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I. P. Volchok[1], S. E. Belsky[2], A. V. Blakhin[2], F. F. Tsaruk[2], Adel Abdel Basset Rashid[3], Mourtada Srour[4]
[1] Zaporizhia National Technical University
[2] Belarusian State Technological University
[3]Beirut Arab University
[4]Lebanese University

IMPROVEMENT OF MECHANICAL CHARACTERISTICS OF SECONDARY ALUMINUM ALLOYS WITH LASER TREATMENT

This work substantiates the feasibility of laser treatment of secondary cast aluminum alloys. The authors performed examination of the influence of iron content and laser treatment on a number of mechanical characteristics of the alloy close to the AK9M2 alloy in terms of chemical composition. Special attention was paid to the fatigue characteristics. It was determined that the fatigue characteristics were generally reduced after performance of laser treatment. An increase in the concentration of iron in the alloy also lead to reduction of the fatigue characteristics of the tested materials.

The authors demonstrated that performance of laser treatment with subsequent surface polishing and aging contributes to improvement of fatigue characteristics.

Key words: aluminum alloys, impurities, hardening, laser treatment, fatigue characteristics.

Introduction. Cast aluminum alloys are currently used in various industry fields (aviation, shipbuilding, road and rail transport, process equipment). Aluminum alloys have high levels of specific strength, plasticity and corrosion resistance. The main disadvantages of such materials are low hardness and strength.

Due to high energy intensity required for production of primary aluminum alloys and presence of large amounts of scraps and production waste, replacement of primary alloys with secondary ones is highly relevant. However, due to high volume of impurities, their mechanical properties are significantly inferior to the properties of primary alloys. The most commonly found impurity is iron, which forms intermetallic phases during the crystallization process. Such phases serve as stress concentrators and significantly reduce the complex of mechanical properties of aluminum alloys, especially their fatigue characteristics [1–8].

One of the methods to improve mechanical properties of aluminum alloys is laser treatment of product surfaces. Such treatment significantly increases hardness and wear resistance of the surface [9, 10]. Studies have demonstrated that this method of surface strengthening is feasible for secondary aluminum alloys, since the presence of a significant number of inermetallic phases eliminates the need for surface doping [11]. However, fatigue characteristics are significantly reduced after such treatment [12]. Therefore, this work aims to study the possibilities to improve mechanical properties of secondary alpax using laser treatment.

Main part. The study was performed on three fractions of the AK9M2 alloy with nearly permanent chemical composition in terms of the main elements: 9.73–9.84% Si, 2.27–2.4% Cu, 0.054–0.060% Mn, 0.67–0.093% Mg, but with variable iron content: 0.51, 1.03 and 1.525%. During transfer from the resistance furnace into the ladle, the alloy was treated with the modifier [10]; alloy blanks were thermally treated according to the T6 mode: hardening at (500 ± 10)° during 5 hours, aging at (180 ± 10)° during 7 hours. Laser treatment was performed on the pulse laser “Kvant-12” (surface fusion mode, τ = 4 ms, λ = 0,6943 μm, track overlapping – 30%). Fusion of 2 mm thick flat blanks was performed on two sides. The average thickness of fused layer amounted to about 200 μm.

Fatigue tests were performed with the help of flat beam specimen with section of 6×h mm made of the secondary aluminum alloy AK9M2 with various iron contents and surface conditions (fig. 1).

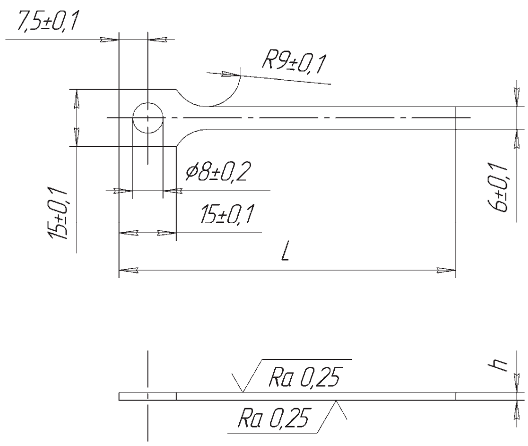

Fig. 1. Specimens for loading with alternating bend

Specimen thickness h was accepted as (1.95 ± ± 0.06) mm. Test specimens were loaded with alternating bend on a specially designed unit [13, 14], which operated with resonance frequency of 18.2 kHz (fig. 2).

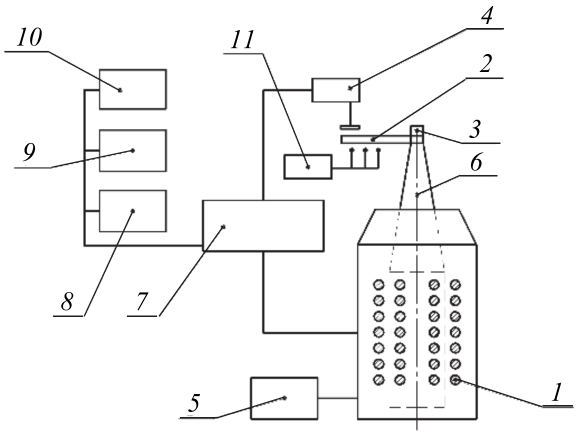

Fig. 2. Diagram of the test bench for excitation of bending oscillations at resonance frequency (18.2 kHz): *1* – magnetostrictive transducer with excitation and bias coils; *2* – specimen; *3* – mounting device; *4* – MRTI vibration meter; *5* – bias module; *6* – waveguide concentrator; *7* – PSA amplitude stabilization device; *8* – frequency meter; *9* – oscilloscope; *10* – computer with printing device; *11* – temperature controller

The specimen oscillated in the second self-oscillation modes. Selected ranges and shapes of oscillations ensured fatigue destructions in points of maximum cyclic stresses closer to the middle part of the straight-line section, which would ensure convenient study of changes in the material properties and development of a fatigue crack [15, 16]. Kinetics of the sample damage during loading was evaluated indirectly based on the decrease in the resonance oscillation frequency with development of the fatigue crack. Upon reaching a certain value, reduction in the testing frequency stopped.

Results of tests on the Duramin-5 device (load: 25 g) demonstrated a significant increase in the microhardness H_μ and temporary resistance $\sigma_н$ (the device determines this parameter automatically during hardness tests) as a result of laser fusion of specimen surfaces (table). One could have expected a corresponding increase in the fatigue strength as well. However, there was no increase due to high roughness of the fused surface, as well as residual tense stresses in surface layers of the specimen. Thus, the alloy AK9M2 after laser treatment was inferior to the original treatment in terms of resistance to fatigue destruction.

Strength and microhardness limits of the hardened layer of specimen

Parameter	Fe content, %		
	0.51	1.03	1.52
H_μ, MPa	1525	1598	1620
$\sigma_в$, MPa	423	455	478

After mechanical treatment of fused surfaces of specimens on grinding machines to the roughness level of Ra ~ 0.32 μm, the resistance of the alloy to destruction under the effect of cyclic loads increased significantly (fig. 4, curves 3).

Further improvement of the alloy fatigue was achieved due to artificial aging at 180°C during 10 hours. After complex treatment (laser, grinding and aging), cyclic durability indicators exceeded the indicators obtained after standard thermal treatment according to the T6 mode (fig. 3).

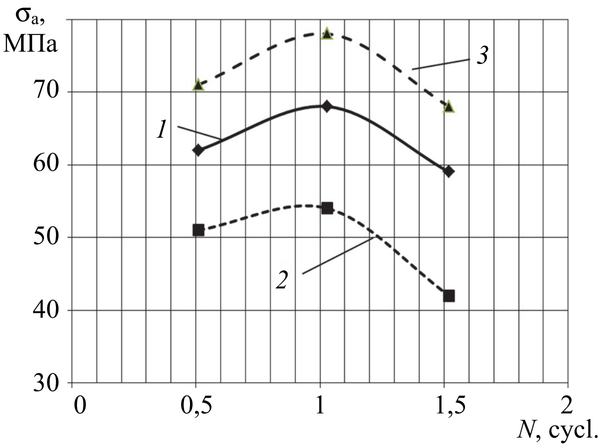

Fig. 3. Thresholds of limited resistance of the AK9M2 alloy specimens depending on the Fe content: *1* – original condition; *2* – after laser treatment; *3* – after laser treatment, polishing and aging

In general, testing results demonstrated the following: laser treatment led to improvement of the main characteristics of construction materials – micohardness (from 975–1000 to 1525–1620 MPa) and temporary resistance to destruction (from 70–160 to 423–478 MPa), which helps expand the field of application of aluminum alloys.

After laser treatment, the harmful inclusion in the basic mass of aluminum alloys, iron, turned out to be useful on condition of its content approximately under 1% (table, fig. 4). In our case, an increase in the iron content from 0.51 to 1.03% caused an increase in the fatigue limit from 68 to 77 MPa at test bases of 10^7; at the same time, the increment of the fatigue limit amounted to about 30%. The results obtained can serve as a basis for using low-grade raw materials mix contaminated with iron for production of aluminum alloys.

Conclusions. Laser treatment is a promising process of surface hardening specifically for secondary aluminum alloys containing significant amounts of iron. The study revealed a significant increase in the surface hardness and strength of the examined specimens of the AK9M2 alloys, which makes it possible to use this alloy for production of parts for machines operating in heavy duty conditions.

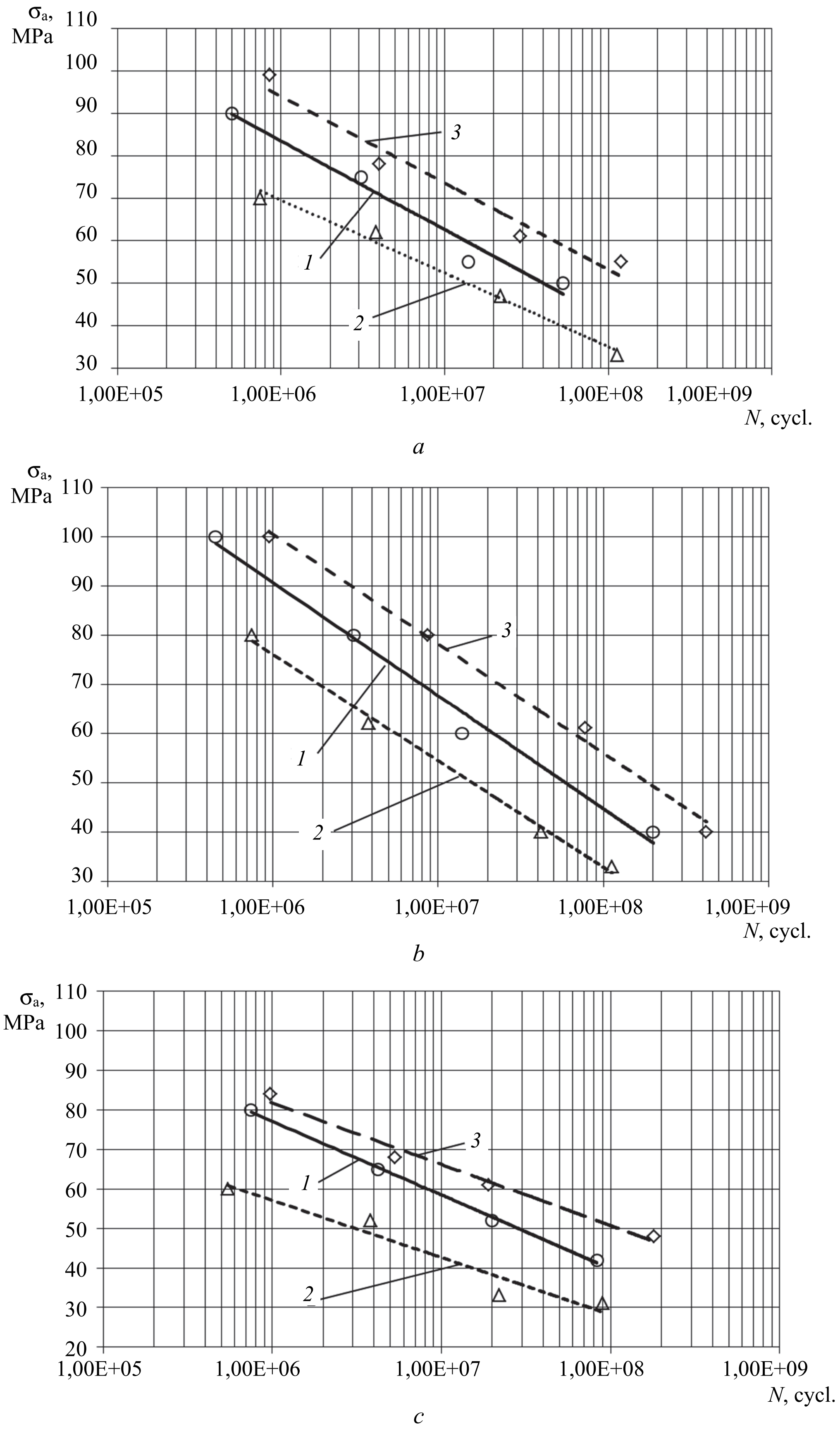

Fig. 4. Fatigue curves of 50% probability of destruction of the AK9M2 alloy specimens:
a – 0.51% Fe; *b* – 1.03% Fe; *c* – 1.52% Fe; *1* – original condition;
2 – after laser treatment; *3* – after laser treatment, polishing and aging

However, laser treatment significantly reduces characteristics of cyclic strength of the examined material according to the data given in table [7], which were obtained for another aluminum alloy. Additional finishing treatment, which consists in aging and mechanical polishing, increases fatigue characteristics by 10–15% as compared to the original material. It has been determined that the optimal content of iron in the alloy for improvement of mechanical properties is 1.0%, which is due to transformation of iron-containing phases during laser treatment.

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Information about the authors

Volchok Ivan Petrovich – DSc (Engineering), Professor, the Department of Composite Materials, Chemistry and Technology. Zaporizhia National Technical University (64, Zhukovsky str., 69063, Zaporizhia, Ukraine).

Belsky Sergey Epggrafovich – PhD (Engineering), Professor, the Department of Material Science and Engineering of Technical Systems. Belarusian State Technological University (13a, Sverdlova str., 220006, Minsk, Republic of Belarus). E-mail: dmiptu@belstu.by.

Blakhin Aleksey Vladimirovich – PhD (Engineering), Assistant Professor, the Department of Material Science and Engineering of Technical Systems. Belarusian State Technological University (13a, Sverdlova str., 220006, Minsk, Republic of Belarus). E-mail: blakhin@belstu.by.

Tsaruk Fedor Fedorovich – PhD (Engineering), Assistant Professor, the Department of Material Science and Engineering of Technical Systems. Belarusian State Technological University (13a, Sverdlova str., 220006, Minsk, Republic of Belarus). E-mail: Tsaruk@belstu.by.

Adel Abdel Basset Rashid – Beirut Arab University, Lebanon, Tyre. E-mail: adel_Rasheed_1975@hotmail.com.

Mourtada Srour – Assistant Professor, Lebanese University, Lebanon. E-mail: adel_Rasheed_1975@hotmail.com.

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