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Change In Shrinkage Of Aluminum Alloy During Crystallization As A Result Of Alloy Modification

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Abstract: Aluminum alloys differ from other non-ferrous alloys due to their high casting properties. This article analyzes the effect of modification of aluminum alloys on their shrinkage. The studies were carried out on alloys of the aluminum–silicon and aluminum–copper systems. These alloys were modified with lithium fluoride, and changes in their shrinkage were investigated. Based on the conducted experiments and tests, a relationship between the shrinkage of aluminum alloys and the amount of modifying additive was established. The article also presents the authors' conclusions drawn from the obtained results.

Keywords: Aluminum, shrinkage, modification, silicon, copper, foundry properties.

INTRODUCTION:

At present, the demand for aluminum alloys in the mechanical engineering industry is steadily increasing from year to year [1–3]. This is due to the fact that their mechanical, physical, and service properties in many cases surpass those of other lightweight alloys [4–7].

During the cooling of an alloy in a casting mold, intensive volumetric shrinkage occurs. Within the first few minutes, a fine-grained solid shell forms on the surface of the casting, and its thickness gradually increases. As a result, the subsequent cooling and solidification of the alloy take place within this surface layer without any contact with the external atmosphere.

In castings produced from a number of alloys, volumetric shrinkage leads to the formation of defects in the form of shrinkage cavities and porosity. At the same time, some alloys (for example, gray cast iron) expand during solidification, which is attributed to the precipitation of graphite having a lower density and a larger specific volume compared to the primary metal matrix [8–10].

For castings produced from all alloys, a further reduction in volume and linear dimensions during subsequent cooling in the solid state is also characteristic. This paper investigates the effect of modifying aluminum alloys with lithium fluoride on the magnitude of their shrinkage.

METHODS

The overall reduction in the volume and dimensions of castings is referred to as shrinkage. In casting practice, volumetric and linear shrinkage are distinguished.

Volumetric shrinkage is defined as the difference between the volume of the liquid alloy that fills the mold cavity and the volume of the casting after solidification. Linear shrinkage refers to the difference between the linear dimensions of the mold cavity and those of the cooled casting.

For convenience, shrinkage is expressed as a percentage relative to the initial volume of the liquid alloy (for volumetric shrinkage) or relative to the initial linear dimensions of the mold cavity (for linear shrinkage). For a number of alloys, volumetric shrinkage can be considered approximately three times greater than linear shrinkage.

If no constraints impede the reduction in volume and dimensions of the alloy during shrinkage, this process is referred to as free shrinkage. Shrinkage varies depending on the chemical composition of the alloy. For example, the shrinkage of gray cast iron decreases with increasing carbon and silicon contents, as well as with decreasing manganese and sulfur contents. In aluminum alloys, an increase in silicon content leads to a reduction in shrinkage [11–13]. In magnesium alloys, increasing the aluminum and zinc contents reduces shrinkage.

In practical casting processes, the reduction in casting dimensions usually occurs under conditions of constrained shrinkage, where mold protrusions, cores, and other elements act as obstacles [14]. Therefore, in many cases, the actual shrinkage is smaller than the free shrinkage. Actual linear shrinkage is referred to as casting shrinkage and is also expressed as a percentage. The value of casting shrinkage is always lower than that of free shrinkage, and the larger and more complex the casting, the greater the difference between them.

Depending on the physical properties of the alloy and its cooling conditions, volumetric shrinkage during solidification may manifest itself in various forms:

a) as concentrated internal cavities located in the regions of the casting that solidify last (shrinkage cavities); in some cases, such cavities may reach the surface and become open;

b) as a uniform change only in the external dimensions, in which case the casting walls are obtained in a dense state;

c) as fine, dispersed voids distributed around individual grains of the alloy throughout the casting thickness; such fine voids are referred to as shrinkage cavities or porosity.

RESULTS

In the experiments, lithium fluoride (LiF) was added to the samples in amounts of 5%, 10%, and 15%. In the first experiment, the AK7 alloy was poured into pre-prepared sand–clay molds to serve as a reference alloy, after which LiF was introduced into the charge composition in amounts ranging from 5% to 15%. Subsequent experiments were carried out on the D16 alloy. The experiments were continued following the same procedure described above. After solidification, the samples were removed from the molds, and their linear dimensions were measured. The linear shrinkage was determined using the following formula.

$$\Delta l_r = \frac{l_1 - l_2}{l_1} \cdot 100\% \qquad (1)$$

where Δl_1 is the length of the mold, mm, and Δl_2 is the length of the casting, mm.

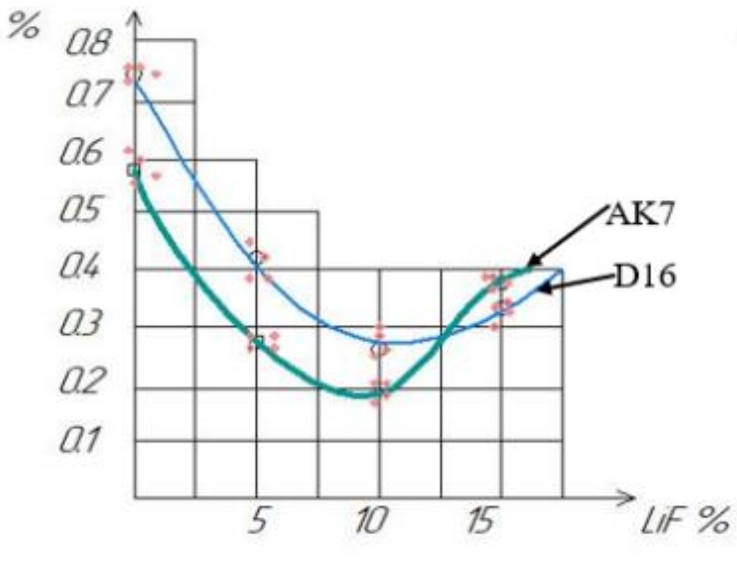

Figure 1. Effect of lithium fluoride (LiF) content added to the aluminum alloy on shrinkage.

The lengths of the extracted samples were measured based on the sample length and the mold length. On the basis of the obtained results, a graph showing the dependence of shrinkage on the lithium fluoride content was constructed (figure 1).

CONCLUSIONS

The experimental results demonstrate that modification of aluminum alloys with lithium fluoride has a significant effect on their shrinkage behavior during solidification.

The addition of 5% lithium fluoride to the charge composition leads to a noticeable reduction in shrinkage, indicating an improvement in the casting properties of the alloy.

The minimum shrinkage value was observed at a lithium fluoride content of 10%, which can be considered the optimal modification level under the given experimental conditions.

A further increase in lithium fluoride content beyond 10% resulted in an increase in shrinkage, suggesting that excessive modifier addition negatively affects the solidification behavior of the alloy.

Based on the obtained results, it is recommended to modify aluminum alloys with lithium fluoride in the range of 5–10% in order to achieve reduced shrinkage and improved casting quality.

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