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IMPROVING THE STRENGTH AND CORROSION PROPERTIES OF ALUMINIUM ALLOYS WHEN MODIFICATION WITH NANODISPERSED COMPOSITIONS

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Aluminium alloys of the Al-Si and Al-Mg-Sc systems, which are promising for nuclear power generating facilities, were studied. The AK9 aluminium casting alloy and the 1545 wrought alloy were selected as the study materials. Modification of aluminium alloys with a multicomponent nanodispersed modifier based on Mg_2Si and SiC was proposed. Grain grinding of modifying alloys by 1.5–2 times, strength properties increasing by 12…18% and corrosion resistance improving were achieved. The mechanism of action of the multicomponent nanodispersed modifier in an aluminium melt was proposed. The use of such modifiers facilitates the technological process, is environmentally safe, and leads to a uniform distribution of the introduced nanocompositions, which increases the strength and stability of alloys. The results achieved showed the effectiveness of modification aluminium alloys with nanodispersed compositions.

INTRODUCTION

The technology of manufacturing high-quality products plays a significant role in the development of mechanical engineering and energy industry. The introduction of new efficient, less metal- and energy-intensive technologies will allow creating high-performance, reliable and long-lasting, competitive equipment. Structural aluminium alloys of the Al-Si and Al-Mg-Sc systems promising for nuclear power were studied in order to be able to use them at operating temperatures up to 500 ^{o}C for nuclear reactors.

Publications on the problem of modification aluminium alloys were analyzed [1–4]. Wrought aluminium alloys of the Al-Cu-Mg, Al-Mg-Sc systems for welded sheet structures and heat pipes of nuclear reactors and aluminium casting alloys of the Al-Si system are widely used in stressed mechanical engineering structures. Analysis of the state of the art of the problem of mechanical, technological and operational properties of structural aluminium alloys allows us to conclude that it is advisable to modification the melt with nanodispersed refractory compositions. For effective consumption of nanomodifier, the compositions should have the following properties: correspondence of the physico-chemical nature of the modifier elements and the alloy matrix; isomorphic crystal lattices; small difference in atomic radii; lack of solubility in the main matrix; high melting point of the introduced composition, which has a certain critical size during crystallization [3].

Promising directions for aluminium alloys modification are carried out in the field of powder modifiers application. The use of such modifiers facilitates the technological process, is environmentally safe, and leads to a uniform distribution of the introduced nanocompositions over the casting cross-section, which increases the strength, ductile properties, and stability of alloys. Carbides, nitrides, carbonitrides, silicides and other refractory elements and compounds can be the modifiers [4, 5, 7, 10].

PURPOSE AND TASK STATEMENT

The purpose of this work is to improve the mechanical properties and corrosion resistance of aluminium alloys when modifications with nanodispersed compositions. To achieve this purpose, the following tasks were set: to conduct a study of the mechanical properties complex, necessary technological characteristics, corrosion resistance and alloy structure before and after modification.

Aluminium alloys of the Al-Si and Al-Mg-Sc systems are used for critical parts in mechanical engineering. Such alloys have sufficient indicators of mechanical properties, ductility, deformability, weldability, which determines their prospects for critical structures. However, the use of aluminium alloys is complicated by the simultaneous propagation of various types of corrosion during operation. Taking into account the high requirements for mechanical engineering and nuclear technology products.

Industrial enterprises of Ukraine use modification of aluminium casting alloys with sodium salts. However, low-melting sodium salts are not technologically advanced for massive melts treatment, since the short time of action of the modifier does not allow achieving the necessary grain grinding and improving the mechanical and technological characteristics of alloys. A promising direction for improving the quality and properties of aluminium alloys is the use of dispersed refractory modifiers based on carbides, nitrides, borides, and pure metals with particle sizes up to 100 nm [9, 11].

MATERIALS AND METHODS OF THE STUDY

In this paper, the mechanical and corrosion properties of the АЛ4 casting alloy (AK9) of the Al-Si system and the 1545 wrought alloy of the Al-Mg-Sc system were studied before and after modification. The chemical composition of the studied alloys is shown in Table 1.

Table 1

Chemical composition of the AK9 and 1545 alloys

Alloy	Al	Si	Mg	Cu	Sc	Zn
AK9	base	10	0.3	0.1	-	0.2
1545	base	–	5.7	0.1	0.5	0.15

In order to improve the quality and workability of aluminium alloys, their melts were modification with a combination of fine powders based on magnesium silicide and silicon carbide with an average particle size of up to 100 nm. Mg_2Si+SiC nanodispersed powders obtained by plasma-chemical synthesis.

To determine the corrosion resistance of modified aluminium alloys, tests for general, intergranular and layer corrosion, as well as corrosion cracking, were carried out.

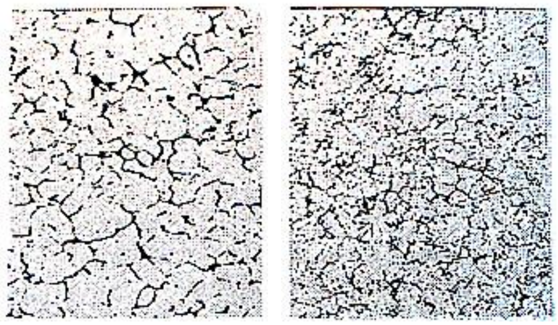
RESULTS AND DISCUSSION

Experimental melts of the AK9 and 1545 alloys in the initial and modified state were carried out. Modification of alloys is carried out in an induction furnace with a capacity of 50 kg. The complex modifier in tablet form was prepared by mixing nanodisperse powders in a special attritor and pressing them into briquettes, followed by annealing. The amount of modifier 0.1% of the mass of the melt was introduced to the bottom of the furnace while stirring. The temperature of the melt was (740±5) °C, the modification time was 3...5 min. The nanodispersed modifiers were selected based on the isomorphic nature of aluminium and Mg_2Si+SiC (face-centered cubic lattice) crystal lattices, and a small difference in atomic radii with the matrix.

The role of the nanodispersed modifiers additives is reduced to the creation of additional artificial crystallization centers in the melt. To do this, such additives should be commensurate with the critical germs of the alloy matrix phase and provide a sufficient amount of them to obtain a fine structure during casting.

To determine the optimal amount of the multicomponent modifier based on Mg_2Si+SiC experimental melts and testing of samples that underwent heat-strengthening treatment were carried out.

The structure of the alloys was studied by stereometric microscopy. The grain structure of the AK9 alloy is shown in Fig. 1.



a *b*

Fig. 1. The grain structure of the AK9 alloy: a – before modification; b – after modification, x100

The average grain size was determined by stereometric metallography. Before the modification, the grain size was 15.6…16.9 µm, after the modification – 7.6…11.2 µm, so the size of grain grinding in the modified state is 1.5–2 times less than in the initial state.

The strength properties of aluminium alloys are significantly affected by the particle size of the hardening phase. Industrial experiments using dispersed particles of Mg_2Si+SiC in a wide size range of 50…100 nm. In the course of pilot experiments, mechanical tests were carried out to determine the tensile strength properties of samples with different contents of the multicomponent modifier.

The test results are presented in Table 2.

Table 2

Yield strength of the 1545 alloy samples with different content of Mg_2Si, SiC

Melt No.	Content of Mg_2Si, SiC, %	$\sigma_{0.2}$, MPa	$\sigma_в$, MPa
1	initial state	344	384
2	0.05	376	415
3	0.10	408	446
4	0.15	360	402

It was found that the maximum values $\sigma_{0,2}$ and $\sigma_в$ correspond to the optimal content of the powder composition: 0.10% with a subsequent increase in the modifier, the strength properties are decreased, while the strength properties of the modified alloy composition increased by 12…18% compared to the initial state. According to the data in Table 2, the dependence of the yield strength of the modified 1545 alloy on the content of the modifier is constructed.

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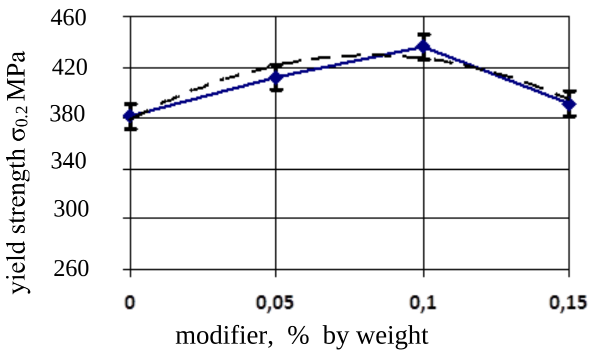

Fig. 2. Dependence of the yield strength of the modified 1545 alloy on the content of the multicomponent modifier, where the dashed line is the state after heat treatment, and the solid line is the state before heat treatment

Measurement of experimental values, strength properties $\sigma_{0.2}$, σ_B when deviated from the average values is 3...5%, which is permissible. The heat-strengthening treatment consisted of quenching and artificial aging [11]. The maximum values of the yield strength are obtained for the content of the multicomponent modifier of 0.1% by weight. At the same time, the yield strength of the modified 1545 alloy is increased to 446 MPA, which is 18% compared to the initial state. The ultimate tensile strength of the modified alloy is increased by 12% compared to the initial state.

To obtain comparative data on the corrosion resistance of alloys, tests for general corrosion were carried out according to the standard method. To simulate the operating conditions, the test method was chosen under conditions of 100% relative humidity, as well as the method of periodic exposure of a 3% NaCI solution at room temperature. The corrosion resistance of aluminium alloys was evaluated by metallographic method and by changes in the weight of samples. Intergranular corrosion (IGC) was determined according to the standard method [5, 9].

The results of the general corrosion tests showed that the modification with the multicomponent modifier $Mg_2Si+SiC$ leads to an increase in the corrosion resistance of alloys by reducing the corrosion rate. The corrosion rate of the AK9 alloy in the modified state is reduced from $11.04 \cdot 10^{-6}$ up to $9.84 \cdot 10^{-6}$ kg/(m^2·day), which is 18%. The increase in corrosion resistance can be explained by changes in the structure of alloys. When modification, the length of interfacial boundaries increases. Intermetallics and impurity atoms that were located at interfacial boundaries in alloys before modification are distributed over a larger area after modification. Consequently, impurities will have a less negative impact on the corrosion resistance of alloys. The stress state of the modified structure also plays an important role [6, 8]. When introducing dispersed particles of $Mg_2Si+SiC$ microscopic volumes of alloys become more energetically stressed, which increases the corrosion resistance of the system.

The sensitivity of alloys to IGC appears due to structural heterogeneity of grain boundaries, isolation of secondary phases, depletion or enrichment of adjacent areas of **α**-Al of solid solution with alloying elements. No tendency to IGC was found in the modified casting (AK9) and wrought (1545) alloys. Corrosion cracking was evaluated on the base metal and weld made by argon-arc welding. The test results are shown in Table 3.

It was found that modified aluminium samples show corrosion resistance for a longer life time.

Table 3

Data on corrosion cracking of the AK9 and 1545 alloys

Alloy	Corrosion cracking			
	Base metal		Weld	
	Stress, MPa	Test duration before cracking, days	Stress, MPa	Test duration before cracking, days
AK9 initial	0.9	40	200	40
AK9 modifier	0.9	more than 45	250	45
1545 initial	0.8	45	220	45
1545 modifier	0.9	more than 55	250	60

SCIENTIFIC NOVELTY

The scientific novelty of the paper lies in the development of the effect of the multicomponent nanodispersed modifier based on $Mg_2Si+SiC$ of plasmochemical synthesis on grinding the structure and improve the mechanical and corrosion properties of aluminium alloys.

CONCLUSIONS

1. The application of the multicomponent modifier of nanodispersed compositions based on Mg_2Si and SiC of plasma-chemical synthesis with particle sizes up to 100 nm was proposed.

2. The structure of the strength and corrosion properties of the AK9 aluminium casting alloy of the

Al-Si system and 1545 wrought alloy of the Al-Mg-Sc system before and after modification was studied.

3. Grain grinding of modified alloys by 1.5–2 times and strength properties increasing by 12…18% compared to the initial state were achieved. The mechanism of action of the nanodispersed modifier in a melt was proposed.

4. High corrosion resistance of the modifying alloys is achieved over a long life time, while reducing the corrosion rate of the modified alloys by 18%.

5. The results achieved showed the effectiveness of modification aluminium alloys with nanodispersed compositions.

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ПІДВИЩЕННЯ МІЦНІСТНИХ ТА КОРОЗІЙНИХ ВЛАСТИВОСТЕЙ АЛЮМІНІЄВИХ СПЛАВІВ ПРИ МОДИФІКУВАННІ НАНОДИСПЕРСНИМИ КОМПОЗИЦІЯМИ

А.В. Давидюк, Н.Є. Калініна, А.Ф. Санін, Д.Б. Глушкова, С.В. Демченко, В.О. Саєнко

Проведено дослідження алюмінієвих сплавів систем Al-Si, Al-Mg-Sc, перспективних для атомних енергетичних установок. Матеріалами дослідження обрано ливарний алюмінієвий сплав АК9 і деформований сплав 1545. Запропоновано модифікування алюмінієвих сплавів комплексним нанодисперсним модифікатором на основі Mg_2Si і SiC плазмохімічного синтезу. Досягнуто здрібнення зерна модифікованих сплавів у 1,5–2 рази, підвищення міцністних властивостей на 12…18% та покращення корозійної стійкості. Запропоновано механізм дії комплексного нанодисперсного модифікатора в алюмінієвому розплаві. Застосування таких модифікаторів полегшує технологічний процес, є екологічно безпечним, призводить до рівномірного розподілу введених нанокомпозицій, що підвищує міцність сплавів та їх стабільність. Досягнуті результати показали ефективність модифікування алюмінієвих сплавів нанодисперсними композиціями.