MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A HYPEREUTECTIC ALLOY AlSi18, MODIFIED BY A NANODIAMOND AND PHOSPHORUS

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Abstract: *A study of a hypereutectic aluminum-silicon alloy AlSi18, modified by a conventional modifier - phosphorus (P) and a nanosized powder of a nanodiamond (ND) has been carried out. Refinement by 40.8% of the primary Si crystals and by 51% of the Si crystals in the composition of the eutectic has been obtained for the phosphorus-modified alloy in result of the modification. The refinement of the above values for the alloy modified by ND is 41.5% and 94% respectively. The phosphorus-modified alloy AlSi18 has an increased tensile strength (R_m) by 18.5%, relative elongation (A_5) by 14.3% and hardness by 1.5%. The alloy, modiified by ND has an increased by 20.4% tensile strength (R_m), increased relative elongation (A_5) by 7.15% and hardness decreases by 6.2%.*

Key words: *NANODIAMOND, MODIFICATION, CRYSTALLIZATION*

1. Introduction

Experiments with new types of nanomodifiers (NM) have been carried out in the recent years. Nanomodifiers are ultrafine nanopowders with particles sizing 4-100 nm, with a high melting phoint (~ 2273 - 3273 K depending on the composition), obtained either by self-propagating high-temperature synthesis (SPHTS) [1] or by plasma-chemical synthesis (PCS) and used for producing nitrides, carbides, oxides, oxi-carbides, etc. [1-3]. Nanosized diamonds or nanodiamonds (NDs) are also used. The production of nanosized diamond particles is carried out by blasting. When blasting explosives with a negative oxygen balance, the released carbon is transformed into a diamond at the corresponding pressure values P and temperature T [4]. After proper processing, the nanoscale diamond can be used for aluminum alloys modifying.

Most of the existing studies have been performed on hypoeutectic aluminum-silicon alloys, eutectic aluminum-silicon alloys and other types of alloys [5-9]. The influence of ND on the structure and mechanical properties of A356 alloy was investigated in [10]. In the present work, a study was conducted on the modifying effect of a standard modifier (P), on the one hand, and a nanomodifier - nanodiamond (ND), on the other hand, on both the structure and the mechanical properties of the hypereutectic aluminum-silicon AlSi18 alloy.

2. Experimental Studies

Table 1. Chemical composition of AlSi18 alloy, wt.%

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Pb	Al
17.55	0.120	0.025	0.047	0.001	0.001	0.005	0.102	0.01	Ост.

The chemical composition of the alloy is shown in Table 1.

The alloy is modified by a standard modifier - phosphorus, which is introduced in the form of a ligature CuP10 - copper phosphorus alloy. The nanosized nanodiamond powder is manufactured by Nanostructured & Amorphous Materials, Inc. and has an average particle size of 3-5nm. To improve the wetting of the ND particles in the melt, cladding by Ni was performed, using a currentless method [3].

For the purpose of the study, experiments were carried out with an unmodified, modified by a standard modifier and modified by a nanomodifier ND AlSi18 alloy. The melting of the alloy is carried out in a graphite electric resistance laboratory furnace by using preliminary cleaned and dry stock materials. The melting process takes place under a layer of roof-refining flux in an amount of 0.5 wt% from the amount of the stock material. The resulting melt is stirred vigorously for removing non-metallic inclusions and then the slag is removed. This is followed by degassing the alloy at 760 °C by purging with argon for 3 minutes and removing the metal mirror from the slag. Unmodified samples are casted after that. Similarly to the above the alloy is melted and prepared for the introduction of a copper-phosphorus modifier or a nanomodifier ND.

The introduction of a standard modifier (P) into the melt in the amount of 0.4 wt% of the alloy quantity is carried out at a temperature of 770°C. After introducing the modifier into the melt, it is stirred vigorously until the modifier is fully absorbed and degassed at 760°C - 770°C by purging with argon for 3 min.

In the case of alloy nanomodification after refining and degassing the melt, it is modified by a ND modifier, with a concentration in the melt equal to 0.1 wt% at a temperature of 760°C. For this purpose, the calculated amount of ND corresponding to this concentration is packed in an aluminum container, which is attached to the impeller and the impeller is introduced into the melt. Mechanical stirring is then performed in order to melt the container and homogenize the melt for 3-5 min at revolutions of about 120 - 130 min^{-1}.

a) *b)*

Figure 1 a) Melting furnace with a homogenization unit, (1b) a mold with a "Wedge"-type casting,

Figure 1a) shows the moment of homogenization by using an impeller. Prior to casting, the mold – a steel mold with a vertical dividing surface (Fig. 1b) - is heated up to 200 ° C and coated with a fire-resistant coating. "Wedge"-type castings are produced by removing the crucible from the furnace by means of a special device and pouring into the mold. Figure 1b) shows a mold with an AlSi18 casting. All experiments were performed at near temperatures of the melt. To meet these conditions, the temperature of the mold is measured by a contact thermocouple.

The “wedge”- type casting weighs ~ 0.850 kg. The trapezoidal part of the casting is designed as a feeder to provide good nutrition for of the working part during crystallization. After removing the feeder, the cylindrical sample from the casting with sizes of Ø20 x 230 mm is used for taking samples for examination. cylindrical sample marked with (1) respectively, while the samples

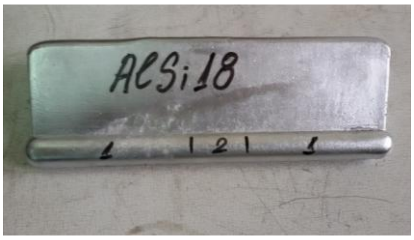


Figure 2. A “Wedge”-type casting with marked sampling points

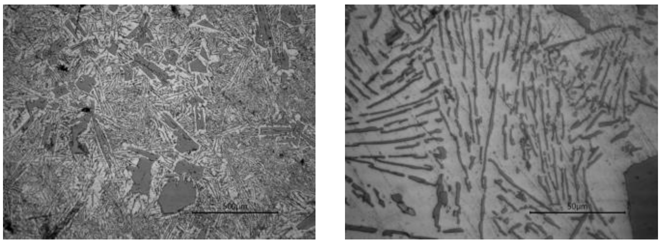
for structural analysis are produced from the part (2) (Fig. 2). The samples for macro and microstructure analysis are wet grinded by using sandpaper numbers 240, 320, 400 and 600, 800 and 1000. They are then mechanically polished with a diamond paste and a lubricant. The macrostructure of the alloys is etched by a Poulmont reagent (60 p. HCl (conc), 30 p. HNO3 (conc), 5 p. HF, 5 p. H2O). The microstructure of the samples is etched expressed by a Keller reagent (1 p. HF, 1.5 p. HCl, 2.5 p. HNO3, 95 p. H2O). The structures are qualitatively characterized with the help of Zeiss metallographic JENAVERT microscopes. Top View image processing software is used for the quantitative metallographic analysis.

The average size of the primary silicon crystals as well as the size of the silicon particles in the eutectic were determined. The influence of both the standard P modifier and the ND nanomodifier on the structure of the investigated hypereutectic aluminum - silicon alloy AlSi18 was established.

The mechanical tests of the samples, produced in accordance with the standard, were carried out on a Zwick/Roell Z 250 tensile test machine. The average values of the mechanical properties tensile strength Rm and relative elongation A5 were determined for the cases of modification by ND and by a combination of a standard modifier P and ND.

3. Results and discussions

3.1. Microstructural studies

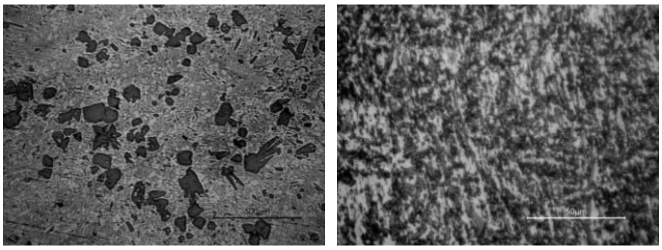


a) b)

Figure 3. Microstructure of unmodified AlSi18 alloy: a) primary Si crystals, b) Si crystals in the composition of the eutectic

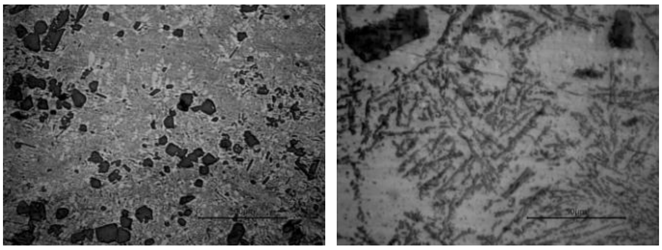
The microstructure of the unmodified AlSi18 alloy samples consists of eutectic and separated primary silicon crystals (Fig. 3a). The shape of the primary silicon crystals is different: straight-walled polygons, well-shaped plates, which in the plane of microscopic observation resemble needles or irregularly shaped plate-type crystals. The arbitrary average diameter of the primary silicon crystals in the unmodified AlSi18 alloy is within the range 87.2-97.6 μm.

Several types of zones are observed in the eutectic of an unmodified AlSi18 alloy (Fig. 3b). The first type is with well-shaped elongated needle-type plates, measuring up to 250-260 μm in length. In the second type small silicon crystals of several microns in size are observed, which form groups or are adjacent to each other and, at small microscopic magnifications, resemble a broken needle. In the third zone type, fine silicon crystals resembling "fish bone" are observed.



a) b)

Figure 4. Microstructure of AlSi18 alloy modified by P: a) primary Si crystals, b) Si crystals in the composition of the eutectic



a) b)

Figure 5. Microstructure of AlSi18 alloy modified by ND: a) primary Si crystals, b) Si crystals in the composition of the eutectic

The microstructure of the alloy AlSi18 samples, modified by phosphorus and modified by ND, consists of eutectic and separated primary silicon crystals. The shape of the primary silicon crystals in the two alloys is different from the one of the unmodified alloy. Primary silicon crystals in the form of polygons predominate in both the phosphorus modified alloy (Fig. 4a) as well as in the samples, modified by ND (Fig. 5a), and the amount of primary irregularly shaped crystals is negligible. The size of the primary silicon crystals in the two samples is similar: for the AlSi18 alloy modified by phosphorus - 55.7 μm and for the AlSi18 alloy modified by a nanomodifier ND - 54 μm.

The eutectic of the AlSi18 alloy modified by a phosphorus is made up of well-shaped needles around which small silicon crystals adhere (Fig. 4b). The average maximum needle length is in the range of 115-135 μm. In the AlSi18 alloy modified by ND nanomodifier, the amount and the average length of the eutectic needles decreases - their average maximum length is about 15–16 μm, but the fraction of small equi-axed silicon compartments increases (Fig. 5b).

Table 2. Microstructure parameters of the initial and modified AlSi18 alloy

Alloy	Modifier	Arbitrary average diameter of the primary Si crystals D [μm]	Refinement, %	Average maximum needle length of the Si crystals in the composition of the eutectic [μm]	Refinement, %
AlSi18		92,4		250-260	
AlSi18	P	55.7	40.8	115-135	51
AlSi18	ND	54	41,5	15-16	94

The results obtained from the quantitative metallographic analysis are shown in Table 2.

The table shows that, as a result of the modification of AlSi18 alloy by standard modifier (phosphorus) the arbitrary average diameter of the primary Si crystals decreases by 40.8% and the size of the Si crystals in the composition of the eutectic - by 93.2%.

The modification of the alloy by ND nanomodifier results in a reduction of 41.5% in the arbitrary average diameter of the primary Si crystals and of 94% in the size of the Si crystals in the composition of the eutectic.

3.2. Mechanical tests

Table 3. Results from mechanical tests of AlSi18 alloy

Alloy	Modifier	Rm/Mpa	Re/Mpa	A_5 /%/	HB2,5/62,5/30
AlSi18		108		1.4	65
AlSi18	P	128		1.6	66
Change, %		+18.5		+14.3	+1.5
AlSi18	ND	130	85	1.5	61
Change, %		+20.3		+7.1	-6.2

The results from the mechanical tests carried out on an unmodified, modified by standard modifier P and modified by ND nanomodifier alloy AlSi18 are shown in Table 3.

It can be seen from the table that the phosphorus-nanomodified AlSi18 alloy has an increased tensile strength (Rm) by 18.5% and increased elongation (A5) by 14.3% compared to the unmodified alloy. Hardness increases by 1.5%.

The alloy modified by ND-modifier has an increased tensile strength (Rm) by 20.4% and increased elongation (A5) by 7.1% compared to the unmodified alloy. Hardness decreases by 6.2%.

4. Conclusions

As a result of the conducted studies of the modification of the hypereutectic aluminum-silicon alloy AlSi18, modified both by a standard modifier (P) and by a nanomodifier - ND, identical refinement of the primary Si crystals was observed, while the refinement of the sizes of the silicon crystals in the eutectic composition differ significantly. For the alloy modified by phosphorus the refinement of the Si crystals in the composition of the eutectic is 51% and for the ND- modified alloy the refinement is 94% compared to the unmodified alloy. The formation of such a finely dispersed structure is probably due to the modifying influence of the nanodiamonds on the eutectic of the alloy.

The tensile strength (Rm) of a phosphorus modified and a ND modified hypereutectic AlSi18 aluminum-silicon alloy, as well as the relative elongation (plasticity) increase respectively with 18.5% and 14.3% for the phosphorus - modified and with 20.3% and 7.1% for the ND - modified alloy. This is due to the reduced notch effect exerted by the modified primary silicon crystals on the alloy structure, as well as to the finely dispersed structure of the modified eutectic in which the primary Si crystals are located. The macro-hardness of the alloy modified by phosphorus increases by 1.5% while the same value decreases by 6.2% for the ND - modified alloy.

The obtained results show that the modification of AlSi18 alloy by a nanomodifier ND can successfully replace its modification by a standard phosphorus (P) modifier. This will have an ecological effect and will improve the hygienic working conditions in foundries, using this alloy.

5. References

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