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Influence of Sand Fluidization on Structure and Properties of Aluminum Lost Foam Casting

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Abstract

The article presents investigation results of the effect of sand fluidization on the structure and mechanical properties of AlSi9 aluminum alloy. Castings were made by lost foam casting process with sand fluidization in mold at the stages of their solidification and cooling. Sand fluidization was achieved by blowing sand bed with compressed air in a foundry container. The metallographic study was carrying out on samples cut from different sections of the castings. Mechanical properties were determined on specimens made from cast samples. Microstructural analysis showed that sand fluidization increases the cooling rate, as a result, the main microstructural components of the alloy – SDAS, eutectic silicon and needles of the rich-iron phase – decrease. Moreover, in different sections of the casting structure is more uniform. With an increasing the air flow rate, a greater refinement of the structure is observed. Through the use of sand fluidization, the mechanical properties of LFC aluminum alloys increase to the level of gravity die castings.

Keywords: Innovative foundry technologies, Lost foam casting, Aluminum alloy, Sand fluidization

1. Introduction

Castings from aluminum alloys are widely used in the automotive industry, often being a replacement for heavy steel and iron cast parts for lightweight and more economical cars. It is well known that the properties of castings from aluminum alloys obtained in metal molds are higher than those cast in sand molds [1]. The gravity die casting, having a number of drawbacks (the high cost of the die mold, the impossibility of making castings of complex configuration, etc.), is superseded by other, more progressive casting methods, one of which is lost foam casting (LFC). With all its advantages (castings of complex configuration are obtained without using of cores, high geometric accuracy and low roughness of castings) LFC has one drawback – the mechanical properties of aluminum alloys are lower than those cast in metal mold. In this regard, many investigations of recent years are aimed at developing methods to improve the properties of aluminum castings obtained by LFC.

One of the methods for increasing the mechanical properties of aluminum alloys is the pressure application to the solidifying metal [2]. Another way is the applying of vibration on the metal at it solidification [3]. There are also methods for simultaneous exposure to vibration and pressure [4]. These studies show that the applying of vibration and/or pressure during the solidification of Al-Si alloys has a positive effect on their properties – the tensile strength, elongation, hardness increase, and the porosity of castings decreases.

There is a method [5], which allows to accelerate the process of castings solidification and cooling. The method is based on the features of LFC – the use of dry silica sand without a binder as a molding filler. Such a bulk static sand bed under the influence of an upward air flow of a certain speed passes into a fluidized state.

With sand fluidization, the heat exchange mechanism changes, and the thermal conductivity of the sand layer increases significantly.

The good heat transfer properties of the fluidized bed led to its use for heat treatment of castings from aluminum alloys, which showed a positive effect on the structure and properties [6]. However, an idea of investigation is to make a fluidized bed in the sand mold in which the casting is located and affect its structure and properties at the casting stage.

Studies [7] showed that the cooling rate of aluminum casting in the fluidized bed of silica sand is 20 times higher than in a static one. Since Al-Si alloys are sensitive to cooling rate, the aim of the work was to establish the laws of the influence of sand fluidization on the structure and mechanical properties of aluminum castings obtained by LFC.

2. Research methodology

This study was conducted on samples and on an industrial casting "body" weighing 0.95 kg (Figure 1 a), which has different wall thicknesses. Castings and samples for mechanical tests were made of aluminum alloy AlSi9 DSTU 2839-94 with a specific gravity of 2660 kg/m^3. Chemical composition of alloy is given in Table 1. The alloy was melted in an induction furnace IAT-0.06 with graphite crucible. The pouring temperature was 730±5 °C.

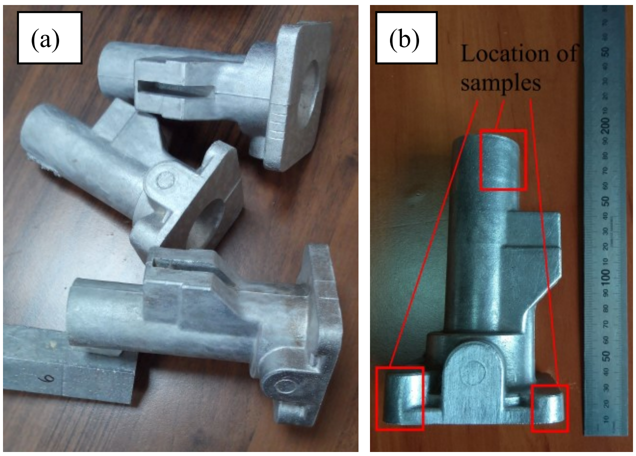

Fig. 1. Casting "body"

Table 1.
Chemical composition (wt. %) of alloy used in experiments

Alloy	Si	Mg	Mn	Cu	Fe	Al
AlSi9 DSTU 2839-94	8 - 11	0.2-0.4	0.2-0.5	< 1.0	<0.9 <1.2*	rest
Investigated alloy	9.13	0.24	0.20	0.92	0.94	rest

* for gravity die casting

For the experiments a metal container with dimensions 190x190 mm and a height of 500 mm (Figure 2) was used. The container has a perforated bottom covered with a fine mesh which is a gas distribution grid. Under the grid there is a cavity that can be connected to a vacuum system or to a compressed air system.

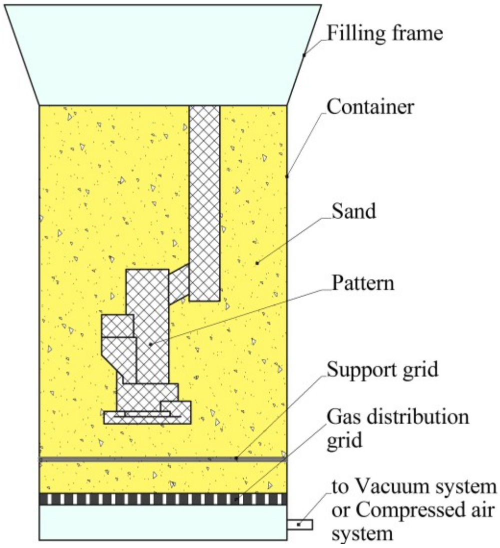

Fig. 2. Container with pattern block

Casting patterns made of expanded polystyrene foam with a density of 25 kg/m^3 were assembled into a pattern block and painted with distene sillimanite refractory slurry with viscosity 17 s by viscometer VZ-4. The pattern assembly was placed in container and filled with silica sand with 0.16 mm average grain size. The container was vibrated to compact the sand, and its top was covered with plastic film. After molding the container was connected to a vacuum system and the mold was poured with melt, the vacuum in the mold was 0.035 MPa.

After alloy pouring, the vacuum was disconnected from the container, and the castings were cooled in one of three modes:

A) The casting was cooled in static sand without any impact, as with conventional LFC.

B) After pouring, the molds were held for 60 s, and (having previously connected the container to the compressed air system), the air supply was turned on of the container bottom to the sand fluidization. The air flow rate was 0.064 m/s, which corresponded to fluidization number of 1.2. Sand fluidization was maintained for 180 s, after which the casting was held in static sand (about 10 minutes) and removed from the mold.

C) Similarly to the previous mode, the casting was cooled in a fluidized sand bed, but at an air flow rate of 0.080 m/s, which corresponded to fluidization number of 1.5.

In order to avoid sand overflowing from the mold during its fluidization, a filling frame 200 mm high was installed on the top of the container. Also, the container is additionally equipped with a support grid, which did not allow the casting to fall to the gas distribution grid.

To study the microstructure, samples were cut from the walls of the castings with a thickness of 10, 20, and 40 mm (Figure 1 b). After grinding, polishing and etching with a 2% aqueous hydrofluoric acid solution, the thin sections were examined using an optical microscope. Tensile tests were carried out on specimens (3 pieces for each mode) cut from a cast samples according to standard DSTU EN 10002-1: 2006. Hardness of castings was measured by Brinell method according to standard DSTU ISO 6506-1: 2007.

3. Results and discussion

3.1 Microstructure evaluation

Figure 3 shows the microstructure of castings obtained by conventional LFC and with sand fluidization, according to the modes described above. The microstructure of investigated alloy contains the following main components: α-Al solid solution (in the form of dendrites), eutectic α-Al + Si (in the form of dark particles), Al_5FeSi iron intermetallic compounds (in the form of light needles), and other intermetallic compounds. Comparing the microstructures visually, it can be noted that in the case of LFC with sand fluidization, the microstructure is finer than with conventional LFC technology, obviously due to a higher solidification rate.

Distance averages between secondary dendrite arm spacing (SDAS) in different sections of the casting obtained by different technologies are given in Table 2. In the wall with 10 mm thickness of the casting obtained with sand fluidization, decrease of SDAS is observed by 1.2-1.5 times in comparison with the microstructure of conventional LFC castings. In the wall of 20 mm, SDAS decreases already by 1.4-1.6 times, and in the wall of 40 mm by 1.5-1.8 times.

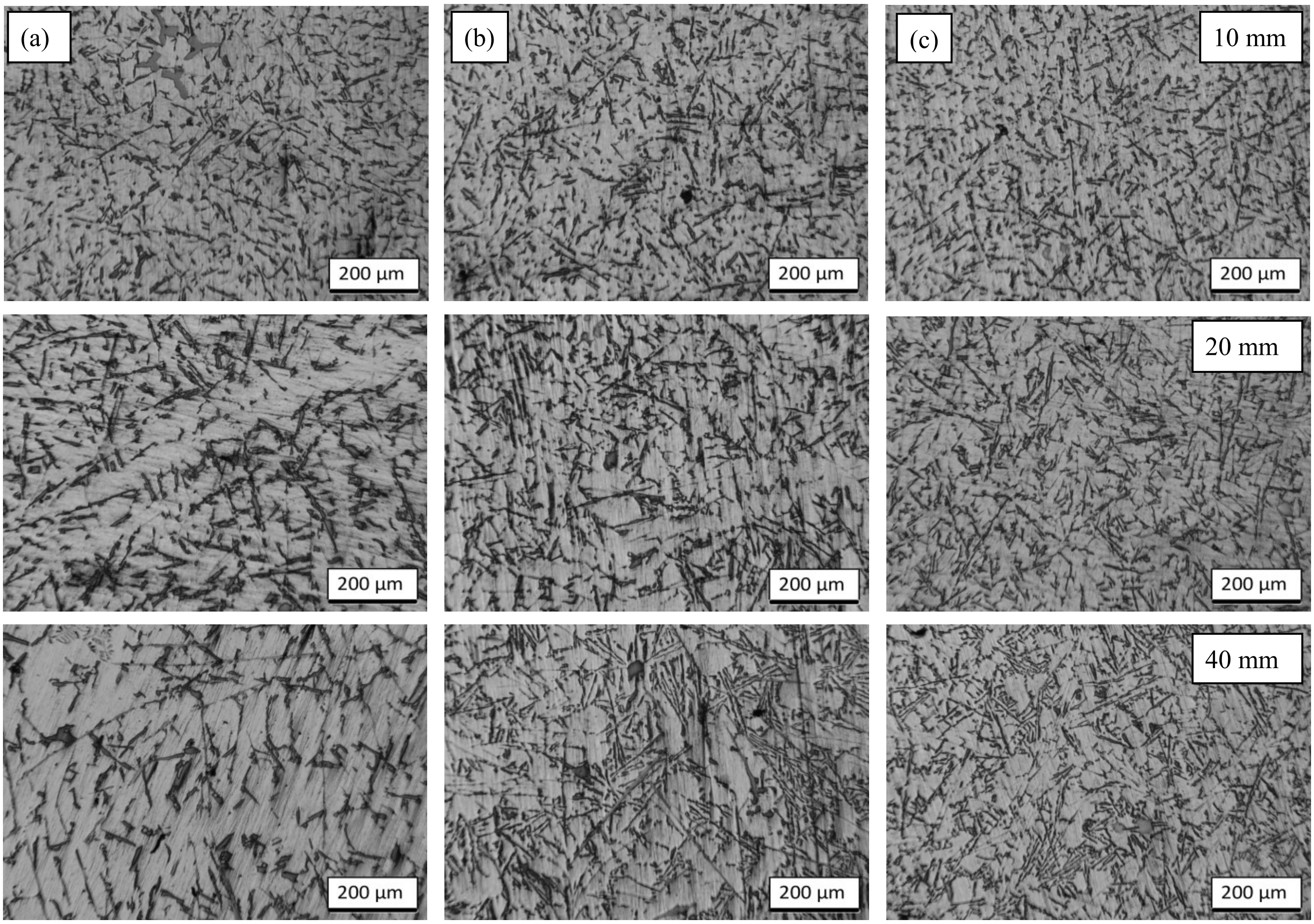

Fig. 3. Microstructure of different wall thickness of castings obtained by conventional LFC technology (a), technology with sand fluidization mode B (b) and mode C (c)

Table 2.
Sizes of microstructural components

Casting technology	Casting wall thickness		
	10 mm	20 mm	40 mm
	SDAS, μm		
LFC	37.1	44.4	66.9
LFC mode B	28.9	32.1	38.1
LFC mode C	26.5	27.6	31.3
	Al_5FeSi needle length, μm		
LFC	124.4	230	268.8
LFC mode B	95	163.8	180.6
LFC mode C	78.1	134.4	150
	Eutectic silicon size, μm		
LFC	41.2	58.5	70.3
LFC mode B	39.2	43.7	44.3
LFC mode C	37.1	36.8	39.8

An analysis of the microstructure of castings also shows that with increasing wall thickness of the casting, SDAS increases, which indicates a higher solidification rate of the melt in a thin section. The results also show that the microstructure of castings obtained with sand fluidization is more uniform in different sections.

The main part of iron is present in the alloy structure in the form of a β-phase – Al_5FeSi needles. Since the iron content in the studied alloy is extremely high, rather long needles of iron intermetallic are observed in the structure of LFC castings (Fig. 3). In castings obtained with sand fluidization in a wall 40 mm thick, a decrease in the length of iron-rich needles by a factor of 1.5-1.8 is observed in comparison with conventional LFC castings (Table 2). In a 20 mm thick wall, the length of Al_5FeSi needles decreases 1.4-1.7 times, and in a 10 mm wall – 1.3-1.6 times. It is known [8] that the β-phase in the form of Al_5FeSi needles acts as a stress concentrator and sharply reduces the plasticity of Al-Si alloys. Since the lengths of iron-rich needles in castings obtained with sand fluidization are shorter, their negative impact on mechanical properties is reduced in comparison with castings obtained by conventional LFC technology.

In the microstructures of all castings (Figure 3) rough eutectic silicon particles are observed, which can lead to a sharp decrease in the plastic properties of the alloy. Visually, finer eutectic silicon particles are observed in thinner walls. In castings obtained by conventional LFC technology, eutectic silicon particles have a larger size than in castings obtained with sand fluidization (Table 2). So, in walls 40 mm thick of castings obtained with sand fluidization, a decrease in the lengths of eutectic silicon particles by 1.6-1.8 times is observed in comparison with castings obtained by conventional LFC. In a section of 20 mm, their length decreases by 1.3-1.6 times, and in a section of 10 mm, by 1.1-1.2 times. Reducing of eutectic silicon particles is due to the higher cooling rate when using sand fluidization.

3.2 Mechanical properties

The ultimate tensile strength and elongation of as-cast alloy were determined on samples that were manufactured under the same conditions as castings. Hardness was measured directly on the castings. Table 3 shows the results of mechanical tests and the values of mechanical properties regulated by the Ukrainian national standard DSTU 2839-94 Aluminum Casting Alloys. Specifications.

Table 3.
Mechanical properties of AlSi9 casting

Casting technology	Ultimate tensile strength, MPa	Elongation to fracture, %	Hardness, HB
Sand, Investment, GDC, HPDC (as cast) (DSTU 2839)	≥157	≥1.0	≥60
GDC, HPDC (T1*) (DSTU 2839)	≥196	≥0.5	≥70
LFC	148	0.8	69
LFC mode B	198	1.1	80
LFC mode C	223	1.2	82

*T1 – artificial aging without preliminary hardening
GDC – gravity die casting; HPDC – high pressure die casting

The results show that in castings obtained by conventional LFC technology, the strength and ductility are slightly lower than the standard regulates. This is due to the fact that the iron content in the investigated alloy exceeds the limit normal for sand casting (Table 1). At the same time, when sand fluidization was used at an air flow rate of 0.064 m/s, the tensile strength of AlSi9 alloy increased to 198 MPa, and at an air rate of 0.080 m/s, up to 223 MPa. The elongation also increased to 1.1 and 1.2%, respectively. This is due to a decrease in the size of the β-phase Al_5FeSi and eutectic silicon. However, despite the fact that the iron-rich phase was reduced, the plastic properties of the alloy under study remained at a relatively low level, due to the high iron content.

The hardness of the LFC casting is at a sufficient level. And when applying sand fluidization, it had increased by 15%. This is because, at a high cooling rate of the casting, the Al matrix is hardened by alloying elements. It should also be noted that as a result of sand fluidization during LFC, the alloy strength, ductility and hardness are at a level similar to a T1 heat treatment.

4. Conclusions

1. The sand fluidization in the mold at the casting stage allows to increase the cooling rate of the aluminum alloy. As a result, the size of SDAS decreases by 1.5-1.8 times, the size of eutectic silicon by 1.3-1.6 times, the length of the needles of iron intermetallic 1.4-1.8 times. Sand fluidization also contributes to a more uniform structure in different sections of the casting.
2. The strength of aluminum LFC due to sand fluidization was increased by 25-40%, ductility and hardness by 10-20%. This allows the use of such castings instead of the more expensive die castings.
3. The results of the work showed that the LFC technology has the potential to improve the properties of aluminum alloys

due to sand fluidization in the mold. There is also the need to conduct a more advanced study of the effect of sand fluidization on the properties of aluminum alloys of various grades.

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