The effect of overheating of aluminum melts on the mechanical properties of castings

Rustam Muradov[1], *Mansur* Akhmetjanov[2*], *Malokhat* Juraeva[2], *Makhammadjon* Soliev[1], and *Shavkatjon* Mamajanov[1]

[1]Namangan Engineering-Technological Institute, Namangan, Uzbekistan
[2]Bukhara Engineering Technological Institute, Bukhara, Uzbekistan

Abstract. The article investigates the effect of overheating of aluminum melts on the mechanical properties of castings. The authors use the data of chemical analysis and study the microstructure of castings. The rationale for the relevance of the topic is based on a review of modern scientific and technical developments, as well as a review of scientific periodicals in the field of metallurgical processes over the past five decades. It is noted that at present a large amount of experimental data has been accumulated, which indicates that metal melts are complex dynamic systems. A significant effect of the structural state of the initial melt on the formation of the structure and properties of ingots obtained from this melt has been established. In this work, the effect of heat treatment of the melt was studied on a high-strength cast aluminum-magnesium alloy with a wide crystallization range (433 K). In order to obtain dense castings, pouring was carried out in a bottomless mold with a slotted gating-feeding system, installed on the surface of a copper water-cooled box. This provided directional solidification of the alloy. Experimental results are presented, chemical analysis data are processed, and the microstructure of castings is studied.

1 Introduction

A review of modern scientific and technical developments shows that for the development of the metallurgical industry, research in the field of studying the effect of heat treatment of the initial melt on the structure and properties of crystalline ingots or castings is important [1-4]. It is known that most technological processes for the production of metal alloys include the transfer of charge materials to a molten state and the subsequent solidification of the system with various, sometimes very high, cooling rates [5-9].

In order to improve the structure and service properties of ingots, castings, and deformed semi-finished products, researchers usually searched for optimal solidification conditions [10]. The first stage of this process, namely, the initial melt, received little attention. Traditionally, this stage has attracted very little interest from researchers in the field of metallurgy. In most cases, the developed approaches that could affect the system of the original melt at this stage consisted of additional alloying in order to optimize its composition or refining to remove harmful impurities.

* Corresponding author: rmuradov1956@mail.ru

A review of scientific periodicals in the field of metallurgical processes over the past five decades indicates that a large amount of experimental data has accumulated, which indicates that metal melts are complex dynamic systems [11-13]. A number of works have shown that metallic melts exist in various structural states and pass from one such state to another under the influence of various external influences. Moreover, a significant influence of the structural state of the initial melt on the formation of the structure and properties of ingots obtained from this melt has been established. During further processing, the initial structural state of the melt also affects the structure and properties of deformed semi-finished products.

The analysis of these processes in relation to steels, cast irons and some other alloys was systematized in the monograph [11], published back in 1984. In [12], a generalization of data on the effect of liquid metal processing in the production of aluminum alloys is given. The work [8] contains a review of the effect of thermal treatment of melts on the properties of amorphous materials.

Many authors consider the effect of heat treatment of initial melts on the structure and properties of crystalline metal alloys. It was shown in [1] that there are several types of microheterogeneity and microheterogeneity of liquid metal solutions. Studies show that the structure depends on the composition, temperature and background. Therefore, using temperature and pressure variations and other physical influences, this structure can be modified. Moreover, at a suitable cooling rate, it is possible to preserve changes in the structure of the melt up to liquidus and to preserve the effect of these influences on the structure and properties of the crystallized alloy. In [1], the authors formulated the idea of the possible efficiency of the optimized heat treatment of the melt as the simplest external influence on the liquid metal system.

In this article, we investigate the effect of overheating of aluminum melts on the mechanical properties of castings using chemical analysis data and studying the microstructure of castings.

2 Materials and methods

The effect of thermal treatment of the melt (TTR) was studied by us on a high-strength cast aluminum-magnesium alloy AL27-1 (8.0-10.5% Mg and Ti, Zr, Be - each within 0.15 ... 0.20%), which has a wide crystallization range (433 K). It was revealed that a wide crystallization interval is the cause of volumetric solidification in crystallizing castings. At the same time, the supply becomes more difficult and, as a result, shrinkage defects are formed in the volume of the metal, often combined with gas porosity.

In order to obtain dense castings, pouring was carried out in a bottomless mold with a slotted gating-feeding system (GFS), installed on the surface of a copper water-cooled box, which was supposed to provide directional solidification of the alloy.

As charge materials, aluminum grade AB000, magnesium Mg1 and ligatures Al-3% Zr, Al-4.26% Ti and Al-4.4% Be were used, provided for by the workshop technology.

Melt refining was carried out with C_2Cl_6 hexachloroethane before the temperature was raised.

3 Results

The results of testing TTR in the «mixing» mode, when the temperature of the «hot» part of the melt reached 1273 K, and the «cold» part - 973 K, showed the following. With an increase in the pouring temperature, the tensile strength σ_b of the test specimens (the castings were heat treated according to the T4 mode: hardening and subsequent aging), cut from the cast specimens (33.5 x 103.0 x 55.0 mm), increases. It is when pouring from 1083 K 430 MPa (required according to the technical documentation ≥ 320 MPa), and when pouring with a temperature of 933 K of an unheated alloy - 415 MPa. Relative elongation δ in this case increases from 24.0 to 28.0% (required ≥ 15.0%), and hardness (HD) increases from 930 to 950 MPa (required ≥ 750 MPa).

Due to some complexity of performing this mode in a production environment, a simpler TTR mode was tested. This mode is called «pouring the melt from the overheating temperature». The results of testing the mechanical properties of the cut samples showed that the most favorable combination of σ_b (445 MPa) and δ (30%) is obtained by pouring with a temperature of 1023 K. In this case, HD lies in the range of 860-1000 MPa.

With an increase in pouring temperature, the mechanical properties showed a downward trend. Approximately in the same way, the mechanical properties (heat treatment mode - T4) of cast and cut from a thin-walled «impeller» part cast into a chill mold with a rough mass of 2 kg, the internal cavity of which was formed by a sand core, changed in approximately the same way.

The processing of chemical analysis data showed that, despite the significant overheating of the melt and even the formation of slags on its surface, the content of the components does not undergo significant changes. That is, we can assume that the elements, although they fade, are proportional in proportions that ensure the constancy of the composition. In some cases, the melt was unintentionally brought to a boil, but even then its chemical composition remained practically unchanged. Some fluctuations in the content of certain components can be attributed to the permissible errors of chemical and spectral analyses.

The study of the microstructure of castings showed (an increase of 200 times) that with an increase in the pouring temperature of the alloy, the grains of the α-solid solution are crushed, and the precipitates of the β-phase along the grain boundaries become thinner. Electronic microstructures (10,000 times magnification) showed that at a lower pouring temperature (933 K), the grains of the α-solid solution consist, as it were, of separate blocks with distinct boundaries between them. In this case, the boundary between the grains of the α-solid solution is also clearly visible. With an increase in the casting temperature (1203 K), the grain structure becomes homogeneous, and the continuity of the precipitates of the β-phase along the grain boundaries is broken. Changes in the level (growth) of the mechanical properties of castings can be associated with such changes in the structure with an increase in the pouring temperature.

As a result of the analysis carried out and the methodology described in [14], it is possible to propose the following mechanism for the effect of an increased temperature of overheating of the melt and pouring on the mechanical properties of castings from the AL27-1 alloy. In [15], the authors, using X-ray diffraction analysis data, established that in the AL27-1 liquid alloy, up to overheating up to 1223 K, there are groups of atoms of the composition Al_2Mg_3. With an increase in the temperature of the liquid metal to the region of 1073...1123 K, they are destroyed and the alloy acquires a more homogeneous structure. When poured into a mold, the metal crystallizes at such a rate (obviously sufficient for this process) that provides partial fixation of the state of the overheated melt. As shown in [15], this rate brings the process to such an extent that in the crystallized AL27-1 alloy, no precipitates of the β-phase are detected at all, i.e. its formation is suppressed by a high crystallization rate.

In addition, according to the work of A.G. Spassky [16], who is the founder of the theory of heat treatment of melts, we see that with an increase in the temperature of casting an alloy with a wide crystallization interval, under conditions of increased heat removal (in our case, when casting into a mold, water-cooled in the direction from its lower part to its upper part), a large temperature gradient arises over the cross section of the crystallizing metal. In this regard, the hardening of the casting occurs from its surface to the depth in thin, successive layers, which contributes to improved nutrition. Confirmation of such a mechanism can be found in [17-20]. In [21], the authors give results for the AL27-1 alloy. These results were obtained by analyzing the quality of real shaped castings. It was found that the details of the alloy AL27-1 practically could not be obtained sufficiently dense when casting in earthen molds without the use of special technological measures. Such technological measures, for example, include the installation of massive refrigerators on sand rods, which enhance heat removal from the crystallizing metal. It is also possible to use the crystallization method in an autoclave, where increased pressure ensures the supply of metal to the crystallizing areas, since this process occurs throughout the entire volume of the casting during solidification in air.

4 Conclusion

In conclusion, we note that in view of the fact that with an increase in the temperature of the melt, despite the presence in its composition of beryllium, which forms a protective layer of BeO oxide on the surface, its oxidation and gas saturation increase to a certain extent. In order to eliminate these negative consequences of overheating, the melt during pouring into a mold was filtered through magnesite chips (particle size of the order of 10–15 mm) filled into a graphite-chamotte crucible with a hole in the bottom. The crucible was heated before pouring to an experimentally found temperature, equal to half the sum of the melting and pouring temperatures, and was installed on the profitable part of the mold before pouring. The results of testing the mechanical properties of castings showed that when pouring with filtering, σ_b for test samples is always higher than that of a conventional non-superheated alloy, and δ is higher than that of a conventional alloy at low (933 K) and high (1333 K) pouring temperatures.

It has also been found that the density of the filtered alloy is always higher than that of the unfiltered one. The latter is especially clearly seen on the alloy subjected to long standing (3 hours), when a high density was obtained as a result of filtration (determined by hydrostatic weighing) and there was no porosity at all temperatures. This fact may support the assumption made in [22-25] that atomic hydrogen is adsorbed in melts on finely dispersed oxide inclusions. Inspection of the filter pieces after their participation in the filtration of the melt showed that their surface was covered with a white substance, which could be filtered out impurity particles.

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