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TECHNOLOGICAL PROCESSES OF WELDING HIGH PRECISION THIN-WALLED PRODUCTS FROM ALUMINUM ALLOYS USING A LASER HEATING SOURCE

ТЕХНОЛОГІЧНІ ПРОЦЕСИ ЗВАРЮВАННЯ ВИСОКОТОЧНИХ ТОНКОСТЕННИХ ВИРОБІВ З АЛЮМІНІЄВИХ СПЛАВІВ З ЗАСТОСУВАННЯМ ЛАЗЕРНОГО ДЖЕРЕЛА НАГРІВУ

Summary. *The work is devoted to the development of the technological process of welding sealing of high-precision thin-walled products of the space industry from light alloys. This process includes: preparation of the product for welding by chemical etching of the welded parts with alkali, followed by neutralization with acid; assembly for welding of welded parts; basing in equipment and welding of a product with simultaneous control/management of its heating temperature; diagnostics of the level of its stress-strain state. It has been established that it is advisable to use laser welding as a welding process for sealing thin-walled high-precision products of the space industry from light alloys. An effective approach to minimizing (eliminating) such characteristic defects of laser welding as the formation of hot cracks and internal pores is the concomitant* *heating of the laser radiation zone. Such concomitant heating can be implemented using a hybrid laser-microplasma welding technology.*

Ключові слова: *лазерне зварювання, алюмінієві сплави, тонкостінні конструкції, супутній підігрів, мікроплазма*.

Анотація. *Робота присвячена розробці технологічного процесу зварювальної герметизації високоточних тонкостінних виробів космічної галузі з легких сплавів. Цей процес включає: підготовку виробу до зварювання хімічним травленням деталей, що зварюються, лугом з подальшою нейтралізацією кислотою; збирання під зварювання деталей, що зварюються; базування в оснащенні та зварювання виробу з одночасним контролем/керуванням температурою його нагрівання; діагностику рівня його напружено деформованого стану. Встановлено, що в якості зварювального процесу для герметизації тонкостінних високоточних виробів космічної галузі з легких сплавів доцільно використовувати лазерне зварювання. Ефективним підходом до мінімізації (усунення) таких характерних дефектів лазерного зварювання, як утворення гарячих тріщин та внутрішніх пор є супутній підігрів зони дії лазерного випромінювання. Такий супутній підігрів може бути реалізований при використанні гібридної лазерно-мікроплазмової зварювальної технології.*

Key words: *laser welding, aluminum alloys, thin-walled structures, co-heating, microplasma.*

Aluminum alloys are widely used in modern industry for the manufacture of lightweight structures with high strength and corrosion resistance. Such designs may include products of instrumentation, chemical and food industries, electric power and electronic technologies, transport, etc. [1]. In the manufacture of such structures, it is often necessary to make high-quality permanent joints [2]. For this, various welding methods are used [3]. In the case of manufacturing thin-walled one-piece structures, it is advisable to use such welding methods that provide local thermal heating of the weld zone. For example, laser, plasma or hybrid laser-arc welding methods [4].

In the manufacture of the noted structures, the possibility of using high-strength aluminum alloys is of particular interest. Such alloys make it possible to create lightweight structures with improved mechanical properties, which makes their use in modern industry relevant. Among high-strength aluminum alloys, Al-Zn-Mg-Cu system alloys (series 7xxx), which have the highest mechanical properties, are of the greatest interest. However, welding of such alloys is difficult due to their tendency to form hot cracks and pores. Therefore, studies of structure formation during welding of thin-walled joints from these alloys using concentrated energy sources are relevant.

To join thin-sheet aluminum alloys, both traditional (arc or plasma) fusion welding methods and more modern ones (laser and hybrid laser-plasma) can be used. When using arc welding methods, the width of the seam usually exceeds the depth, which is caused by the convective mechanism of metal penetration. It was shown in [5] that the intensity of such heat transfer and the flow of liquid metal in the weld pool is affected by alloying elements acting as surface active substances. In addition, the surface temperature, and therefore the welding parameters, also has an influence. It was shown in [6] that when welding with a free-burning arc in the convective flow of the metal of the weld pool, the force of the surface tension gradient and the electromagnetic force predominate. The same penetration can be obtained by welding by laser and laser-plasma methods [7]. In this case, the dominant force factor that determines the hydrodynamics of the melt is the Marangoni force. The formation of the molten zone in all considered cases is mainly influenced by convective energy transfer. Its shape and the amount of input energy can lead to the formation of hot cracks (especially when welding high-strength alloys of the 7075 type) [8].

The most effective today is the use of laser or laser-plasma welding with a penetration in which the penetration width is less than the depth. This type of penetration is called deep and is characterized by the formation of a steam-gas channel [9]. The features of the existence of a steam-gas channel are associated with its pulsations, which can contribute to the formation of pores in the remelted metal [10]. The formation of cracks in this case is associated with an increase in the crystallization rate of low-melting eutectics caused by an increase in the welding speed [11].

The purpose of this work is to create technological processes for welding high-precision thin-walled products from aluminum alloys using a laser heating source using the example of a sealed cylindrical structure with disk flanges welded with a non-through seam from two ends.

To achieve this goal, the following tasks were solved:

- select the parameters of the laser welding mode according to the criterion for obtaining a sealing seam with incomplete penetration;

- to conduct experimental studies of the welding process using laser radiation;

- to establish the main features of laser welding with incomplete penetration of thin-walled products made of aluminum alloys.

To select the parameters of the laser welding mode according to the criterion for obtaining a sealing weld with incomplete penetration, a number of experiments were carried out. The samples were made of 7075 aluminum alloy plates with a size of 50×50×1.5 mm, as well as cylindrical samples of 7005 alloy with a size of Ø41×41 mm (Fig. 1). In the latter case, disk flanges with a wall thickness of up to 1.5 mm were welded to the cylindrical part. The depth of penetration when making a sealed seam should have been 0.5-0.7 mm. To improve the results of laser welding (namely, to eliminate the risk of hot cracks and internal pores), concomitant microplasma heating was used. Laser welding with microplasma heating was essentially a hybrid laser-microplasma welding [12]. During the experiments, the parameters of the regimes indicated in Table 1 were selected.

a) b)

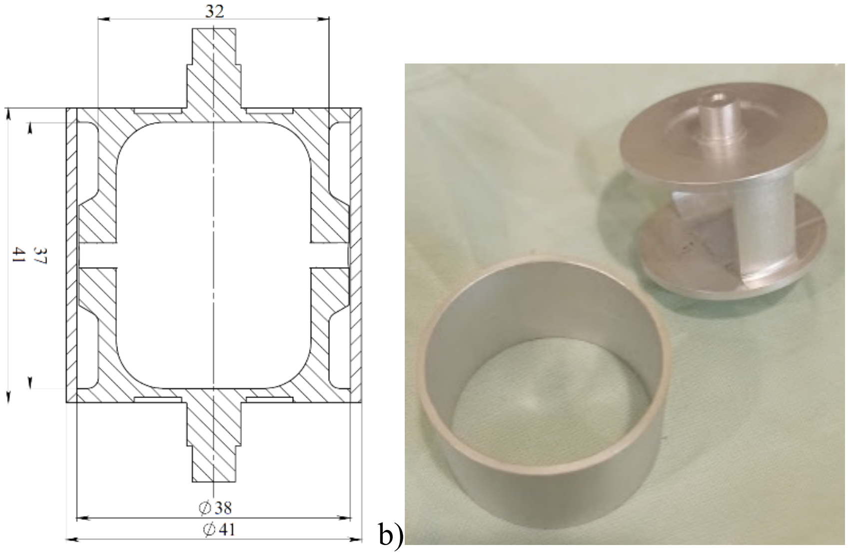


Fig. 1. Welded product:

a) – sketch of the section; b) – parts connected by welding

On the basis of the conducted research, two welding technologies were developed for the sealing of high-precision thin-walled products of the space industry from light alloys: laser and hybrid laser with accompanying microplasma heating. In accordance with the developed technologies, experiments were carried out on welding imitation samples of cylindrical products. Aluminum alloy 7005 was used as the material of the samples. Welding was performed using appropriate replaceable welding heads, which were fixed on a 3D manipulator (plotter). The simulated samples to be welded were based in a rotator mounted on the plotter table. Welding was carried out in automatic mode with a gradual decrease in the power of the welding source after the end of the process (Fig. 2). Modes and results of welding for both developed welding technologies are shown in Table 1. An example of a welded imitator sample is shown in Fig. 3.

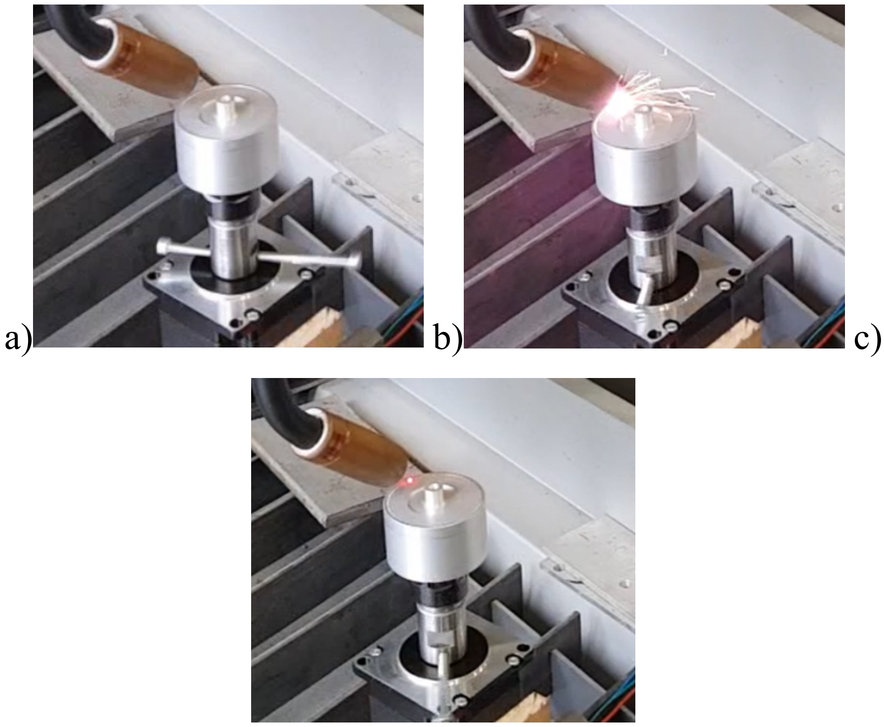
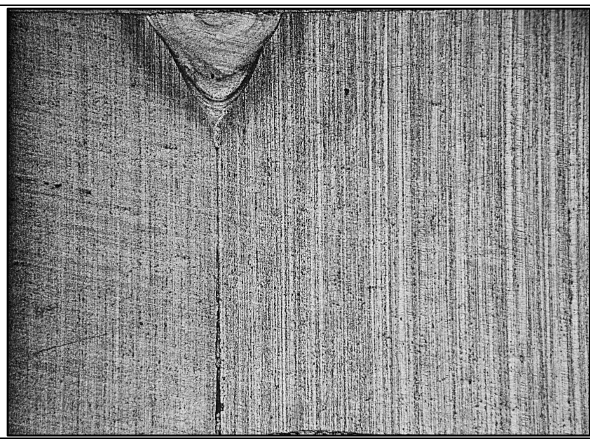


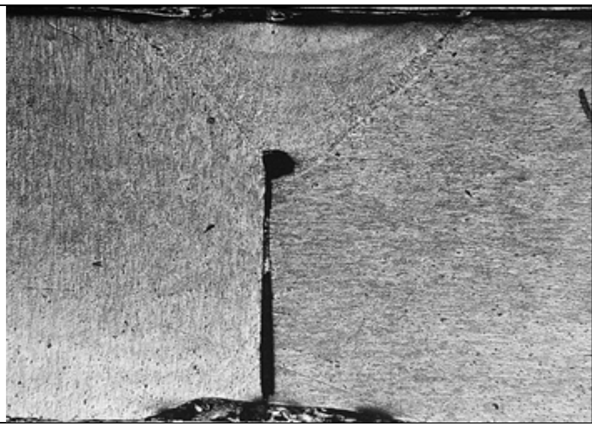
Fig. 2. The process of laser welding of the simulator sample:

a) – before the start; b) – in process; c) – stop after welding

Table 1

Mode parameters of three developed welding technologies and obtained results

№ п/п	The name of the technology / Mode parameters	Boiling parameters h, b [mm]	Result
1.	Laser welding / P = 400 W, V = 4 m/min, Q_W = 8 l/min	h=0,6 mm; b=0,6 mm	

2.	Laser welding with accompanying microplasma heating / P = 250 W, V = 4 m/min, I=45/31 A, U=27 V, nozzle diameter d=2 mm, Q_{pl}=0,3 l/min, Q_W=18 l/min	h=0,56 mm; b=1,1 mm	

Note: P – radiation power, V – welding speed; I – welding current; U – arc voltage; d – plasmatron nozzle diameter; Q_{pl} – consumption of plasma-forming gas; Q_W – consumption of shielding gas

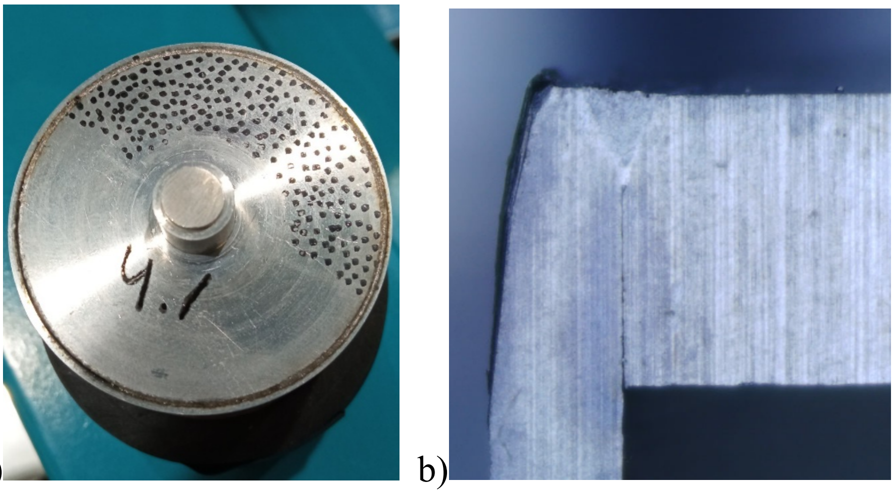
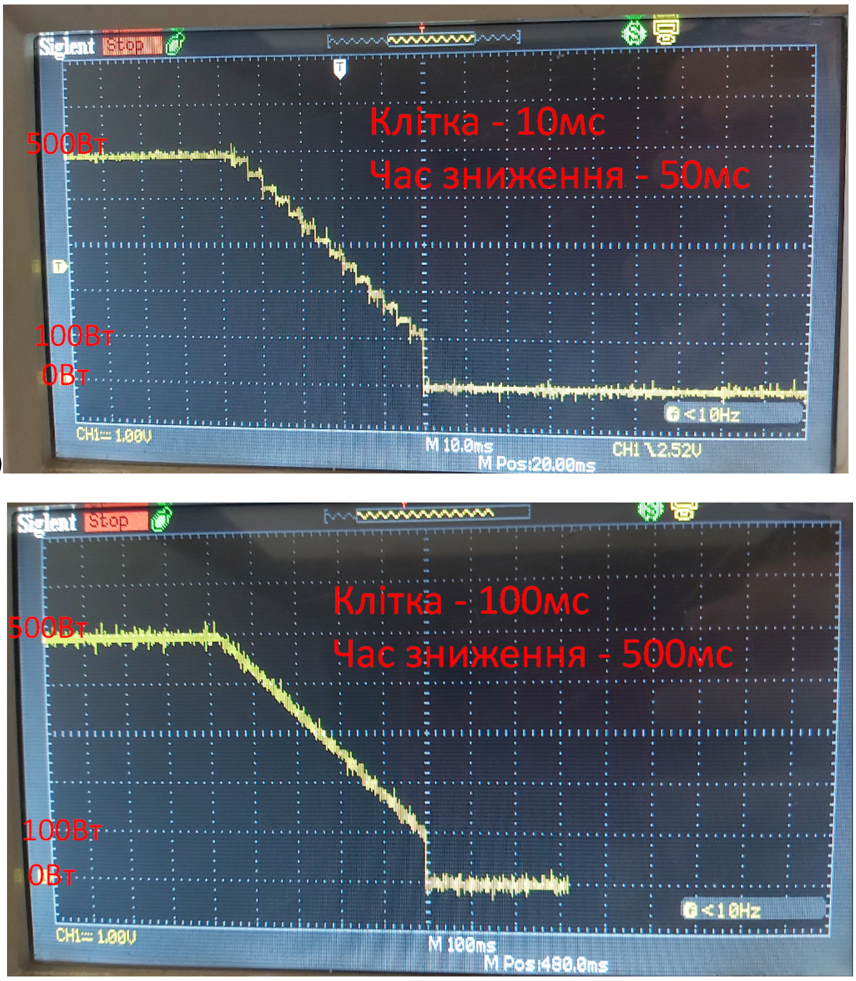


Fig. 3. The top view of the welded imitator sample (a) of a cylindrical product and the macrostructure of the cross-section of the weld (b) made in this imitator sample

According to the developed technologies, the closing of the annular seam is performed by remelting the initial section at a distance of about 10...15 mm. At the same time, the power of the welding source is gradually reduced. Thus, during laser welding with radiation power of 400 W in the area of remelting of the seam, the power is reduced to 100 W in 3 stages by reducing it by 100 W at each stage. Oscillograms of an example of a smooth step-by-step decrease in power from 500 to 100 W and to 0 W for different times are shown in Fig. 4. This approach makes it possible to obtain a defect-free hermetic area of the seam closure (Fig. 5).



a)

b)

Fig. 4. Smooth reduction of the power of laser radiation from 500 to 100 W, followed by its shutdown: a) – in 50 ms; b) – in 500 ms

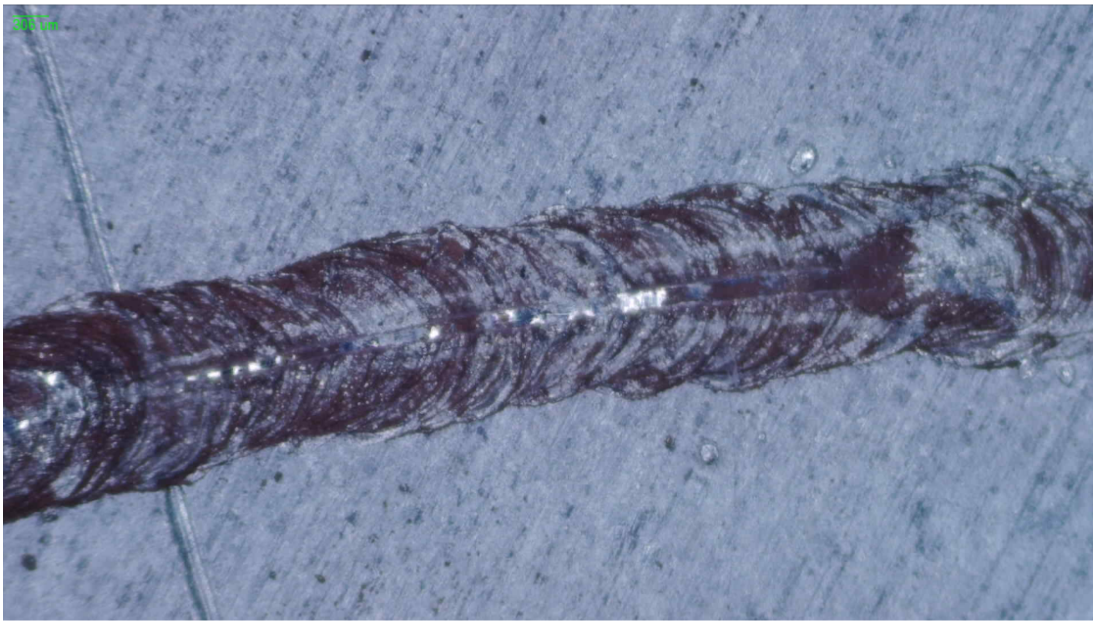


Fig. 5. The appearance of the closure area of the annular seam during laser welding

As studies have shown, observing the temperature regime in the welding process can be performed in two ways: by selecting the parameters of the welding regime, which ensure post-welding heating not higher than 100...120°C, and by simultaneously cooling the welded product by blowing with streams of protective gas. To implement the last method, a special ring equipment was developed, which is located around the end of the product being welded. The excess pressure of the shielding gas in the welding chamber, which occurs with such a cooling scheme, is compensated by the continuous pumping of the shielding gas through the chamber by the gas preparation system.

Thus, the technologies of welding sealing of high-precision thin-walled products of the space industry from light alloys consist of the following stages:

1) preparation of products for welding by chemical etching of parts to be welded with alkali followed by acid neutralization;
2) assembly of welded parts for welding;
3) securing the assembled part in the rotator of the welding complex;
4) execution of two ring seams for sealing the product by laser or laser-microplasma welding in the modes listed in Table 1;
5) control of the heating temperature of the product during the welding process and control of its temperature with the help of shielding gas flows;
6) removal of the finished product from the welding zone and diagnosis of its stress-strain state (SSS);
7) replacement of the welded product with a new one assembled for welding, repetition of welding processes and diagnosis of SSS.

Conclusions

1. A technological process of welding sealing of high-precision thin-walled products of the space industry made of light alloys has been developed, which includes: preparation of the product for welding by chemical etching of the parts to be welded with alkali followed by acid neutralization; assembly for welding of parts to be welded; basing in equipment and welding of the product

with simultaneous control/management of its heating temperature; diagnosis of the level of its stress-strain state.

2. It has been established that it is advisable to use laser welding as a welding process for sealing high-precision thin-walled products of the space industry made of light alloys.

3. An effective approach to minimization (elimination) of such characteristic defects of laser welding as the formation of hot cracks and internal pores is the simultaneous heating of the zone of action of laser radiation. Such accompanying heating can be implemented when using hybrid laser-microplasma welding technology.

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