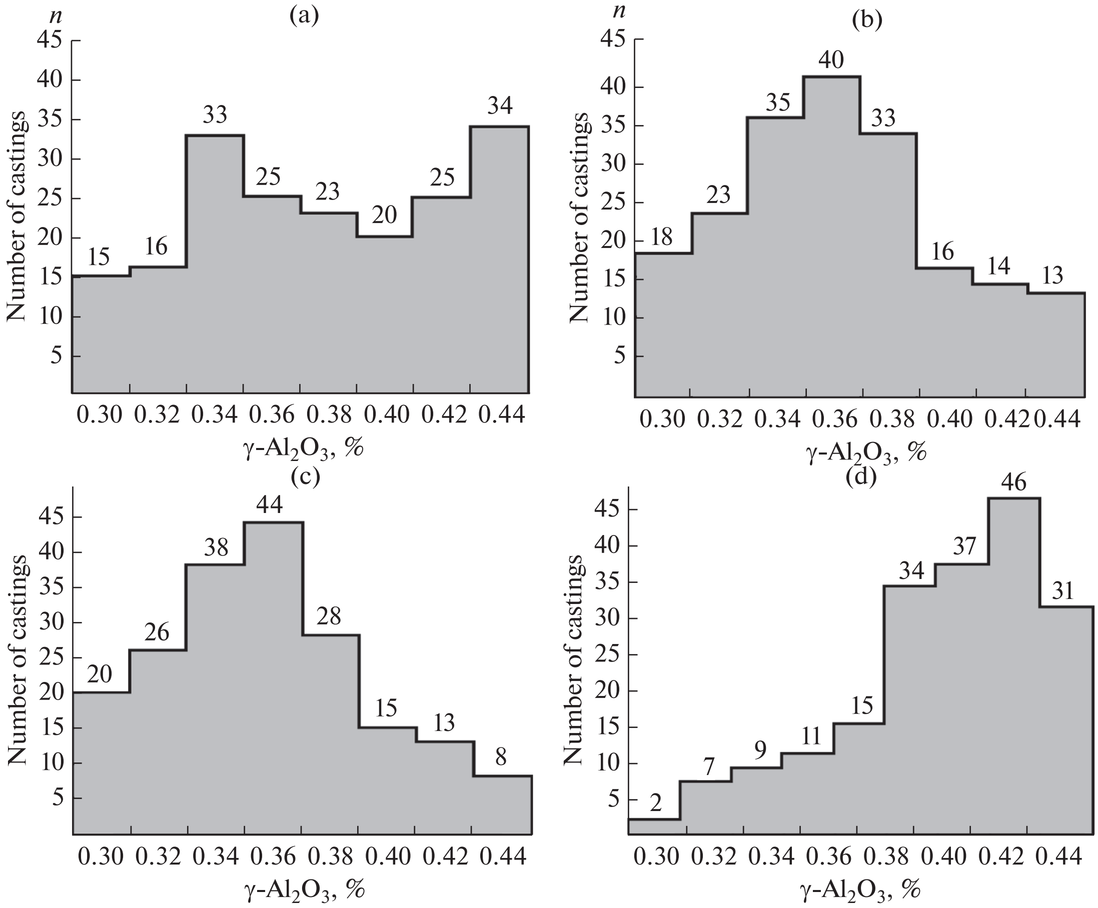

Fig. 3. Content of nonmetallic inclusions (γ-Al_2O_3) in castings of the cap of the gas analyzer case fabricated by the LFC method at t_{over} = 880–890°C and various melt holding times. (a) τ = 0–1 min, (b) 4–5 min, (c) 8–10 min, and (d) 12–13 min.

CONCLUSIONS

It is shown that, when using an increased amount of secondary materials in the charge (~50–80%), the temperature–temporal parameters of smelting of aluminum alloys (t_{over} = 880–890°C at τ = 8–10 min) and pouring (t_{pour} = 820–830°C) into the casting mold provide the minimal content of nonmetallic inclusions (γ-Al_2O_3) and required characteristics of strength and tightness of thin-wall castings made of AK7 alloy fabricated by the LFC method. Analytical dependences, which associate the strength and tightness of castings with melt holding in a melting aggregate and amount of secondary materials in the charge, are derived.

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