Рис. 4. Кривые крутящих моментов, полученные от пленок $Fe_{86}Mn_{13}C$ в крутильном магнитометре

Таким образом, исследованы структура и магнитные свойства пленок $Fe_{86}Mn_{13}C$, обнаружена когерентная связь аустенитно-мартенситной структуры, предложена трехмерная кластерная модель мартенситного превращения, описывающая известные ориентационные соотношения фаз при мартенситных переходах.

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IMPROVEMENT OF MECHANICAL PROPERTIES OF BOAT-TYPE SCREWS OF ALUMINIUM-SILICON ALLOY AK12 WITH THE HELP OF THERMAL-CYCLE PROCESSING

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The use of thermal-cycle processing improves the mechanical properties of boat screws of aluminium-silicon alloy AK12.

Keywords: thermal-cycle processing, mechanical properties, boat-type screw, aluminium-silicon alloy AK12.

ПОВЫШЕНИЕ МЕХАНИЧЕСКИХ СВОЙСТВ ЛОДОЧНОГО ВИНТА ИЗ АЛЮМИНИЕВО-КРЕМНИЕВОГО СПЛАВА АК12 С ПОМОЩЬЮ ТЕРМОЦИКЛИЧЕСКОЙ ОБРАБОТКИ

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Термоциклическая обработка повышает механические свойства лодочного винта из алюминиево-кремниевого сплава АК12.

Ключевые слова: Термоциклическая обработка, механические свойства, лодочный винт, алюминиево-кремниевый сплав АК12.

One of the first inventions for use the thermocyclic treatment (TCT) of alloys was patented in 1978 [1]. In it on the example of aluminum-silicon alloy there was fixed that as a result of 8–12-multiple cycling the «heating ↔ cooling» process of molded articles its strength ($\sigma_\text{в}$ – for 40,8 %) and plasticity (δ – for 76,4 %) improve at the comparison with a standard regime of thermal treatment «hardening → cooling on air → ageing». The materials of the conference [2] on which there were 75 reports presented show the universality of TCP by its using for improving the mechanical properties of products made of cast iron, steel, aluminum and titanium alloys.

Works on the TCT use are carried out at the present time to improve the mechanical properties of metal products, including those made of aluminium-silicon alloys [3].

TCT was used in this work to improve the mechanical properties of three-bladed helical boat propeller (blades mainly) poured of aluminium-silicon alloy AK12 (10,0–13,0 % Si; the rest – Al) into the casting mold of same alloy. To prevent the influence of molten metal for the form its surface was painted by the fireproof paint containing 3,92 mass % of nanopowder silicium nitride Si_3N_4(other components: 5,88 % of oxide zinc ZnO; 11,76 % alkali silicate Na_2SiO_3, water is the rest) [4].

We investigated the blades of a three-bladed helical boat propeller 240 mm in diameter (Fig. 1) cast into a mold made from AK12 alloy (11,2 % Si, 0,4 % Fe, 0,01 % Mg, 0,02 % Cu, and trace amounts of Zn). The thickness of the blades of a complex curvilinear form (surface area = 80,207 cm^2) varied from 1,5 at the periphery to 6,5 mm at the site of transition to the hub.

The microstructures of aluminum-silicon alloys of hypoeutectic and eutectic compositions in the cast state consists of primary dendrites of the α-solid solution and the eutectic, which fills up the space between their branches. The mechanical properties of the these alloys depend on the shape of the precipitates of the silicon phase in the eutectic and the surface area occupied by it. The more rounded the particles of this phase and the smaller their area of cross section, the higher are the mechanical properties of the alloys [5]. According to the service conditions, the blades must have high strength and plasticity. During the use of well-known conditions of heat treatment of binary silumins, the mechanical properties were observed not to increase very much [6]. This is related to the fact that binary silumins do not contain the elements that form strengthening phases and the conditions of the heat treatment used do not give rise to a high degree of coagulation or spheroidizing of the silicon phase owing to the insufficiently high rate of the "dissolution ↔ precipitation" processes. The acicular precipitates of the silicon phase are spheroidized by thermocyclic treatment (TCT) [7]. Although the general rules of the structural formation of silumins are basically well known during TCT [8], additional investigations are required for the selection of TCT conditions of castings of certain configurations.

The TCT of the boat propeller was performed by the scheme 500 ↔ 20 ºC or 550 ↔ 20 ºC with the number of cycles n = 3; 5; and 7 and a holding time of 10 min at the upper temperature (T_u) and the lower temperature (T_l) and cooling from T_u in the next cycle in either air or water (the conditions of the TCT are presented in Table 1). In order to determine the mechanical properties from the least curvilinear part of the blade (transverse direction), samples were cut out (Fig. I, b) with a width of b = 10 mm. Measurements of the variable thickness h of the samples showed that it linearly varied along the length of the sample. The initial thickness h_i of the samples at the site of their failure was determined from the equations:

$$h_i = h_2 - (h_2 - h_1)\,\frac{l_i}{l}, \qquad (1)$$

where h_1 and h_2 were the thicknesses of the sample at its thin and thick edges respectively, mm; l_i was the distance between the edge and the site of the failure, mm; and l was the length of the sample after the failure, mm. The magnitudes of l and l_i were determined after the tests.

Knowing the initial thickness h_i and the width of the samples (b = 10 mm), we calculated their initial surface area F at the site of the failure, mm^2:
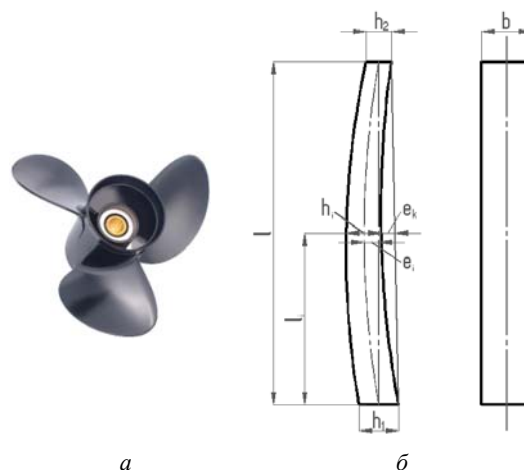
$$F_i = h_i\,b. \qquad (2)$$

Fig. 1. A three-bladed helical boat propeller
[http://www.spbsport.ru/brands/135] (a) and a nonstandard
sample for testing the mechanical properties sectioned
out of a blade of a helical boat propeller (on fig. 1, *a*)

We determined the apparent ultimate tensile strength (or the true threshold stress at the moment of the failure), viz., σ_u^bend. Because of the curvilinear form, the sample was not only subjected to tension but also to bending and corrections were made in the calculated values of σ_u^bend. It is well known that

$$\sigma_u = \frac{P}{F_i}, \qquad (3)$$

where P is the maximum force, N.

Considering the bending component

$$\sigma_u^{bend} = \frac{P}{F_i} + \frac{P \cdot e_i}{W}, \qquad (4)$$

where e_i is the eccentricity of the sample at the site of the failure, mm; $P \cdot e_i$ is the bending moment, N, mm; and $W = b \cdot \frac{h_i^2}{6}$ is the areal moment of inertia, mm.

The eccentricity e_i at any point i (Fig. 1) was determined by the equation:

$$e_i = e_k + h_i [2 - (h_1 + h_2)]/4, \qquad (5)$$

where e_k is the eccentricity on the lateral surface of the sample, mm.

Using simple transformations, Eq. (4) takes on the form

$$\sigma_u^{bend} \; \frac{P}{F_i}(1 + \frac{6e_i}{b}) = \sigma_u \cdot \beta. \qquad (6)$$

The results of the tests are presented in Table I. It can be seen that, under all conditions except 9, the properties of the samples after TCT are consistently greater than the properties in the cast state. The highest strength properties were reached after TCT under conditions 4. Upon TCT under identical conditions but cooling in air, the strength indices were somewhat lower in value.

The high level of the mechanical properties of the AK12 alloy after TCT under some conditions was caused by the features of the microstructural formation. Cyclic repetition of the heating and cooling conditions of the alloy leads to fragmentation, spheroidization, and coagulation of the crystals of the silicon phase as a result of the occurrence of the processes of partial dissolution and precipitation of the phase components. The dissolution of silicon in aluminum was observed to be maximum upon heating to 500–550 ºC during the course of the TCT. During the subsequent cooling to 20 ºC, the excess silicon precipitated out of the matrix solution. A TCT with a greater number of cycles than the optimum produced high mechanical properties but led to growth of acicular silicon crystals. For example, after TCT with n = 3, a significant amount of refinement took place compared to the structure of the cast alloy with respect to the silicon component of the eutectic (Fig. 2, a, b). Upon TCT with n = 5, the silicon component of the eutectic became coarser in size (Fig. 2, *c*) whereas, for n = 7, the eutecfic significantly coarsened.

Consistent with the structural features, the maximum strength properties were obtained in the alloy after TCT with n = 3, which formed the finest dispersion of the eutectic, whereas the highest plasticity was obtained in the alloy after TCT with n = 5 where the eutectic silicon was spheroidal in shape. These results of the investigation are in agreement with the literature data: it was determined in [9; 10] that a higher strength resulted from refinement of the silicon phase whereas plasticity increased due to the spheroidization of the precipitates of this phase.
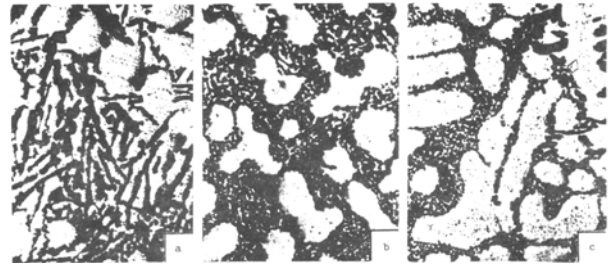

Fig. 2. Microstructure of the AK12 alloy (× 150): a – as-cast state; b, c – TCT by the scheme 550 ↔ 20 ºC, cooling in water, n = 3 and 5 respectively

Table 1

Mechanical properties samples sectioned out of a blade of a boat propeller

Conditi-ons of TCT	Scheme of TCT	Number of thermal cycles, n	Coding me-dium	σ_u	σ_u^{bend}	$\delta_{apr'}$,	HB
				N/mm^2		%	
Cast (starting) state		–	–	107	145	3.3	50
1	500 ↔ 20 ºC	3	Air	129	173	10.0	55
2		5		119	160	20.0	51
3		7		124	167	8.6	52
4		3	Water	149	194	6.7	56
5		5		119	160	6.7	51
6		7		126	172	10.0	51
7	550 ↔ 20 ºC	3	Air	138	186	6.7	56
8		5		111	139	20.0	51
9		7		107	143	4.7	53
10		3	Water	121	163	13.3	56
11		5		115	148	13.3	51
12		7		111	148	6.7	53

Notations: σ_u^{bend} is the apparent ultimate tensile strength determined by considering the bending of the sample of a curvilinear propeller blade during the tensile test.

However, one should note that, in spite of the fairly high absolute increase in the strength of the alloy (compared to the as-cast state), not a single one of the conditions of TCT met the requirement of GOST 2685–75, viz., $\sigma_u \geq 160$ N/mm^2. Correcting σ_u by Eq. (6), we obtained an estimate for the value of the ultimate tensile strength considering bending, i. e., σ_u^{bend}. It was determined (Table 1) that, after TCT of the alloy by the scheme 500 ↔ 20 ºC σ_u^{bend} bend was greater than σ_u by 30,0–36,8 %, i. e., β = 1,33 in Eq. (6) and σ_u^{bend} = 160–194 N/mm^2. Upon TCT by the scheme 550 ↔ 20 ºC, σ_u^{bend} turned out to be greater than σ_u by 24,7–31,8 % (β = 1,296) and was equal to 139–186 N/mm 2. Thus, at lower T_u, the calculated values of σ_u^{bend} do meet the requirements of GOST 2685–75 ($\sigma_u \geq 160$ N/mm2). The legitimacy of the correction to σ_u by considering the bending moment is supported by the results of investigation of the mechanical properties of standard cylindrical samples 12 mm in diameter cast from the AK12 alloy of the same composition in a vertical mold. Such samples after TCT by the scheme 500 ↔ 20 ºC followed by water quenching had $\sigma_u = 210$ N/mm^2.

Conclusions. The mechanical properties of samples of the AK12 alloy sectioned out of blades of helical boat propellers after TCT are higher in value than those for the as-cast samples. The highest values of σ_u were reached after TCT by the cheme 500 ↔ 20 ºC (n = 3) followed by water quenching.

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ТЕОРЕТИЧЕСКОЕ ИССЛЕДОВАНИЕ СОРБЦИИ АТОМОВ ЛИТИЯ НА УГЛЕРОДНЫХ НАНОСТРУКТУРАХ*

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Представлено теоретическое исследование различных углеродных наноструктур (фуллерены, buckygyt, дефекты углеродных плоскостей) как потенциального материала для изготовления анодов в литий-ионных батареях. Рассмотрены процессы сорбции атомов и кластеров лития в объем и на поверхности данных материалов.

Ключевые слова: литий-ионные батареи, сорбция лития, углеродные наноструктуры, фуллерены, теория функционала плотности (DFT).