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THE STRUCTURE AND PROPERTIES FORMATION OF THE MODIFICATED Al−Mg−Si−Cu ALLOY

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Abstract. ***Purpose***. Determining the laws of the complex effect of modification on the Al−Mg−Si−Cu AL28 alloy structure formation and mechanical properties in cast and heat-treated states and optimization of the parameters of the complex modifying − heat treatment to obtain a new material with a high complex of properties based on the alloy under study. ***Methodology.*** The microstructural, X-ray, spectral analysis, hardness measurement, tensile tests are used. The studies were carried out according to standard methods on the equipment that passed the state verification. ***Originality.*** The determination of the structure formation of the Al−Mg−Si−Cu AL28 alloy under the conditions of the complex effect of 0.05 % Sr and 0.05 % TiCN modification and heat treatment was carried out for the first time. ***Practical value.*** The established regularities made it possible to optimize the qualitative and quantitative composition of the modification and the thermal and temporal parameters of heat treatment; as a result, a material with a significantly increased complex of mechanical properties was obtained.

Keywords: aluminum alloy; strontium; titanium carbonitride; quenching; aging

ФОРМУВАННЯ СТРУКТУРИ ТА ВЛАСТИВОСТЕЙ МОДИФІКОВАНОГО СПЛАВУ СИСТЕМИ Al–Mg–Si–Cu

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Аннотація. ***Мета.*** Визначення закономірностей комплексного впливу модифікування на структуроутворення і механічні властивості сплаву АЛ28 системи Al−Mg−Si−Cu в литому і термічно обробленому станах та оптимізація параметрів комплексної обробки «модифікування − термічна обробка» для отримання нового матеріалу з підвищеним комплексом властивостей на основі дослідного сплаву. ***Методика.*** Використані мікроструктурний, рентгеноструктурний, рентгеноспектральний аналіз, вимірювання твердості, випробування на розтягнення. Дослідження проведені за стандартними методиками на обладнанні, що пройшло держперевірку. ***Наукова новизна***. Визначення закономірностей структуроутворення в сплаві АЛ28 системи Al−Mg−Si−Cu в умовах комплексного впливу модифікування 0.05 % Sr і 0.05 % TiCN та термічної обробки проведено вперше. ***Практична значимість***. Встановлені закономірності дозволили оптимізувати якісний та кількісний склад модифікування та термочасові параметри термічної обробки, в результаті отриманий матеріал з істотно підвищеним комплексом механічних властивостей.

Ключові слова: алюмінієвий сплав: стронцій: карбонітрид титану: гартування: старіння

ФОРМИРОВАНИЕ СТРУКТУРЫ И СВОЙСТВ МОДИФИЦИРОВАННОГО СПЛАВА СИСТЕМЫ Al–Mg–Si–Cu

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Аннотация. *Цель.* Определение закономерностей комплексного влияния модифицирования на структурообразование и механические свойства сплава АЛ28 системы Al−Mg−Si−Cu в литом и термически обработанном состояниях и оптимизация параметров комплексной обработки «модифицирование − термическая обработка» для получения нового материала с повышенной комплексом свойств на основе исследуемого сплава***. Методика.*** Использованы микроструктурный, рентгеноструктурный, рентгеноспектральный анализ, измерение твердости, испытания на растяжение. Исследования проведены по стандартным методикам на оборудовании, прошедшем госповерку. ***Научная новизна.*** Определение закономерностей структурообразования сплава АЛ28 системы Al−Mg−Si−Cu в условиях комплексного воздействия модифицирования 0.05 %Sr и 0.05 % TiCN и термической обработки проведены впервые. ***Практическая значимость.*** Установленные закономерности позволили оптимизировать качественный и количественный состав модифицирования и термовременные параметры термической обработки, в результате получен материал со значительно повышенным комплексом механических свойств.

Ключевые слова: алюминиевый сплав; стронций; карбонитрид титана; закалка; старение

Introduction

Improving the quality and reliability of products and constructions is one of the most important tasks facing metallurgists and machine builders. The decision of these problems is directly related to the improvement of the properties of structural materials, including various aluminum based alloy, both casting and deformable alloys [1].

Modification is one of the most effective ways used to produce alloys, in particular, based on aluminum, with a unique set of properties, first of all it is about simultaneously increasing the strength and plastic properties of the material due to the formation of a favorable structure and phase composition [2].

There is data about the positive effect of the strontium modification on aluminum alloys [3], which indicate an increase in plasticity without an increase in strength, and a positive effect on the structure formation of these alloys of fine powders TiCN is also known. The effect of heat treatment on the structure formation of aluminum alloys is also well studied [4; 5]. However, there is no information about the complex modification effect of strontium and titanium carbonitride, with following heat treatment on Al−Mg−Si−Cu alloys. It does not allow to purposefully control their structure formation to produce new high-tech materials with an increased level of properties in order to manufacture high-quality products.

Thus, the establishment of structure formation patterns of heat-treated complex microalloyed by Sr + TiCN Al−Mg−Si−Cu alloys is an actual task.

Purpose

The purpose of the work is to determine the patterns of the complex effect of modification on the structure formation and mechanical properties of the Al−28 Al−Mg−Si−Cu alloy in cast and heat-treated states to obtain a new material with an increased complex of properties based on the research alloy.

Material

The object of the study is an aluminum alloy conditionally named Al–28, modified with 0.05 % TiCN, and a complex of 0.05 % Sr + 0.05 % TiCN (Table 1).

Table 1

The Chemical Composition of the Al–28 Alloy

Chemical element, % mass.						
Al	Si	Mg	Cu	Fe	Sr	TiCN
base	1,7…1,8	5,1…5,4	0,5-0,6	<0,6	–	–
	1,7…1,8	5,1…5,4	0,5-0,6	<0,6	0,04-0,06	0,04−0,06
	1,7…1,8	5,1…5,4	0,5-0,6	<0,6	–	0,04−0,06

Methodology and results

The microstructural, X-ray, spectral analysis, hardness measurement, tensile tests are used. The studies were carried out according to standard methods on the equipment that passed the state verification.

The structure formation and phase composition of the Al–Mg–Si–Cu system alloy (conventionally called Al−28) were studied at various cooling rates (Fig. 1, 2, Table 2).

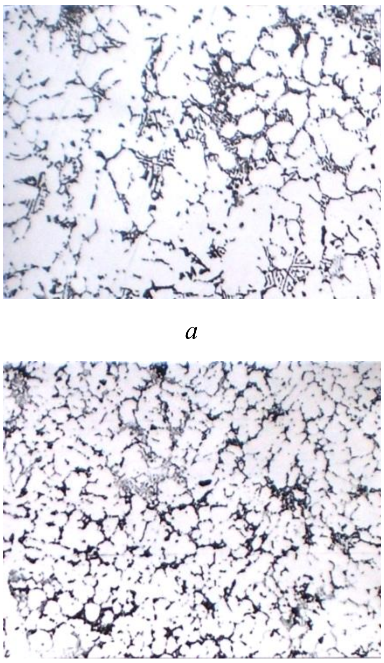


Fig. 1. Microstructure of the Al−28 alloy (×100), etching − 0.5 % HF: a − cooling rate ~ 0.1 K/s; b − cooling rate ~ 100 K/s

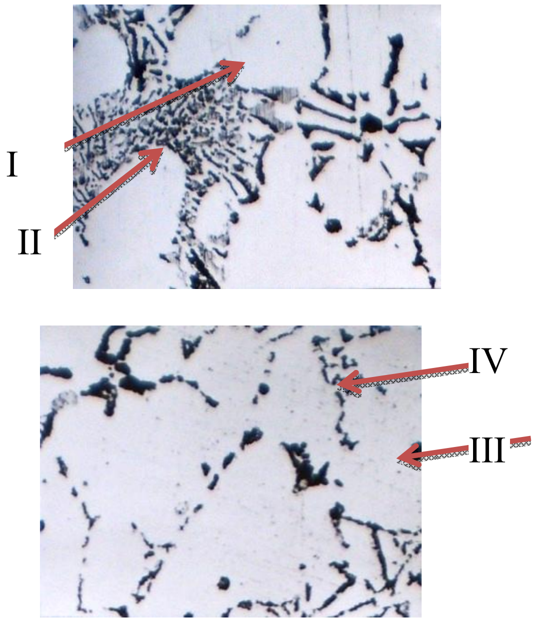


Fig. 2. Intermetallic phases in the Al−28 alloy (×400), etching 0.5 % HF: I − (Al, Si, Fe); II − Mg_2Si; III − $CuMgAl_2$; IV − $FeAl_3$

The structure of the unmodified alloy Al−28 which crystallized at different cooling rates, consists of weakly branched, rounded in cross section, α-Al dendrites solid solution and various intermetallic compounds.

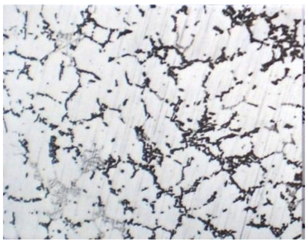
By the methods of color selective etching, spectral and structural analysis the phase identification was carried out. Crystals of skeletal or plate type, poorly digestible, identified as phase type (Al, Si, Fe) (presumably Al_5SiFe or Al_8SiFe_2). Bluish-colored, finely differentiated crystals, forming with α-Al cooperative and conglomerate eutectics, defined as the Mg_2Si. The light brown phase, non-uniform in color, crystallizes in the form of plate crystals with a more round section boundary than (Al, Si, Fe) identified as $CuMgAl_2$ (or $CuMg_4Al_6$). Eutectic is a three-phase structural component: (α-Al−Mg_2Si−Al_5SiFe (Al_8SiFe_2)).

Table 2

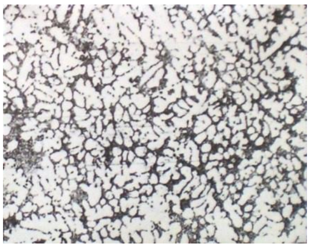
The Phase Composition of the Al−28 Alloy

Phase	Lattice type	Lattice parameter , Å
Mg_2Si	Cubic	a = 6,39
$FeAl_3$	Orthorhombic	a = 47,43, в = 15,45, c = 8,07
$CuMg_4Al_6$	–	–
$Cu_3Mg_6Al_7$	Cubic	a = 12,12
(Al, Si, Fe)	Hexagonal	–
α-Al_2O_3	Hexagonal	a = 4,75, c = 6,49
$MgAl_2O_4$	Cubic	a = 8,0831
(Mg−Al−O)	Monoclinic	a = 9,305, в = 5,64, c = 12,0
β-AlMg	Cubic	a = 28,28
(Al, Cu, Mg, Si)	Hexagonal	c = 4,05, a = 10,04

The most effective influence on the microstructure and mechanical properties of the A1−Mg−Si−Cu Al−28 alloy makes complex modification of 0.05 % Sr + 0.05 % TiCN (Fig. 3).



a



b

Fig. 3. Microstructure of the Al−28 alloy modified by 0.05 % TiCN + 0.05 % Sr (×100), etching 0.5 % HF: a − Vcooling = 0.1 K/s; b − V cooling ~ 100 K/s

The eutectic in the modified Al−28 alloy is three-phased: α-Al−Mg_2Si−AI_5SiFe (Al_8SiFe_2). The addition of the 0.05 % Sr + 0.05 % TiCN to the alloy leads to the precipitation of the iron-containing phase mainly independently or at the eutectic boundary (α-Al−Mg_2Si) − α-Al dendrites, or in α-Al dendrites. Strontium in eutectic is not detected. It dissolves in the matrix.

The primary crystals of α-Al with the adding of modifiers do not change the shape of growth and grow in the form of dendrites with varying degrees of branching and a different cross-section of the branches. The Mg_2Si eutectic component in the modified 0.05 TiCN + 0.05 Sr alloy grows in the form of rounded or skeletal crystals.

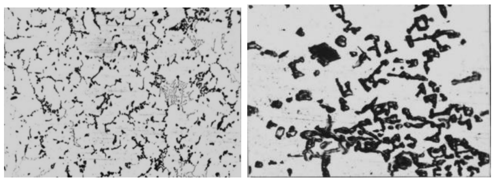
The structure is formed with a high degree of co-operativity of the eutectic and the predominance of rounded interfaces in the Mg_2Si, which has a beneficial effect on the hardness of the alloy (Table 3).

Table 3

Influence of Modification on Al-28 Alloy Hardness

Alloy	Hardness, HB
Al−28	56
Al−28 + 0.05 %TiCN	65
Al−28 + 0,05 %Sr + 0.05 %TiCN	62

The regularities of the structure and properties formation of the alloy Al−28 (0.05 % Sr and 0.05 % TiCN) during heat treatment are established. The heat treatment was carried out according to the regyme: heating temperature for − (t_q) − 535 ^{0}C, holding for 3.5 hours, cooling − in water; aging temperature (t_a) − 175 ^{0}C, holding for 3 hours. The microstructure of the Al−28 alloy (0.05 % Sr + 0.05 % TiCN) after the heat treatment according to the overhead mode is shown in Figure 4.



a *b*

c

Fig. 4. The general microstructure of the Al−28 alloy (a), modified with 0.05 % Sr + 0.05 % TiCN, after heat treatment (×100) and intermetallic phases: Mg_2Si (b), (Al, Si, Fe) (c) ×500, etching − 0.5 % HF

The hardening during aging of these alloys is mainly due to the precipitation of dispersed Mg_2Si particles from a solid solution. There is a significant spheroidization and grinding (Fig. 4), which favorably influences the formation of the final structure of the material. The iron-containing phase in does not experience significant changes − only a slight grinding of it and dissolving a small amount of small crystals is observed.

The results of measurements of the mechanical characteristics of the alloy AL28 are shown in Table 4.

Table 4

Mechanical properties made of alloy Al−28

Alloy	σ, MPa	δ, %
Unmodified	200	1,0
0,05 %Sr i 0,05 %TiCN modified	220 220 220	1,6 2,0 2,0

Thus, the modification of the Al−28 alloy with a complex of 0.05 % Sr + 0.05 % TiCN leads to an increase in the ultimate strength in the heat treated state by about 10 %, and plasticity, by 2 times as compared to the initial unmodified state.

Conclusions

1. The structure formation and phase composition of the Al−Mg−Si−Cu system (conventionally named AL28) alloy at various cooling rates were studied.

2. The most effective influence on the microstructure and mechanical properties of the AL28 alloy is made by the complex modification of 0.05 % Sr + 0.05 % TiCN. As a result, a structure with a high degree of co-operative eutectics and a predominance of rounded sections of the

section in the framework of Mg_2Si is formed, which has a beneficial effect on the mechanical characteristics of the material.

3. In the modified A1−Mg−Si−Cu alloys, the sequence of phase transformations typical for the initial alloy is preserved, only their temperature ranges change. As a result the phase composition and quantitative ratios of the intermetallic phases in the research A1−Mg−Si−Cu alloys change in the process of modification. No triple eutectics involving strontium were found in the studied alloys.

4. As an optimum, we can recommend the complex treatment of “modifying 0.05 % Sr + 0.05 % TiCN + heat treatment” of the AL28 alloy, which provides an increase in ultimate strength by about 10 %, and plasticity − 2 times compared to the original unmodified state.

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