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**THE USE OF GAS-DYNAMIC PRESSURE TO IMPROVE  
THE MECHANICAL PROPERTIES OF ALUMINUM  
CASTING ALLOYS WITH HIGH IRON CONTENT**

*Presents the analysis of technological methods to reduce the negative impact of iron on the mechanical properties of aluminum casting alloys. It is shown that traditional methods have practically exhausted their resource efficiency. Proposed combined method of influence on the formation of an alloy with high content of iron using ultra-modifier and increasing the gas pressure in the crystallization. On the basis of the results of experimental studies of the application of the technology of gas-dynamic impact to improve the quality of castings from aluminum alloys with high iron content.*

*Key words: aluminum alloys, technology, gas-dynamic influence, modification, microstructure, mechanical properties.*

**Introduction**

High content of iron is among the problems that prevent to obtain high-quality aluminum alloy casts. Iron is a harmful impurity in aluminum alloys since it forms compounds of various compositions (like  $\text{FeAl}_3$ ,  $\text{Al}_2\text{SiFe}$ ,  $\text{Al}_4\text{Si}_2\text{Fe}$ ,  $\text{Al}_5\text{SiFe}$  etc.) [1]. At normal crystallization temperatures, all iron-containing phases feature a coarse crystalline structure and therefore highly contribute to deteriorating mechanical properties, plasticity in particular. In hypoeutectic silumins, for example, iron forms a triple intermediate phase  $\beta(\text{AlFeSi})$  with alloy components, which is crystallized as a coarse needle-shaped precipitation considerably affecting the plastic properties of alloys. Iron effect on elongation  $\delta$  of A360 alloy, is shown in Figure 1 [2].

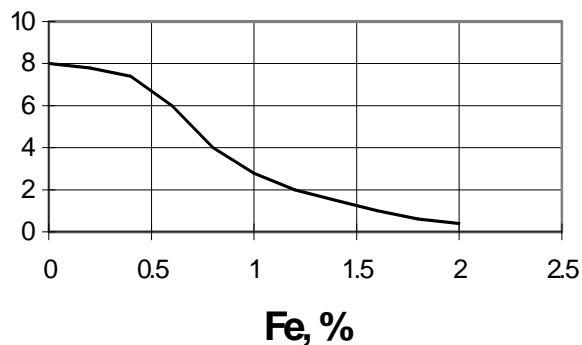


Figure 1 – Iron effect on elongation of A360 alloy

Iron effect on elongation of A360 alloy, is polynomially dependent, as expressed by equation:

$$\delta = -3,1141 \cdot Fe^4 + 14,581 \cdot Fe^3 - 20,75 \cdot Fe^2 + 4,2909 \cdot Fe + 7,928; \quad (1)$$

where  $\delta$  = - is elongation [%]; Fe - is iron content [%].

Aluminum alloys are saturated with iron mainly from iron pots of holding and melting furnaces, crucibles, and re-melt of aluminum scrap containing steel lining and silicon pieces that haven't been removed before melting. Eutectic silicon and iron-containing phases in Al-Si alloys feature a covalent interatomic bonding, which is responsible for the direction of their crystallization. To reduce anisotropy of valent electrons stress fields in the crystallization centers formed, the nature of interatomic interaction needs to be changed. Among other options, the shape and size of phase inclusions with covalent interatomic bonds can be changed by introducing impurities into a melt so that their atoms would weaken covalent component of the interatomic bond while dissolving in the growing crystal, thereby reducing orientation effect of the crystal on the adjacent liquid phase.

While this problem has been successfully resolved in the part of changing eutectic silicon inclusion shape, practical aspects of modification of iron-containing phases still need to be addressed. Preventive measures are therefore widely used in order to rule out all contacts of steel and cast-iron melting and charging tools with aluminum melt-containing crucibles. The main challenge of obtaining high-quality coatings on steel and cast-iron crucibles lies in ensuring the required stability and mechanical strength of the coating. Therefore, the development of

technological solutions aimed to rule out a negative effect of iron in aluminum casting alloys is still urgent.

### Literature review

Iron is partially soluble in aluminum and its alloys. At temperatures close to aluminum melting point,  $\text{Al}_3\text{Fe}$  crystals start to precipitate from alloys with over 1.7% content of iron. These crystals are more dense than aluminum alloy and look like large plates. Therefore, after iron aluminide is frozen-out, it can be separated from the alloy using one of the following methods [3].

A several hours settling of an iron rich aluminum alloy showed that iron components were mainly coalescing in the bottom part of the bath and, to a smaller extent, along the walls of the crucible. Iron therefore is depleted in the upper part of the melt. For example, after a seven-hour settling at  $700^{\circ}\text{C}$ , iron content in aluminum alloy at the depths of 28, 36, and 45 cm has reduced from 2,76% to 1,59%, 2,01%, and 2,75%, respectively.

This method therefore is unable to ensure an adequate reduction in iron content and a clean-cut separation of the iron component. Attempts have been made to apply directed crystallization (i.e., cooling of crucible bottom) in order to achieve better concentrations of iron [4]. In this case, solid phase crystals precipitate in the bottom part alone. Since there is no heat convection inside the liquid under such conditions, the crystals formed are not supposed to spread throughout the metal. To allow crystallization to proceed normally, diffusion rate in the liquid may not be less than the cooling rate. With a plain settling, scarce and relatively large crystals are forming a thin (5-8 mm) layer on the crucible bottom, this layer getting thicker (up to 20 - 25 mm) with directed crystallization. With 3 - 4% iron content in the alloy, this method provides that 75% of the resulting alloy contain 1,7 - 1,9% iron. Settling with directed crystallization therefore basically allows eutectic - solid phase separation, though its capacity is extremely low.

Centrifuging has been used to accelerate separation between liquid and solid phases of various densities. Tests showed that iron content in the upper layers could be reduced from 3% to 1,5 - 1,7% at high rotation rates alone.

An attempt to demagnetize iron-containing phase of the aluminum alloy has also failed, since  $\text{Al}_3\text{Fe}$  is not susceptible thereto. Solid

phase was adequately separated from the liquid by filtration. There's not enough information on outer parameters and modification effect on the shape and size of iron-containing phases in aluminum alloys [5-8].

This paper is therefore aimed to review approaches to neutralization of negative effects on iron in aluminum casting alloys by using various techniques, and to analyze the effect of modification and gas-dynamic exposure on the properties of A305 high-iron alloy.

### **Materials and methods**

Binary alloy eutectic systems are rich with metal impurities. For example, eutectic content of iron and silicon reaches 1,7% and 1,56 %, respectively. Separating such phases is impracticable. However, content of metal impurities in eutectic alloys can be reduced by certain components addition to the alloys so that eutectic point would displace to the left. For example, by introducing 25 - 30% copper or nickel into iron-contaminated aluminum, we can obtain a melt with lower iron content. By using 37% magnesium, the resulting melt can theoretically contain about 0,03% iron. 1,5 - 3% manganese also provides a considerable reduction in the iron content.

Apart from iron, other metals can be also isolated from aluminum. For example, magnesium additive is able to extract manganese, chromium, cerium, titanium, vanadium and molybdenum as aluminides, and silicon as magnesium silicide. Zinc addition can reduce solubility of heavy metals aluminides in aluminum alloys.

Since the additional metals mainly remain in the residual melt, the resulting aluminum alloys are fit as foundry alloys alone or are subjected to further treatment. However, in specific cases, iron content can be reduced to acceptable levels by introducing relatively small additives.

Manganese, for example, is a part of numerous alloys and an efficient catalyst for iron separation. In recent years, one more trend has been actively developing, which is neutralization of the negative effect of iron on aluminum alloy properties by changing morphology of formed additional phases by means of alloying. During alloying process, intermetallic compounds are assuming a spherical shape and therefore exert no negative effect on plasticity, crack resistance, and other mechanical properties. Positive results have been obtained by enriching melts with beryllium, manganese, cerium, and other transition metals silumins [4]. This is a more promising trend, since it "recalls to life" certain secon-

dary alloys, which have been previously applied in production of second-grade moldings alone. Moreover, which is more important, it can be used as a basis for future research aimed to improve the quality of aluminum alloys by reinforcing those with iron-containing compounds. This is supported by the reinforcement with ultra-fine Al<sub>3</sub>Fe intermetallic compounds [4] or by means of mechanical milling of intermetallic compounds that have already formed in the melt. As known from [3], favorably shaped fine iron intermetallic compounds can be obtained directly in aluminum alloys by rapid crystallization or, in other words, by a controlled crystallization in such modes and at such parameters which enable additional phases to precipitate with a given morphology and sizes. Control over the intermetallic compounds formation process shall be certainly preceded by a thorough and comprehensive research.

The process of forming iron-containing phases is dependent on the state, structure, macro - and microinhomogeneity of crystallizing melt rather than on thermodynamic and kinetic parameters of crystallization itself. The state of melt, in its turn, is a function of a complex of factors, including the nature of meltdown and dissolution of charging materials during melting, such as iron dissolution kinetics, addition conditions, surface quality, primary solid structure, presence of dissolved gases, impurities, etc. Dissolution of iron in aluminum and its alloys is among the key factors responsible for formation of additional iron-containing compounds. Dissolution of iron and formation of intermetallic compounds are highly influenced by the temperatures and temperature changing rate at various stages.

### Results

Experimental studies of the combined effect of gas-dynamic influence and TiCN modification have been studied on aluminum alloy cast sections of such chemical composition, as shown in Table 1:

Table 1

Chemical composition of Al alloy used in the research.

Al	Si	Fe	Ti	Mg	Cu	Zn
Base	5,5	0,6	0,14	0,6	1,45	0,3

"Conveyor Mount Bearing Head" molding by mass of 1,1 kg, was cast from alloy which is presented in Table 1, into a heated and painted iron mold with a 40mm minimum wall thickness. Casting temperature was 640<sup>0</sup>C. Melt in the iron mold was exposed to gas dynamic effect at

initial pressure of 0,15 – 0,2 МПа with a further increase up to 2 – 3,5 МПа, all in accordance with estimated dynamics of pressure growth in the molding – gas entering device system. Figure 2 shows a microstructure of alloy A305 before and after treatment.

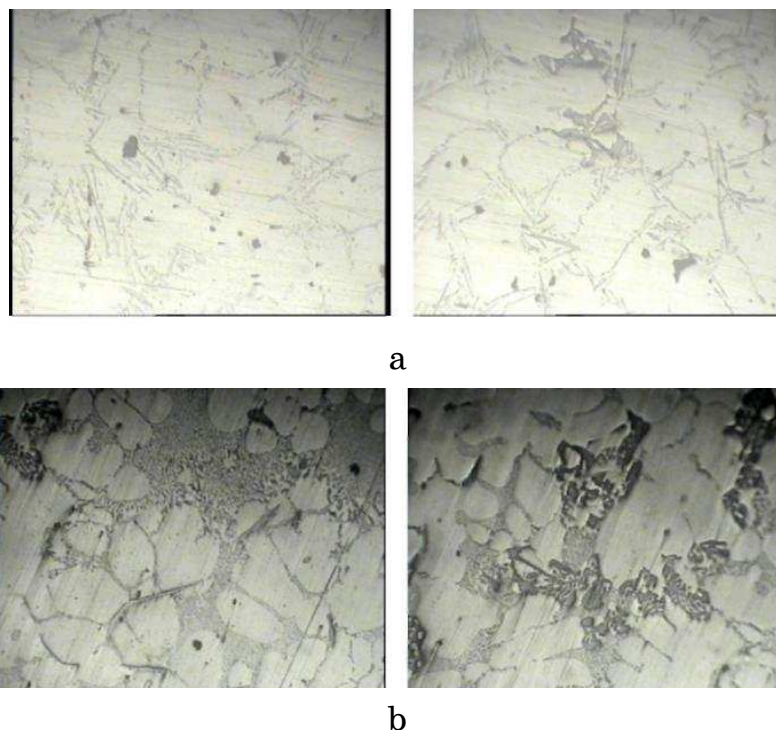


Figure 2. - Microstructure of alloy No 1 before (a), and after combined modification (b)

Table 2 shows test results on determining mechanical properties of A305 alloy moldings, as produced using the combined gas-dynamic and modification treatment, in comparison with respective properties of cast metal produced by conventional casting technology.

Table 2

Mechanical properties of A305 alloy

No of specimen		$\sigma_s$ , МПа	HB, (МПа)	$\delta$ , %
1	Before treatment	165,3	510	2,0
2		163,6	500	1,9
3		165,1	500	1,9
4	After treatment	195,3	512	2,30
5		193,8	508	2,29
6		194,2	511	2,31

Using the proposed technology allowed us to decrease and spheroidize iron-containing phases, to improve mechanical properties by 15-20%, and to reduce the volume of casts discarded due to microporosity and bubbles by 28%.

### Conclusions

1. Available techniques designed to neutralize negative effect of iron on aluminum alloys properties have been reviewed. It has been shown that the combined use of aluminum alloys modification and crystallization processes in non-equilibrium for mechanical properties of high-iron aluminum casting alloys improvement is of a great interest.

2. The studies on the combined gas dynamic effect and modification processes, as applied to improve the properties of A305 castings while crystallizing in the iron mold, have proved that the proposed technology provided for decrease and spheroidize iron-containing phases, 15-20% improvement of mechanical properties, and 28% reduction in the volume of casts discarded due to microporosity and bubbles.

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