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The effect of the modification by ultrafine silicon carbide powder on the structure and properties of the Al-Si alloy

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ABSTRACT

Purpose: Determine the possibility of modifying aluminium alloys of the Al-Si system with an ultrafine SiC modifier with a particle size of 3-5 μm.

Design/methodology/approach: Processing of the Al-Si alloy was carried out by introducing an ultrafine modifier in the amount of 0.1, 0.2, or 0.3 wt.%. Silicon carbide (SiC) with a particle size in the range of 3-5 μm was used as a modifier. To study the microstructure of the formed surface layers, a metallographic analysis was performed according to the standard method on a microscope MIKPOTEX® MMT-14C using TopView software. Microhardness studies of the samples were carried out on a Vickers microhardness tester NOVOTEST TC-MKV1. The microstructure of castings of the AlSi12 grade was studied at magnification from 100 to 400 times on the horizontal and vertical surfaces of the samples after etching with a 2% NaOH aqueous solution.

Findings: Aluminium cast alloy of Al-Si system has been synthesized with the addition of 0.1, 0.2, and 0.3 wt.% ultrafine SiC modifier. It was found that the modification of the AlSi12 alloy by SiC particles of 3-5 μm in size led to an improvement of its microstructure due to the reduction of the volume fraction of micropores and primary Si crystals. It was shown that the AlSi12 aluminium alloy due to the modification by 0.2 wt.% SiC has the best micromechanical properties and macrostructure density.

Research limitations/implications: The obtained research results are relevant for cast specimens of the indicated sizes and shapes. The studies did not take into account the influence of the scale factor of the castings.

Practical implications: The developed modification technology was recommended for use in the conditions of the foundry "Dnipropetrovsk Aggregate Plant" (Dnipro, Ukraine).

Originality/value: The technology of AlSi12 alloy modification of ultrafine SIC modifier with a particle size of 3-5 μm was used for the first time.

Keywords: Al-Si alloy, Silicon carbide, Modification, Mechanical properties, Microstructure, Microhardness

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PROPERTIES

1. Introduction

Cast aluminium alloys should have good fluidity, low shrinkage, low susceptibility to hot cracking and porosity, as well as good mechanical and corrosion properties.

The best casting properties have alloys containing eutectic in their structure. Eutectic provides the highest moisture-fluidity with minimal porosity, minimal heterogeneity, and minimal crack formation [1-3].

Al-Si alloys called silumin have the best casting properties and low specific gravity. According to the Al-Si phase diagram, eutectic is formed at 11.6% of Si content [4-6].

AlSi12 alloy containing 10-13% Si is almost entirely eutectic, has the best casting properties and is used for fine and thin-walled casting (parts of units and apparatus) [7-9]. To improve the mechanical properties of the AlSi12 alloy, it is subjected to modification by introducing ~1% of a mixture of salts of sodium fluoride and chloride into the liquid alloy before casting [10-15].

The paper considers the possibility of modifying aluminium alloys of the Al-Si system with an ultrafine SiC modifier with a particle size of 3-5 μm. The technology for producing ultrafine powders is also used to obtain ceramic coatings [16].

2. Experimental procedures

AlSi12 aluminium alloy (ISO 3522: 2007) was selected for the study. The melting of the alloy was carried out in a CAT-04 furnace. The casting was carried out with a ladle-spoon into a steel shaking mould with an average wall thickness of 7 mm and a height of the working cavity of 150 mm. The inner surface of the mould coated with paint based on disten-sillimanite was heated to a temperature of 380-400The output temperature of the melt was 720 ± 5°C.

Processing of the alloy was carried out by introducing an ultrafine modifier in the amount of 0.1, 0.2, or 0.3 wt.%. Silicon carbide (SiC) with a particle size in the range of 3-5 μm was used as a modifier.

The casting of the moulds was carried out sequentially starting from a melt without introducing the modifier and then increasing stepwise the modifier content. The modifier in the powdered state was added on the surface of the liquid metal in the dispenser and mixed with a casting blade in the following sequence: first 0.1 wt.% SiC was added and the first mould was cast; then the next portion of 0.1 wt.% SiC was added, bringing the content of the modifier in the melt to 0.2 wt.% SiC, and the next mould was cast; then the content of the modifier in the melt was brought up to 0.3 wt.% SiC and a mould was cast with a melt with maximum modifier content.

The mechanical properties of the materials of the castings were determined in accordance with DSTU 1497-84 on standard samples cut from cylindrical castings. Also, individual castings without vibration treatment and modification were made.

Microhardness studies of the samples were carried out on a Vickers microhardness tester NOVOTEST TC-MKV1 at a load of 0.5 mm/min. Mechanical properties were determined by testing type III samples on the universal test machine "INSTRON".

To study the microstructure of the formed surface layers, a metallographic analysis was performed according to the standard method on a microscope MIKPOTEX® MMT-14C using TopView software. The microstructure of castings of the AlSi12 grade was studied at magnification from 100 to 400 times on the horizontal and vertical surfaces of the samples after etching with a 2% NaOH aqueous solution.

3. Results and discussion

The effect of the ultrafine silicon carbide modifier (SiC) in the amount of 0.1, 0.2, and 0.3 wt.% has been studied. The macrostructure of the cast alloy of the test castings is presented in Figure 1.

The above studies of the macrostructure of cast alloy indicate that, as a result of modification of the AlSi12 alloy with ultrafine silicon carbide (SiC) in the amount of 0.1 wt. %, the physical and mechanical properties of the casting were improved, namely the values of relative elongation decreased and the hardness increased. The next increase in the content of silicon carbide (SiC) to 0.2 wt.% and 0.3 wt. % caused a gradual decrease in values of relative elongation, but the hardness decreased as a result of a re-modification effect with the formation of the microstructure of fine eutectic crystals.

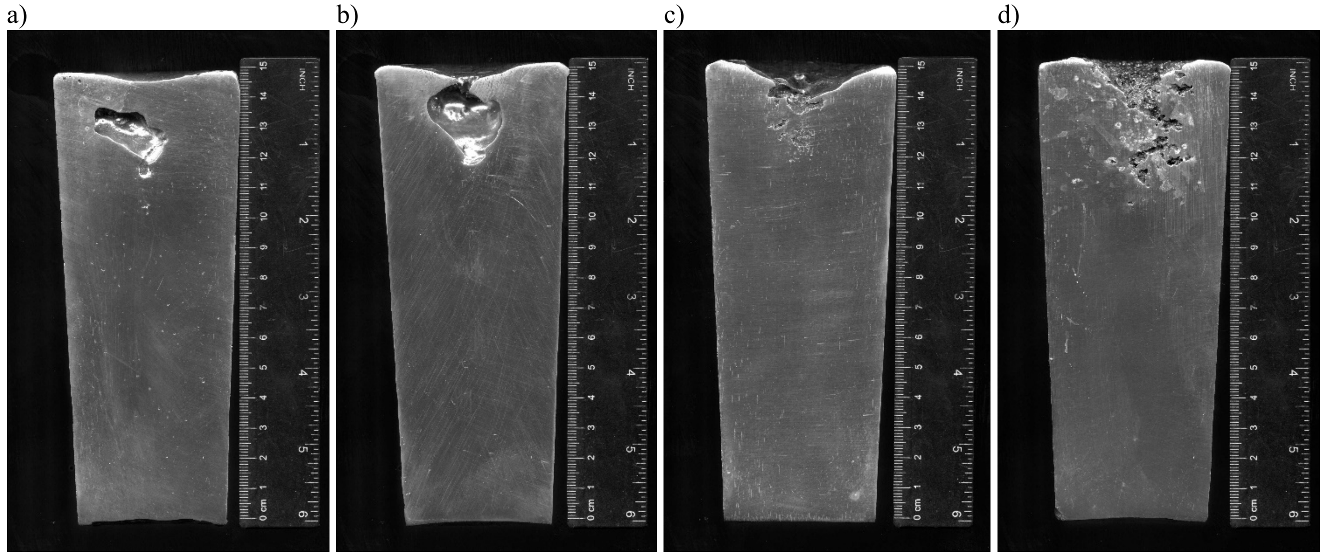

Fig. 1. The macrostructure of castings: a) without a modifier and b)-d) with 0.1, 0.2, and 0.3 wt. % of the silicon carbide modifier, respectively

The macrostructure of the casting without modification includes a closed shrinkage sink mark of irregular shape at a depth of 35 mm. The size of the shrinkage sink mark is 25×20×10 mm. Besides, there are dispersed shrinkage porosity in the form of sink marks with a diameter of 1-1.2 mm, as well as more fine dispersed shrinkage porosity in the entire volume of the casting (Fig. 1a). The macrostructure of the casting subjected to modification by ultrafine silicon carbide (SiC) in the amount of 0.1 wt.% includes a concentrated shrinkage sink mark at a depth of 35 mm. The size of the shrinkage sink is 25×30×15 mm. There is no dispersed shrinkage porosity (Fig. 1b). The macrostructure of the casting subjected to modification by ultrafine silicon carbide (SiC) in the amount of 0.2 wt.% includes a shrinkage sink mark of regular shape at a depth of 15 mm. Besides, there are dispersed shrinkage porosity in the form of sink marks of 3, 5, and 10 mm in size at a depth of 30 mm. There is also more fine shrinkage porosity, which is dispersed throughout the entire casting volume (Fig. 1c). The macrostructure of the casting subjected to modification by ultrafine silicon carbide (SiC) in the amount of 0.3 wt.% includes a shrinkage sink mark of regular shape at a depth of 24 mm. There is dispersed shrinkage porosity consisting of sink marks of irregular shapes of 2×1×1 mm, 3×5×3 mm, and 12×10×5 mm in size. There is also finer dispersed shrinkage porosity in the entire volume of the casting (Fig. 1d).

As a result of studies of the mechanical properties of the samples, final calculations were obtained. The results of the studies are shown in Tables 1 and 2.

Table 1.
Results of determination of metal density of castings after modification and complex treatment

Sample No.	Modifier amount, %	Sample weight in air, g	Sample weight in CCl_4, g	Sample density, g/cm^3
1	0	15.330	6.990	2.929
2	0.1	12.330	5.560	2.902
3	0.2	9.170	4.910	3.430
4	0.3	10.190	5.130	3.209

Table 2.
Results of mechanical testing of machined specimens made from AlSi12 alloy castings modified (ISO 3522:2007)

Sample No.	Modifier amount, %	$\sigma_{0.2}$	σ_U	δ_5	ψ
		MPa		%	
1	0	115	152	6.90	2.50
2	0.1	109	159	2.60	6.04
3	0.2	118	154	2.30	3.44
4	0.3	124	157	1.64	2.11

The density of an aluminium alloy was determined by the method of hydrostatic weighing with an accuracy of 0.001 g/cm^3. The sample, free of cracks and cavities, was weighed on an analytical balance in air and carbon tetrachloride. The density of the sample was calculated using the formula:

$$d_{Al} = \frac{P_a}{P_a - P_w}(d_w - 0.0012) + 0.0012 \quad (1)$$

where d_{Al} is the sample density [g/cm^3], P_a is the sample weight in air [g], P_w is the sample weight in CCl_4 [g], d_w is the density of CCl_4 [g/cm^3].

The results of the study are presented in Table 1.

The results of determining the metal density of the test castings showed a significant dispersion of values (from 2.902 g/cm^3 to 3.340 g/cm^3).

Studies have shown an increase in the average metal density of castings subjected to modification by 1.4% as compared to the metal density of castings obtained by traditional technology.

When analysing the results of mechanical tests, it can be seen that the yield strength is slightly reduced in the second sample which contains ultrafine silicon carbide (SiC) modifier in the amount of 0.1 wt.%. In other cases, no significant difference is observed. The relative reduction of area and the elongation values for the second specimen are greatest, whereas these parameters for the last ones are approximately similar.

The microstructure, phase composition and physical and mechanical properties of AlSi12 aluminium cast alloy after modification by ultrafine silicon carbide were investigated.

To clarify the content of Si and Fe, chemical analysis was performed on a photoelectron spectroscope MFO-4 by the spectral method (Tab. 3). The refined chemical analysis of the silicon and iron content showed complete compliance of the model and all modified aluminium cast alloys with the AlSi12 grade according to ISO 3522: 2007.

Table 3.
Results of chemical analysis on a photoelectron spectroscope MFO-4

Sample marking	Content of Si, %	Content of Fe, %
AlSi12 without the modifier	11.3	0.60
AlSi12 + 0.1% SiC	12.1	0.70
AlSi12 + 0.2% SiC	12.4	0.63
AlSi12 + 0.3% SiC	11.7	0.76

To evaluate the effect of the ultrafine SiC modifier on the structure of cast alloys of the Al-Si system, the macrostructure of the AlSi12 alloy was investigated. The macrostructure of the AlSi12 alloy without the addition of a modifier consists of a solid solution, eutectic and crystals of primary Si. It contains a large number of small pores. It is also possible to observe large pores formed due to the crumbling out of primary Si crystals during grinding and polishing. The size of the large pores is 0.3-0.5 mm. (Fig. 2a). A significant reduction in the number of small pores can be observed in the alloy with the addition of 0.1 wt.% SiC modifier whereas large pores are almost completely absent (Fig. 2b). This indicates a decrease in the volume fraction of primary Si, the presence of which is the main reason for the formation of defects during the preparation of sample surfaces.

a)

b)

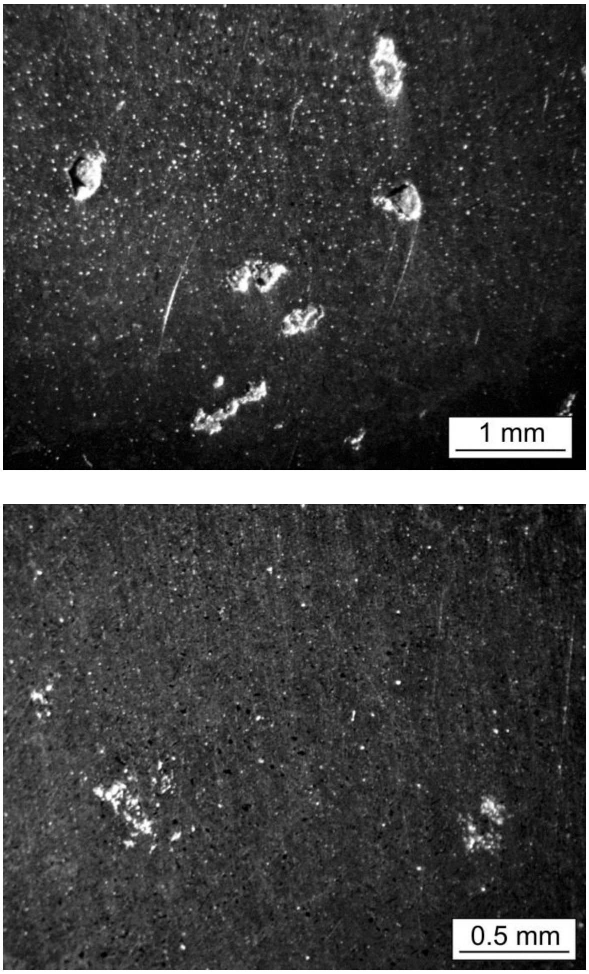

Fig. 2. Microstructure of the AlSi12 alloy (a) without the modifier and (b) with the addition of 0.1% SiC modifier

The microstructure of the AlSi12 alloy without the addition of a modifier consists of a solid solution, eutectic, and large crystals of primary Si that were crumbled out during polishing (Fig. 3a). The size of the crystals of primary Si is 40-200 μm. The microstructure of the AlSi12 alloy contains a large number of small micropores, the size of which is 10-15 μm.

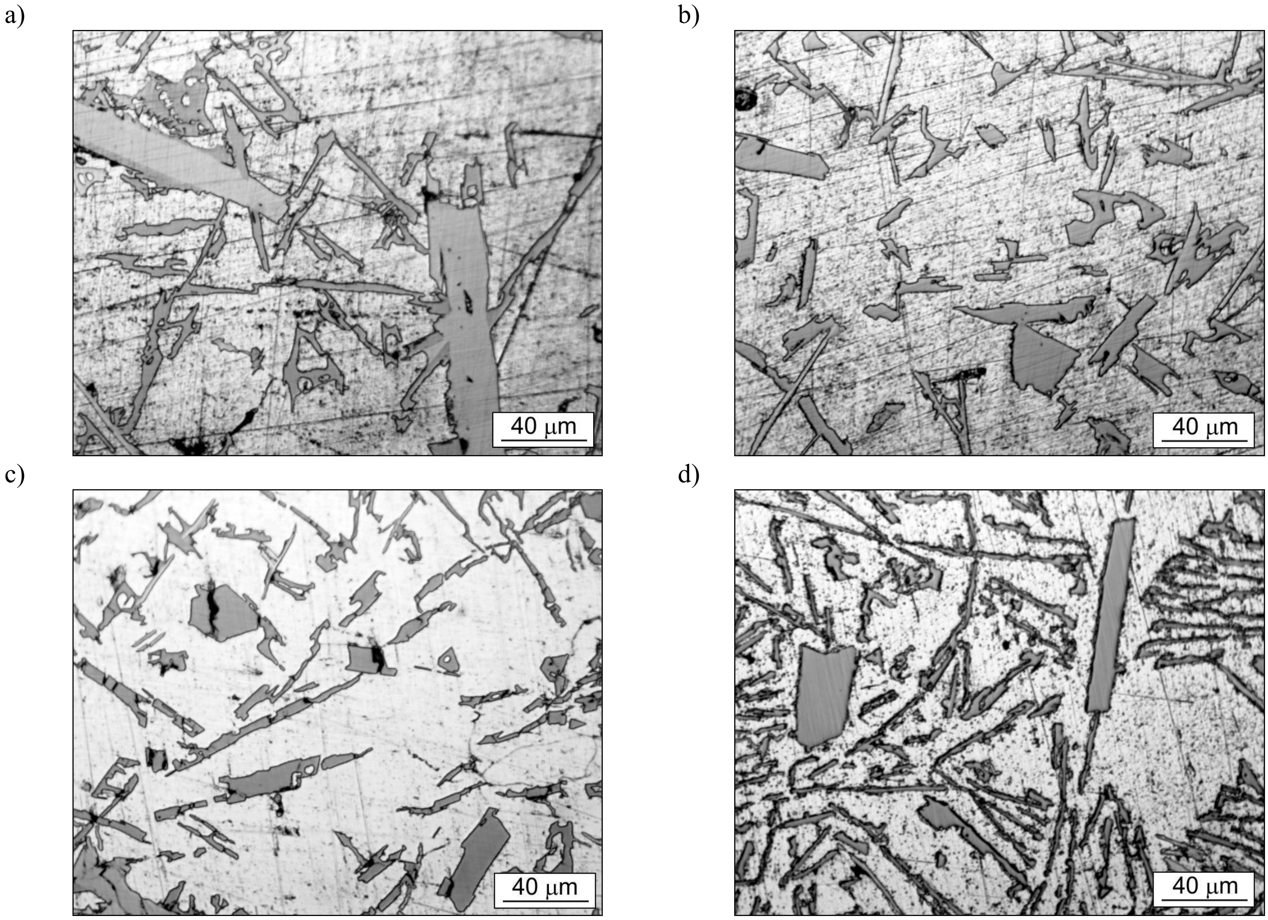

Fig. 3. Microstructure of AlSi12 alloy: a) without the modifier, b) with the addition of 0.1% SiC, c) with the addition of 0.2% SiC, and d) with the addition of 0.3% SiC

Modification of the AlSi12 alloy by an ultrafine SiC compound in the amount of 0.1-0.3 wt.% leads to an increase in the fineness degree of the eutectic structure of the AlSi12 alloy while reducing the volume fraction of primary Si crystals (Figs. 3b,c,d). The size of primary Si crystals decreases with increasing content of the modifier. The microstructure of the modified AlSi12 alloy contains a much smaller number of small micropores as compared to the model alloy.

The AlSi12 alloy, which does not contain a modifier, has minimum values of microhardness, which vary in the range of 50.9-59.7 HV at a load of 0.49 N. The addition of 0.1 wt.% SiC modifier in the structure of the AlSi12 alloy leads to a steep increase in the values of microhardness, which vary in the range of 65.0-81.4 HV at a load of 0.49 N (Fig. 4).

It was found that the addition of the ultrafine SiC modifier to the AlSi12 aluminium cast alloy leads to an average of 8% (17 HV) increase in microhardness values.

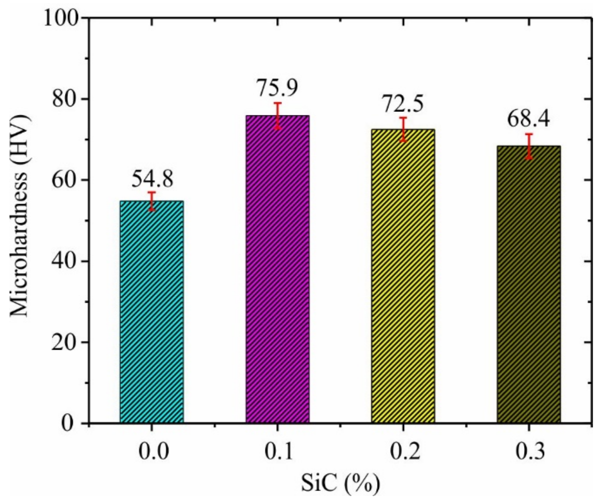

Fig. 4. A dependence of microhardness of the AlSi12 alloy on the amount of the SiC modifier

4. Conclusions

1. Aluminium cast alloy of Al-Si system has been synthesized with the addition of 0.1, 0.2, and 0.3 wt.% ultrafine SiC modifier with a particle size.
2. It was found that the modification of the AlSi12 alloy by SiC particles of 3-5 μm in size led to an improvement of its microstructure due to the reduction of the volume fraction of micropores and primary Si crystals.
3. It was shown that the AlSi12 aluminium alloy due to the modification by 0.2 wt.% SiC has the best micro-mechanical properties and macrostructure density.
4. The developed modification technology was recommended for the use at foundry plants.

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