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Development of the methods of scandium utilization at the laser welding of aluminum alloys of Al-Cu-Li and Al-Mg-Li systems

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Abstract

Today, production of aeronautical equipment involves up-to-date high-strength aluminum alloys of reduced density caused by lithium. Manufacture of wide-body aircrafts includes the technology of riveting of parts which means millions of rivets. Now, this technology is giving place to welding. Welded joints of aluminum alloys have to meet tough strength requirements. It is known that scandium used as a dopant increases the strength characteristics when the addition alloy of aluminum alloys is created. This work deals with the scandium utilization in the laser welding process.
Experimental investigations have been carried out to optimize the laser welding process with the welded joint modified by scandium. The technique of scandium utilization in the laser welding process has been developed. The effect of scandium on the micro- and macro-structure, strength characteristics of the welded joints has been studied. It is found that scandium increases welded joint elasticity for the aluminum alloy of the system Al-Mg-Li (by 20 %), and of the system Al-Cu-Li (by about two times).

Keywords: laser welding, scandium, microstructure, strength, elasticity;

1. Introduction

Up-to-date high-strength Al-Li alloys [1] are used for aeronautical and space equipment. Utilization of Li permits reducing the specific mass of aluminum alloys. Thermally strengthened alloys of the system Al-Cu-Li

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demonstrate high mechanical characteristics, the alloys of the system Al-Mg-Li have the medium strength and are super-light [1-3].

Nowadays, detailed researches are addressed to both the properties of these alloys [4-5], and to the availability of different methods of production of fixed joints; under study are the prospects of the friction stir welding, argon-arc welding, laser welding [6-13] with the strength approaching to the base material strength. Analysis of the results of laser welding of the alloys (systems Al-Cu-Li and Al-Mg-Li) has revealed that the relative strength of the welded joints for aluminum alloys is k = 0.75 – 0.85 of the base material strength regarding the alloying system and surface preparation technology [6], and it is without extra processing of the welded joint. To increase the strength characteristics of the welded joints (the alloys of the systems Al-Cu-Li and Al-Mg-Li), extra mechanical and thermal processing of the joint is needed. In [11], the effect of various kinds of deformation of the welded joint of its strength is shown. It is demonstrated that for the aluminum alloy 1424 (the system Al-Mg-Li), the welded joint strength after the deformation processing reached 0.95 of the base alloy strength. The complex experimental investigation of the mechanical properties of the laser welding of the aluminum-lithium alloy (the system Al-Cu-Li) B-1469 is presented by [9]. It has been founded that thermal processing (annealing, quenching, and artificial ageing) permit reaching the welded joint strength of 0.85 of the base alloy strength in the delivery condition T1. Extra post-processing of the welded joint results in time increment and complication of the technological process of part production from aluminum alloys.

In recent years, modification of the welded joints by nano-size refractory particles, rare-earth chemical elements, filler metal wires of various composition [10, 12-14] provokes high interest as a way to change the chemical composition, control the welded joint microstructure, and increase strength characteristics. Rare-earth elements are the most promising for the welded joint modification.

Scandium (Sc), the rare-earth element, imposes the essential effect on the varying mechanical properties of aluminum. Strengthening effect of scandium results from its high ability to over-saturate a solid aluminum solution during the alloy crystallization. High efficiency of the scandium modifying effect depends on the size-structure correlation between the crystal lattice of aluminum and primary particles Al_3Sc, which form in the pre-crystallization period and make nucleation grains of the solid aluminum solution [15]. As is known, Sc, as an alloying element during the addition alloy creation for the aluminum alloys, increases the strength characteristics for Al-Mg and Al-Cu alloys [16]. The presence of Sc in the Al-Mg alloy reduces noticeably magnesium solubility in aluminum. Analysis of the ingot structure at Al-Cu alloy casting shows that scandium admixtures highly refine grains and increase the alloy strength.

The purpose of this work is to develop the method of joint modification by the rare-earth element Sc for the laser welding of the alloys (the systems Al-Cu-Li and Al-Mg-Li). Analysis of the macro- and microstructure and strength characteristics of the Sc-modified welded joint.

2. Materials and experiment technique

High-strength industrial aeronautical aluminum alloys (made by OAO «Kamensk-Ulal'skij metallurgicheskij zavod», Russia), systems Al-Mg-Li, alloy 1420, and Al-Cu-Li, alloy 1441 are used. Chemical compositions of the alloys 1420 and 1441 (mass %) are given in Table 1.

Table 1. Chemical composition of the aluminum alloys (weight %).

Alloy	Cu	Mg	Li	Zn	Zr	Mn	Ti
1420		5.8-6.2	1.8-2.2	0.05	0.01	0.1-0.25	
1441	1.6-1.9	0.7-1.1	1.7-2.0		0.26	0.04	0.07

Laser welding (LW) of the aluminum alloys (thickness 1.4 mm) was performed in ALTK "Sibir'-1", by the continuous CO_2-laser with the power up to 8 kW, developed in ITAM SB RAS. Laser radiation was focused on the alloy surface by a *ZnSe* lens, its focal distance 254 mm. To protect the welded joint and root, the inert gas helium was used. Macro- and microstructures of the welded joints were analyzed in the optical microscope Olympus LEXT OLS3000. Sample strength was measured at the static extension in the electro-mechanical test machine Zwick/Roell Z100.

The LW process was optimized by energy parameters (laser radiation power, position of the focal spot of the laser radiation about the ingot surface, welding rate) at the early stage for the chosen aluminum alloys of the systems Al-Mg-Li (1420) and Al-Cu-Li (1441), in order to have defect-free welded joints (no cracks, penetrations, cuttings).

As a result, the optimal parameters of the laser action for defect-free welded joints have been found. They are the following: radiation power W = 3 kW, welding rate V = 4 m/min, focus deepening -3 mm from the upper sheet boundary for both systems Al-Mg-Li (1420) and Al-Cu-Li (1441).

The macro-structure of the welded joints has been studied for the optimal LW modes for the two systems Al-Mg-Li and Al-Cu-Li.

Development of the technology of preparation and activation of scandium particles for coating on the aluminum alloys prior the welding. To optimize the technology, the chosen Sc powder fraction contains the particles with d = 40 – 80 µm. Sc particles are coated on the aluminum alloys by the additive method, with a specially made rigid caliber with a cutting, its thickness 100 µm, stainless steel. The coated mass is ≈ 0.6 – 0.8% of the welded joint mass. Sc particles are flatten with a titanium plate over the alloy surface. In fact, a mono-layer is made. The particles are fixed by a lean butanol-based BF-6 solution. The sample with fixed Sc particles is heated slightly to evaporate alcohol.

Then follows the welding process in the previously found optimal modes without Sc, the radiation power of 3 kW and welding rate 4 m/min. In this LW mode, intensive boiling and welded joint rupture took place.to prevent the rupture of the welded joint, the radiation power was reduced. Then the LW was carried out at the following powers: 1.6; 2; 2.4 kW, and welding rate 4 m/min. As the power increased, large pores occurred in the welded joint, which resulted in the joint embrittlement. AT the power of 1.6 kW, faulty penetration was observed. So the optimal power without welded joint rupture and faulty penetration was 2 kW, and there was porosity. It was assumed that the process rate was too high. Sc particles do not manage to interact during the welding, Sc did not mix uniformly in the welded joint. Preserving the chosen power of 2 kW, the laser welding rate was halved. The result was the welded joints with no visible defects.

The micro- macro-structure and mechanical characteristics were studied in the optimal LW modes for the welded joint with and without Sc.

3. Results and discussion

3.1. Analysis of the microstructure

Fig. 1 presents the microstructures of sections of the welded joints with and without Sc obtained in the optimal modes of the laser welding.

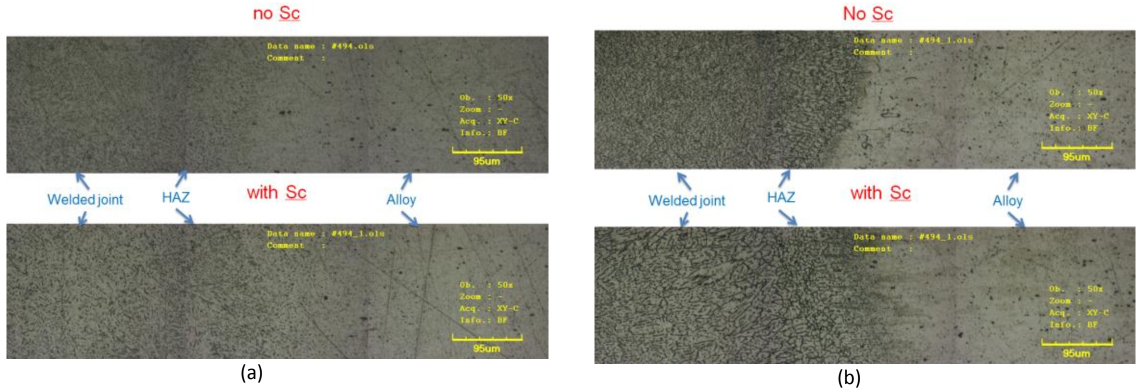


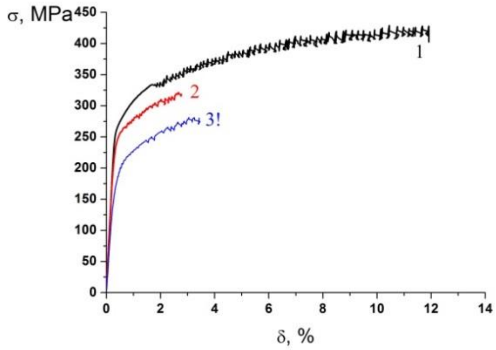
Fig. 1. Photo of the welded joint section and base alloy without Sc and with Sc, a) system Al-Mg-Li, alloy 1420; b) system Al-Cu-Li, alloy 1441.

As is evident from Fig. 1, in the optimal LW mode, Sc influenced the welded joint microstructure, especially for the system Al-Cu-Li alloy (1441).

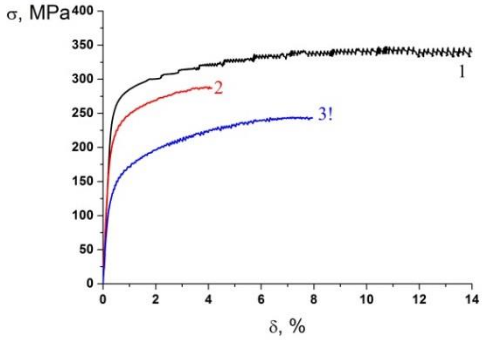
Mechanical tests of the rupture strength for the welded joints and base alloy.

Fig. 2 shows the dependence of the ultimate tensile strength of the base alloy, welded joint, and Sc-modified welded joint. Sc influenced the strength properties, the rupture strength decreased as compared to the unmodified welded joint.

The relative extension rose as compared to the unmodified welded joint. The elasticity of the modified welded joint rose for the aluminum alloy of the system Al-Mg-Li by 20 % and almost doubled for the system Al-Cu-Li.



Alloy 1420



Alloy 1441

Fig. 2. Stress σ versus deformation δ of samples. (1) – base alloy strength; (2) –welded joint strength; (3) – strength of the Sc-modified welded joint.

Decreased process rate and respectively LW time in the knife-like fusion mode enabled to change the strength properties of the Sc-modified welded joint, i.e. stimulated more active mixing of the components and their active interaction, which is proven by the changed microstructure of the welded joint.

4. Conclusions

The technique of scandium application in welded joints has been developed, defect-free welded joints have been made. Scandium effect on the welded joint microstructure has been studied. As is shown by experiments, application of scandium in the laser welding process changes the welded joint microstructure, especially for the system Al-Cu-Li. It is founded that Sc increases the welded joint elasticity for the aluminum alloy of the system Al-Mg-Li by 20 % and almost doubles it for the system Al-Cu-Li.

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References

A.M. Orishich, A.N. Cherepanov, V.P. Shapeev, N.B. Pugacheva, 2014. Nanomodifitsirovanie welds by laser welding metals and alloys. Siberian scientific edition, Novosibirsk, p.229 Rioja R.J., Liu J., 2012. The evolution of Al–Li base products for aerospace and space applications. Metall. Mater. Trans.43, p.3325–3337.

B.D. Annin, V.M. Fomin, E.V. Karpov, A.G. Malikov, A.M. Orishich, 2016. Complex research of laser welding of high-strength alloy V-1469, Aviation materials and technologies 3, p. 9-16.

B.D. Annin, V.M. Fomin, V.V. Antipov, E.N. Ioda, E.V. Karpov, A.G. Malikov, A.M. Orishich, A.N. Cherepanov, 2015. Investigation of the Technology of Laser Welding of Aluminum Alloy 1424. Doklady Physics 60, p.533–538.

Drits A. M., Ovchinnikov V. V., 2012. Weldability and properties of welds of high-strength aluminum alloys of the Al – Cu – Li system. Metal Science and Heat Treatment 53, p.445-449.

Fridlyander I., and et., 2002. Thermally stable aluminum–lithium alloy 1424 for application in welded fuselage. Met. Sci. Heat Treat. l.44 p.3–8.

Fridlyander I., and et., 2007. High-strength structural silver-alloyed underdensity Al–Cu–Li–Mg alloy. Met. Sci. Heat Treat.49, p.279–283.

Gazizov M., Kaibyshev R., 2015.Effect of pre-straining on the aging behavior and mechanical properties of an Al–Cu–Mg–Ag alloy. Materials Science & Engineering 625, p.119–130.

L. B. Ber, V. V. Teleshov, and O. G. Ukolova, 2008. Phase composition and mechanical properties of wrought aluminum alloys of the system Al – Cu – Mg – Ag – X. Met. Sci. Heat Treat. 50, p.220–227.

Light and heat-resistant alloys and their processing: the 80th anniversary of the birth of A.F. Belova. 1986. N.M. Zhavoronokov, Editor. Nauka, Moscow, p.304

Lukin V.I., Skupov A.A., Panteleev M.D,, Ioda E.N, 2016. Influence of additives on the weldability of scandium alloys Al-Mg system. Welding and diagnostics 1, p.3-5.

O. O. Olatunji, Emel Taban, 2016. Trend and innovations in laser beam welding of wrought aluminum alloys. Welding in the World. 60, p.415–457.

S. Riva, K. V. Yusenko, N. P. Lavery, D. J. Jarvis & S. G. R. Brown, 2016.The scandium effect in multicomponent alloys. Journal International Materials Reviews 61, p. 203-228.

Skupov A.A., Panteleev M.D, Ioda E.N., 2016. New filler materials for welding of high-strength aluminum-lithium alloys. Proceedings of VIAM 9, p.30-37.

T. Le Jolu, T.F. Morgeneyer, A. Denquin, A.F. Gourgues-Lorenzon, 2015. Fatigue lifetime and tearing resistance of AA2198 Al–Cu–Li alloy friction stir welds: Effect of defects. International Journal of Fatigue 70, p. 463–472.

Xinyi Zhang,Wuxiong Yang, Rongshi Xiao, 2015. Microstructure and mechanical properties of laser beam welded Al–Li alloy 2060 with Al–Mg filler wire. Materials and Design 88, p.446–450.