

УДК УДК 669.15

INFLUENCE OF PHYSICO-CHEMICAL PROCESSING IN SOLID AND LIQUID STATES ON HYPEREUTECTIC AISi18(B-SN) ALLOY STRUCTURE AND PROPERTIES¹³

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***Abstract.** The peculiarities of AK18 alloy (B-Sn) structure formation, mechanical properties, friction and wear parameters formation depending on the regimes of physical and chemical melt processing and thermocycling in the solid state have been established. Observed structural changes (the β -Si and eutectics ratio, the primary and eutectic β -Si crystals shape and size, eutectics differentiation increasing, the pseudo-primary aluminum solid solution (α -Al) dendrites appearance provide an improvement in the complex of mechanical properties and a reduction in wear friction parameters. The obtained experimental data allow to recommend a complex treatment "hydrogen treatment for 40 min + thermal cycling in the solid state at 475-485°C for 5 cycles" to improve the complex of mechanical properties and reduce the wear friction parameters.*

***Key words:** hyper-eutectic AlSi alloy, microalloying, hydrogen treatment, hydrocircular treatment, thermal cycling.*

ВПЛИВ ФІЗИКО-ХІМІЧНОЇ ОБРОБКИ В ТВЕРДОМУ ТА РІДКОМУ СТАНАХ НА СТРУКТУРУ ТА ВЛАСТИВОСТІ ЗАЕВТЕКТИЧНОГО СИЛУМІНУ АК18(B-Sn)

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***Анотація.** Встановлені особливості ступтуроутворення, формування механічних властивостей, параметрів тертя і зносу сплаву АК18 (B-Sn) в залежності від режимів фізико-хімічної обробки розплаву і термоциклоування в твердому стані. Спостережувані структурні зміни (співвідношення β -Si та евтектики, форми і розміру первинних і евтектичних кристалів β -Si, підвищення диференціювання евтектики, появи дендритів псевдопервинного алюмінієвого твердого розчину (α -Al) забезпечують поліпшення комплексу механічних властивостей та зниження параметрів тертя зносу. Отримані експериментальні дані дозволяють рекомендувати комплексну обробку «воднева обробка 40 хв + термоціклоування в твердому стані при 475-485°C 5 циклів» для поліпшення комплексу механічних властивостей та зниження параметрів тертя зносу.*

***Ключові слова:** заевтектичний силумін, мікролегування, воднева обробка, гідро циркуляційна обробка, термоциклоування*

Introduction

Hypereutectic silumins are used as casting alloys for the production of pistons of internal combustion engines and a number of other parts manufactured by shaped casting methods. Silumins have good

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casting properties, weldability and machinability, high modulus of elasticity, relatively low cost [1]. Often, the use of these alloys for the manufacture of semi-finished products by the method of continuous casting is complicated by the formation in the structure of coarse primary crystals of β -Si solid solution, large plates of eutectic silicon crystals and brittle intermetallic phases, which reduce the manufacturability of the material during casting and the operational properties of the finished products. Crystals of the primary β -Si solid solution are the main source of crack initiation and play a dangerous role in the operation of products, including pistons.

Analysis of publications

The effective factor that determines the favorable structuring of industrial silumins, ensures an increase in their strength and plasticity, is modification [2]. At the same time, there are few data on the positive influence of the boron-tin complex on the size of primary β -silicon crystals and eutectic differentiation. However, the influence of the boron-tin complex on structure formation, phase composition, distribution of elements between phases and structural components, and properties of AlSi18 alloy has not been studied enough.

The positive effect of hydrocirculation (HCT) and hydrogen (HT) methods on the structure and properties of silumins, in particular, density [3-5] is known, but data on the effect of these methods on the structure and properties of modified hypereutectic AlSi alloys are limited [6, 7], which does not allow to choose parameters of targeted influence on the structure and phase composition of the alloy, which ensure the required level of its mechanical properties and wear resistance. In this regard, the study of the structure formation regularities of the AlSi18 type alloy containing the boron-tin complex, the formation of its mechanical and operational properties depending on the regimes of HCT and HT of the melt and rational regimes of thermal cycling treatment (THC) in the solid state with the aim of increasing the complex of mechanical properties and wear resistance are relevant.

The relevance of the study is based on the absence of data on the total effect of modification with a boron-tin complex, hydrocirculation (HCT), hydrogen (HT) treatment of the melt, as well as thermal cycling in the solid state on the formation of the structure and mechanical and operational properties of the AlSi18 alloy, which does not allow choosing the treatment parameters to ensure the required level of mechanical properties and wear resistance.

The purpose of the work is to establish the regularities of structure formation, phase transformations in the AlSi18(B-Sn) alloy, depending on the cooling conditions and the type of physicochemical method of treatment in the liquid and solid state to increase the complex of mechanical properties and wear resistance.

The main research material. The object of the study was the samples of modified AlSi18(0.05B-Sn) alloy (table 1).

Table 1 - Average chemical composition of the AlSi18(0.05B-Sn) experimental alloy

Alloy	Alloying elements, %					
	Si	Fe	Mn	Mg	B-Sn	Al
AlSi18(B-Sn)	18,0	0,3	0,2	0,3	0,05	base

Modern methods of research were used to conduct the experiments: microstructural, X-ray structural, local X-ray spectral, measurement of hardness, microhardness and a complex of mechanical properties on equipment that passed state verification. Thermal cycling in the solid state was carried out in five cycles in the temperature range of 475-485°C. Treatment modes are listed in Table 2.

Table 2 – AlSi18(B-Sn) alloy processing modes

AK18 (B-Sn) alloy processing modes	Sample №
The initial slowly cooled alloy	1
The initial alloy slowly cooled after TCT	2
30 min of HCT followed by slow cooling	3
30 min of HCT followed by rapid cooling and TCT	4
20 min of HT followed by slow cooling	5
20 min of HT followed by slow cooling and TCT	6
40 min of HT followed by a rapid cooling	7
40 min of HT followed by a rapid cooling and TCT	8

Research results and their discussion

The structure, phase composition, and mechanical properties of hypereutectic AlSi18(B-Sn) alloy after physicochemical treatment in liquid and solid states in accordance with Table 2 were studied (fig.1).

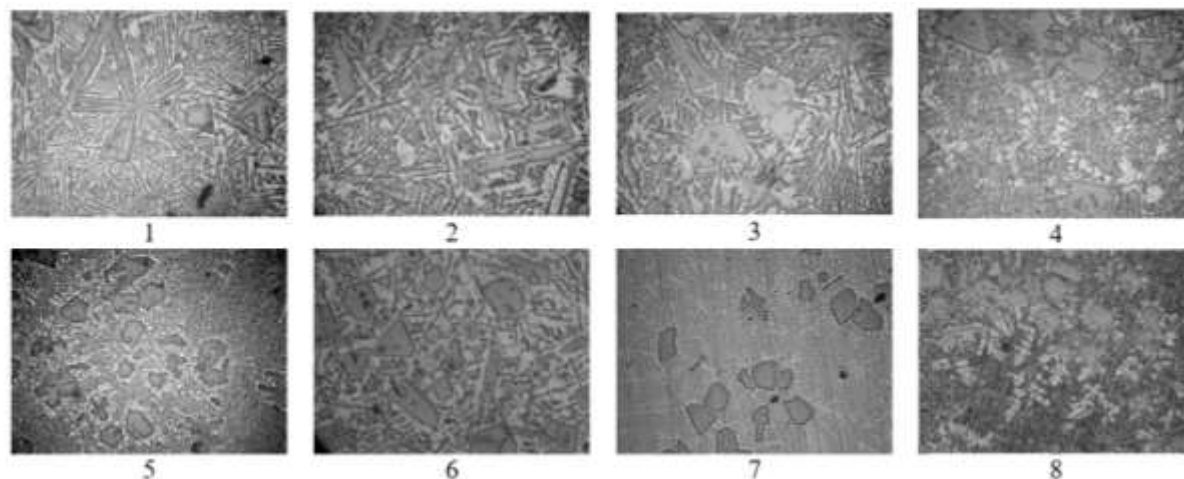


Fig. 1. Microstructure of the AlSi18(B-Sn) alloy after treatments according to Table 2

The main phases and structural components of the modified AK18 alloy are silicon solid solution $\beta-Si$, eutectic - $\alpha-Al + \beta-Si$ and aluminum solid solution $\alpha-Al$. Alloying elements and impurities form intermetallic phases, which, due to metallographic analysis and etching, are identified as intermetallics as $(FeMn)_3Si_2Al_{15}$ type.

Analysis of the microstructures of the samples (Fig. 1) shows that with an increase in the cooling rate, a decrease in the size of the primary crystals of the $\beta-Si$ solid solution and their significant branching is observed (Figs. 1, 1, 2). There is also a decrease in the cross-sections of eutectic silicon crystals and the interlamellar distance in $\alpha-Al-\beta-Si$ eutectics, the eutectic morphology remains lamellar.

Hydrocirculation (Fig. 1, 3) and hydrogen (Fig. 1, 4) treatment, along with thermal cycling, also leads to a change in the shape and size of the crystals of the primary and eutectic silicon solid solution, increased eutectic differentiation, and the appearance of pseudo-primary dendrites of aluminum solid solution ($\alpha-Al$)

The studied alloy is used for the manufacture of pistons of internal combustion engines operating under cyclic loads. When loading during operation, a deformation relief (DR) is formed on the sur-

face of the piston. DR is caused by the phenomena accompanying the plastic deformation of the surface layers - the formation of slip bands, extrusion, intrusion, rotations of the dislocation structure. For the quantitative assessment of fatigue damage of polycrystalline materials, the authors of [8] suggest using parameter D , which characterizes the saturation of the surface layer with traces of DR. If the area of the controlled surface is equal to A , and a part of this surface with area S occupies DR, then:

$$D = \frac{S}{A} \quad (1)$$

The determining factor in the formation of DR is local plastic deformation caused by dislocation mechanisms. Dislocations, moving along slip lines in the direction of maximum stress, reach the free surface, which leads to the formation of steps and shear bands. The formation of a shear step leads to an elementary change in the topography of the surface and, accordingly, to an increase in its area. Thus, the formation of DR should be accompanied by an increase in surface area.

An important characteristic of the strength of the alloy is the plastic deformation of the surface:

$$\varepsilon = \frac{ph}{A}, \quad (2)$$

where h is the average height of DR, which characterizes the wear resistance of the alloy.

The area of the controlled surface is equal to A and is the same for all tested samples.

Figures 2 - 4 show microphotographs, profilograms with 2-D images and 3-D images of the friction track of samples of AlSi18 alloy (B-Sn) depending on the modes of physical, chemical and thermal treatment after wear tests on the "Micron-tribo" friction machine. Profilograms were obtained at the Micron-alpha profilograph.

Table 3 shows the structural parameters of the AlSi18(B-Sn) alloy depending on the processing modes: the quantitative ratio of the primary crystals of the β -Si solid solution and the α -Al- β -Si eutectic, the linear dimensions of the primary crystals of the β -Si solid solution and the cross sections of the crystals of the eutectic silicon solid solution. Analysis of the data in Table 3 shows that hydrocirculation treatment leads to an average increase in the number of primary crystals of the β -Si solid solution by 14% and a decrease in the amount of the eutectic component by 2% compared to the original alloy.

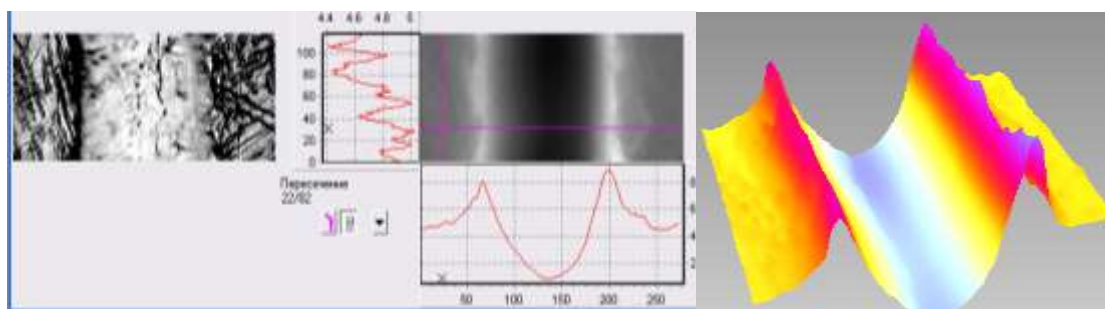


Fig. 2. Microstructure, profilograms with 2-D images and 3-D images of the friction track of the original AlSi18 (B-Sn), slowly cooled alloy

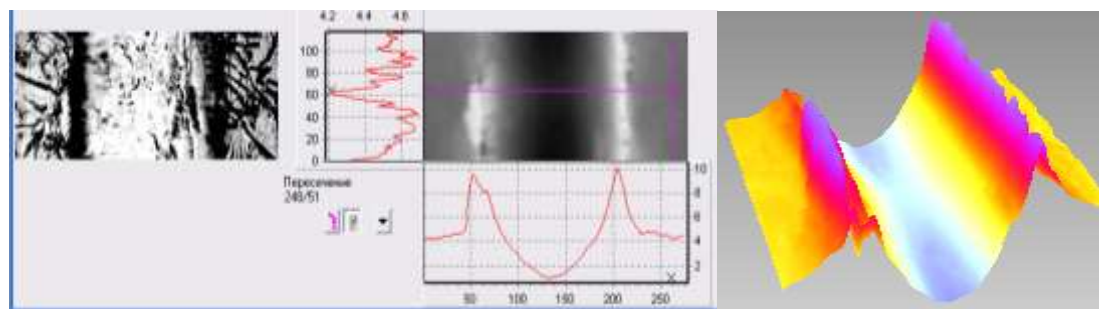


Fig. 3. Microstructure, profilograms with 2-D images and 3-D images of the friction track of AlSi18(B-Sn) alloy after 30 min of hydrocirculation treatment followed by slow cooling and thermal cycling

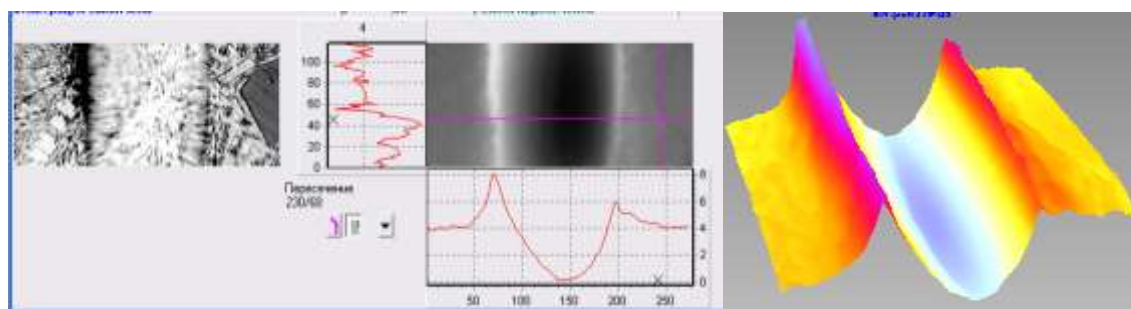


Fig. 4. Microstructure, profilograms with 2-D images and 3-D images of the friction track of AlSi18 alloy (B-Sn) after 40 min of hydrogen treatment followed by rapid cooling and thermal cycling

Table 3 – Structural parameters of AlSi18(B-Sn) alloy depending on processing modes

sam- ple№	average % structural components		Linear dimensions, μm		
	% Primary crystals $\beta - Si$	$\alpha - Al + \beta - Si$	Primary crystals $\beta - Si$	Eutectic Si	Interlaminal distance in the eutectic
1	10	90	245,5	88,5	17,28
2	7,73	92,27	194	32,5	9,92
3	11,4	88,6	255,8	82,6	19,41
4	12	88	193	29,6	9
5	6,33	93,67	158,1	67,2	11,95
6	6	94	108	60	12,3
7	6,48	93,52	103,9	27,1	5
8	6,2	93,8	70	14,6	7

At the same time, hydrogen treatment reduces the number of primary crystals of the β -Si solid solution by an average of 36 % and increases the amount of eutectics by 3 % compared to the original alloy.

The hydrocirculation treatment of the melt practically does not affect the linear dimensions of the primary crystals of the β -Si solid solution. Hydrogen treatment of the melt significantly reduces the linear dimensions of primary crystals of β -Si solid solution and eutectic silicon by an average of 23-35 %.

Thermal cycling in the solid state additionally reduces the linear dimensions of β -Si solid solution and eutectic silicon crystals by 58-84 % compared to the initial state. Hydrogen treatment significantly reduces the intercellular distance in the eutectic by an average of 30%, thermal cycling additionally reduces this parameter by an average of 58 %. The minimum structural parameters are formed

during hydrogen treatment of the melt for 40 min, followed by rapid cooling and thermal cycling, while the amount of the eutectic component is maximum.

Tables 4-5 show the mechanical properties and parameters of friction and wear of the AlSi18 (B-Sn) alloy, depending on the type of physical and chemical treatment in the liquid state and heat treatment in the solid state. A clear relationship between structural parameters, mechanical properties and parameters of friction and wear is observed. Analysis of table 5 data shows that thermal cycling of the tested alloy increases hardness by 43 %, strength by 43 %, microhardness of β -Si solid solution by 74 %, eutectic by 142 %, increasing parameter D and plastic deformation of the surface.

Hydrocirculation treatment of the alloy and thermal cycling additionally increase the hardness of the alloy compared to the initial state by 105 %, strength by 136 %, microhardness of the solid solution by 29 %, eutectics by 94%, while friction and wear parameters are reduced. Hydrogen treatment of the melt for 20 minutes followed by slow cooling practically does not change the mechanical properties of the alloy and reduces the parameters of friction and wear compared to the initial state.

Increasing the duration of hydrogen treatment to 40 min with subsequent rapid cooling and thermal cycling provides an increase in hardness by 27 %, strength by 65%, microhardness of the β -Si solid solution by 40 %, eutectic by 316 % and a decrease in friction and wear parameters, which is due to the structural parameters of the alloy, quantitative the ratio of the eutectic component and the primary crystals of the β -Si solid solution, as well as the redistribution of alloying elements between phases and structural components during processing.

Table 4 - Mechanical properties of AlSi18(B-Sn) alloy depending on the processing mode

sample №	HB	σ_b , MPa	H μ $\beta - Si$, MPa	H μ ($\alpha - Al + \beta - Si$) MPa
1	75,9	99	6600	165
2	109	141,7	11546	400
3	156	234	8514	321
4	130	195	7789	315
5	81	105,3	6600	147
6	155	201	9842	724
7	72,5	94,25	7380	186
8	126	163,8	9292	687

Table 5 - Wear and friction characteristics of AlSi18 alloy (B-Sn) depending on the processing mode

AlSi18 (B-Sn) processing modes	Track depth N, μ m	Friction force F, g	Saturation of the surface layer with traces of DR,D	Plastic deformation of the surface, ε
1	3,7	17	0,42	0,061
2	4	20	0,48	0,067
3	3,4	11	0,46	0,056
4	4,1	13	0,44	0,068
5	2,9	22	0,34	0,044
6	4	16	0,42	0,66
7	3	18	0,38	0,061
8	4	15	0,37	0,48

Thus, the analysis of experimental data allows us to recommend hydrogen treatment for 40 minutes followed by rapid cooling and thermal cycling in the solid state for the formation of a favorable structure and improvement of properties. Such processing parameters provide high strength of

the alloy along with the material's resistance to destruction. This treatment provides high microhardness of the structural components, and the parameters of friction and wear are minimal.

Resume

The structure, phase composition, mechanical properties, friction and wear parameters of AK18 alloy (B-Sn) depending on the modes of melt physico-chemical processing and thermal cycling in the solid state were studied. It is shown:

- hydrocirculation and hydrogen melt processing with thermal cycling in the solid state leads to a change in the quantitative ratio of primary crystals (solid solution and eutectic, the shape and size of primary and eutectic crystals of silicon solid solution, increased eutectic differentiation, the appearance of pseudo-primary aluminum solid solution (α -Al) dendrites;

- the observed structural changes ensure the improvement of the mechanical properties complex and the wear friction parameters reduction;

- the dependence of the wear resistance of the AlSi18(B-Sn) alloy on the modes of physical and chemical treatment in the liquid state and thermal cycling in the solid state was determined using the microindentation method. It was found that increasing the exposure time during hydrocirculation treatment up to 30 minutes leads to a decrease in wear resistance compared to the initial state of the AK18(B-Sn) alloy. The indicator of the wear factor increases almost three times. The use of thermocycling after TCT equalizes the indicators of the wear factor with those of the original alloy. It was established that the AlSi18 (B-Sn) alloy has the maximum wear resistance after hydrogen treatment for 20-40 minutes, the cooling rate does not effect the wear resistance indicators, it is not necessary to use thermal cycling, the wear resistance increases by 20% compared to the original alloy.

- the obtained experimental data allow to recommend for practical use hydrogen treatment for 40 minutes followed by rapid cooling and thermal cycling in the solid state at 475-485°C for 5 cycles to improve the complex of mechanical properties and reduce wear friction parameters.

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