Effect of Al-Y-Ce-La master alloy on structure formation, liquation processes and properties of AK7ch silumine (AL9)

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Abstract. The regularities of changes in the composition and properties (micro- and nanohardness, HB hardness) of the structural components - α -solid solution and eutectic components of the AK7ch alloy (AL9) depending on the value of the addition of Al-Y-Ce-La master alloy are established. With an increase in the addition of Al-Y-Ce-La master alloy a sharp change is observed in the composition and properties of the structural components of the AK7ch alloy - α -solid solution Si in aluminum and eutectic $\alpha + \text{Si}$, as well as complex-doped aluminides from Si, Fe and rare earth metals (REM). The structural components of the AK7ch alloy are identified with the addition of an increasing amount of Al-Y-Ce-La master alloy (α -solid solution of Si in aluminum, eutectic $\alpha + \text{Si}$, complex-doped aluminides of rare-earth metals of variable composition $\text{Al}_x\text{Si}_y\text{REM}_z$ and $\text{Al}_x\text{Si}_y\text{Fe}_z\text{REM}_v$). A correlation between the solubility of silicon in α -solid solution and its microhardness is found. To increase microhardness of the eutectic and hardness of the AK7ch alloy, it is necessary to add the synthesized ligature in the amount of 0.1 wt.%.

1 Introduction

The use of a composite aluminum base master alloy with rare-earth and other transition metals (Ce, La, Pr, Y, Sc, Sr, Zr, Ti, etc.) containing metal reinforcing base micro- and nano-scale compounds like REM aluminides has become a promising trend in improving the functional properties of aluminum alloys. There are few publications on the problem of the effect of REM master alloy on modification of silumin [1-4]. Ce, La, Y and other ligatures or mischmetals from rare-earth metals are widely used to transform primary and eutectic silicon crystals into a more compact and fine dispersed form [6-19]. However, there is no systematic study of the Al-Y-Ce-La master alloy effect on the structure formation, segregation processes and microhardness of structural components of the AK7ch alloy.

The present work speaks on the effect of various additives of the synthesized Al-Y-Ce-La master alloy (from 0 to 0.5 wt. % at the variation interval of 0.1 wt.%) on structure formation, elements distribution as well as microhardness of structural components and hardness of AK7ch (AL9) alloy.

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2 Research methods

Aluminum of A95 grade was superheated to 900°C in the pure argon atmosphere and pure yttrium, cerium and lanthanum were introduced in the ratio - 2: 1: 0.5 (wt.%: 15-20 Y; 7-10 Ce; 3.5-5.0 La) [1,2].

Silumin of AK7ch (AL9) brand was selected as the starting material for modification. The alloy was superheated to 900°C. The melt was refined with a cover-refining flux produced by ALC “Eutectic” (TU RB 100196035.005-2000) [20] at the rate of 0.2 wt.% of the smelting mass.

Melt degassing was carried out by the degassing tablet ALC "Eutectic" (TU RB 14744129.004-98) [21] in an amount of 0.1% wt.% of the smelting mass. After that modifying additives of the master alloy Al-Y-Ce-La were introduced in an amount of 0.1-0.5 wt.% at a variation interval of 0.1 wt.%.

The microstructures of the master alloy and Silumin AK7ch modified with different ligature additives were investigated using the optical microscope and scanning electron microscope (SEM).

Micro X-ray spectral analysis to determine the content of elements was performed using the analytical research complex based on FE-SEM Hitachi Su-70 (Japan) with the attachments of dispersive (Thermo Scientific Ultra Dry) and wave X-ray microscopic analysis.

The microhardness test was carried out according to the standard procedure on a Vickers instrument of the Shimadzu HVM-G brand [22]. Nanohardness was measured on an Integra Prima atomic force microscope [23]. Local analysis was carried out on 3-5 points of a sample, and the average chemical composition of the structural components - α -solid solution, eutectic and intermetallic compounds $Al_xSi_yFe_zREM_v$ - was determined.

3 Results and discussion

The effect of the Al-Y-Ce-La master alloy on the structure formation, elements distribution, microhardness of the structural components of the AK7ch alloy - α -solid solution and eutectic was studied. As an example, Fig.1 shows the microstructure and points of elements analysis and their distribution in the structural components (Table 1) of the alloy AK7ch with 0.3 wt.% of master alloy. In the reflected electrons, the light colored inclusions are $Al_xSi_yFe_z$ aluminides, non-modified and modified by the Al-Y-Ce-La master alloy. The number of these inclusions increases with the increase of master alloy addition.

Table 1. Changes in the element composition in the structural components of the AK7ch alloy.

Structure	Points of elements analysis	Elements content, at. %							
		Al	Si	Mn	Fe	Y	La	Ce	Σ REM
Aluminide $Al_xSi_yFe_zREM_v$ Admixtures: Mn	1-6	80.02	11.78	0.65	4.13	1.93	0,4	0,9	3.23
		$Al_{80,02}(Si,Mn,Fe, REM)_{19,98}=Al_4(Si,Mn,Fe, REM)$							
Structure with eutectic α +Si	7-12	84.67	15.33	-	-	-	-	-	-
α -solid solution Si in Al	13-15	98.66	1.34	-	-	-	-	-	-

Fig. 1. Microstructure and points of elements analysis in the structural components of the AK7ch alloy with 0.3 wt.% of master alloy.

The presence of the $Al_xSi_yFe_zREM_v$ aluminide with an admixture of manganese and α +Si eutectic is confirmed by the peaks of the content of these elements on the distribution curves of the elements (Fig. 2).

Fig. 2. Curves of elements distribution in the structural components of the AK7ch alloy after the addition of 0.3 wt. % and 0.5 wt.% of Al-Y-Ce-La master alloy.

It was established that with an increase in the addition of a master alloy to 0.2 wt.%, a slight decrease in the silicon content in the α -solid solution is observed with its subsequent growth up to 0.5 wt.% (Fig. 3, a).

In the modified $Al_xSi_yFe_zREM_v$ aluminide (Fig.3, b) an increase in the content of silicon and rare-earth metals is observed (especially at the addition of more than 0.3 wt.% of master alloy), and a decrease in the concentration of aluminum at an increase of master alloy addition.

In unmodified $Al_xSi_yFe_z$ aluminide, an increase in the master alloy addition also contributes to an increase in the silicon content and a decrease in the concentration of iron and aluminum (Fig. 3, c). Thus, an increase in the master alloy addition causes the enhancement of segregation processes in the structural components of the AK7ch alloy. These processes should influence the microhardness of the α -solid solution and eutectic. With a decrease of the silicon solubility in α -solid solution (Fig. 3, a), its microhardness decreases to 0.2 wt.%. With further increase of the master alloy addition up to 0.5 wt.%, the solubility of silicon in α -solid solution and its microhardness increase (Fig.3, g). Microhardness of the eutectic changes according to the extreme dependence line with its maxima at 0.1 wt.% of master alloy, followed by its sharp decrease to 0.5 wt.% (~ 1200 MPa). The hardness of the AK7ch alloy increases again at the addition of more than 0.2 wt.% of master alloy (Fig.3, d) due to the increase in the microhardness of the α -solid solution and grinding of the structural components of the AK7ch alloy. The formation of the modified aluminide $Al_xSi_yFe_zREM_v$ should contribute to an increase of microhardness of the eutectic component, but till a certain amount of master alloy addition (0.1 wt.%). Highly-solid aluminides can embrittle the eutectic at large additions; the increase in the alloy hardness is connected with a microhardness increase of the α -solid solution and grinding of structural components.

Fig. 3. Distribution of elements in the structural components of the alloy AK7ch (a-g); and alloy hardness (e) depending on the amount of the Al-Y-Ce-La master alloy addition.

4 Conclusions

- 1) Structural components of the Al-Y-Ce-La master alloy are identified by the method of micro X-ray elements analysis:
 - metal base consists of crystals of pure aluminum and $\text{Al}+\text{Al}_x\text{R}_z\text{M}_y$ eutectics; microhardness of pure aluminum is 254 MPa; nanohardness - 1500 MPa;
 - yttrium-containing REM aluminide has Al_3Y stoichiometry; microhardness value is 6547 MPa (minimum 5230 MPa, maximum 8176 MPa); nanohardness - 9627 MPa (maximum - 9410 MPa and minimum - 9730 MPa);
 - cerium-containing REM aluminide has the $\text{Al}_{11}\text{REM}_3 = \text{Al}_{3.66}\text{REM}$ stoichiometry ($\text{Al}_{3.66}\text{Ce}$, $\text{Al}_{3.66}\text{La}$); microhardness - 4695 MPa (minimum 3230 MPa and maximum 5854 MPa); nanohardness - 8560 MPa (maximum 8750 MPa and minimum 8350 MPa).
- 2) The increase in the addition of master alloy to 0.5 wt.% contributes to crystallization of highly solid complex-doped aluminide $\text{Al}_x\text{Si}_y\text{Fe}_z$ with and without REM (in the original alloy).
- 3) The structural components of the AK7ch alloy are identified at the addition of an increasing amount of Al-Y-Ce-La master alloy (α -Si solid solution in aluminum, α +Si eutectic and complex-doped REM aluminides - $\text{Al}_x\text{Si}_y\text{Fe}_z$ and $\text{Al}_x\text{Si}_y\text{Fe}_z\text{REM}_v$).
- 4) Regularities of changes in the element solubility and microhardness value of the structural components depending on the amount of Al-Y - Ce-La master alloy addition are revealed. Correlations between the silicon solubility in the α -solid solution and its microhardness are found. The hardness of the HB alloy is stated to depend on the values of microhardness of the α -solid solution and eutectic.

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