Analysis of the dependence of the quality of the connection by means of manual and automatic welding of aluminum alloy AD33

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Abstract: The use of laser radiation for welding aluminum alloy AD33 improves the quality of welded joints and the productivity of the process. At the same time, most of the welded structures in production are carried out using automatic laser welding installations, which allow ensuring the required quality of welded joints, including due to the constancy of the technological process.

However, there are a number of industries where manual laser welding installations are irreplaceable and quite in demand. In this case, a distinctive feature of the manual laser welding process is the problem of ensuring the constancy of the duration of exposure to laser radiation on the surface of the workpiece when changing the speed of the laser beam.

The paper presents the results of a comparative study of the dependence of the quality of the welded joint of the aluminum alloy AD33 on the change in the speed of the laser beam for the conditions of manual and automatic laser welding.

Key words: aluminum alloy, laser radiation, welding, weld pool, technological process, microstructure, AD33, laser beam, manual laser welding, Al – Mg – Si, coefficient of thermal deformation of aluminum, vacuum chamber, pulsed laser.

As the volume of production of welded structures expands, aluminum alloys of various classes are increasingly used [1]. The introduction of laser technologies and consideration in shipbuilding speaks of the importance and prospects of improving the quality of the seam by a beam of a beam [2]. The manufacture of sealed devices requires a complex technology and has a peculiarity in the manufacture of structures [3]. Wrought aluminum alloy of AD33 grade (analogue of alloy 6061) of the Al – Mg – Si system is widely used in industry due to its high physicochemical properties. Specific strength, ductility, the possibility of thermal hardening, corrosion resistance and good weldability make AD33 alloy an irreplaceable structural material in the light industry, automotive industry, aircraft and shipbuilding, and civil engineering.

A distinctive feature of welding aluminum alloys is the threshold character of the onset of melting. This effect is explained by a combination of factors such as a high reflectance, high thermal conductivity and high heat capacity of aluminum, the presence of a surface oxide film with a high melting point [4]. Deformation of hardened alloys also characterizes the demand in the market [5]. The same can be said about the interest of the authors in this area and the use of a current pulse on the AD33 alloy [6]. The authors have published the application of anodizing of this alloy and its interest as parts and widely used in the industry [7].

An important priority for the study is the relationship between the microstructure and the mechanical properties of the material [8]. Therefore, for welding aluminum, energy flows with a high density are required. Providing such flows in traditional welding technologies leads to overheating of the workpieces and their thermal deformations. Since the coefficient of thermal deformation of aluminum, and, consequently, the shortening of welded seams is approximately three times higher than that of steel, distortions in the size and shape of the welded structure adversely affect the strength characteristics of welded products.

In addition, as a result of overheating, there is also a change in the molecular structure of the weld and the heat-affected area, leading to a deterioration in the performance of welded structures and a decrease in their operational reliability. A change in the structure of the metal in the heat-affected zone also affects its corrosion resistance.

Analysis of existing methods of fusion welding from the point of view of the thermal effect on the welded material shows that ELW in vacuum and laser welding have the least thermal effect (the smallest area and structural changes in the heat affected zone). However, for ELW in vacuum, a vacuum chamber is required, which is unacceptable for welding large volumetric structures [2].

The laser welding method has important advantages over most other welding methods [9]:

- High power density of laser radiation.

- The short duration and locality of laser action allow welding parts of small thickness with insignificant thermal impact on adjacent areas.

However, the locality of the laser action also predetermines the need for high precision assembly of the structure to be welded and small gaps in the weld.

The quality of welded joints directly depends on the constancy of the technological process. With regard to laser welding, this is primarily the constant duration of the action of laser radiation on the surface of the workpiece [2].

The bulk of the most critical welded structures in production is carried out using automatic technological equipment, which makes it possible to ensure a constant speed of the laser beam, and hence a constant duration of exposure to laser radiation on the surface of the workpiece.

At the same time, in pilot production when using complex and non-standard welding processes, in single and small-scale production when making large-size hull products and structures of complex shape with hard-to-reach seams, manual laser welding installations currently have no alternative and are in sufficient demand. Only mobile installations are considered as an overview of expensive equipment and difficult to operate [10].

A distinctive feature of the manual laser welding process is the problem of ensuring the constancy of the duration of exposure to laser radiation on the workpiece surface when changing the speed of the laser beam [9].

It is known that the duration of exposure to laser radiation determines the temperature of the heated surface, the rate of heating and cooling, the magnitude of the temperature gradients, and the size of the heated layers in the material.

When using pulsed lasers, the duration of the action of laser radiation on the surface of the workpiece is determined by the duration of the radiation pulse τ. The duration of the laser radiation pulse and the velocity V of the laser beam over the surface of the material are related by the ratio:

$$\tau = \frac{2r_0}{V} \tag{1}$$

where r_0 - is the radius of the laser beam on the material surface.

Under the pulsed action of laser radiation on metals, the surface temperature is determined by the following expression:

$$\mathrm{T} = \frac{2q_0 A\sqrt{\alpha\tau}}{k\sqrt{\pi}} + \mathrm{T}_H \tag{2}$$

where A = 1 – R is the absorption capacity of the material, R is the reflectance of the material;

q_0 - is the radiation power density;

k - is the thermal conductivity coefficient;

α - is the thermal diffusivity;

T_H - is the initial temperature of the metal surface.

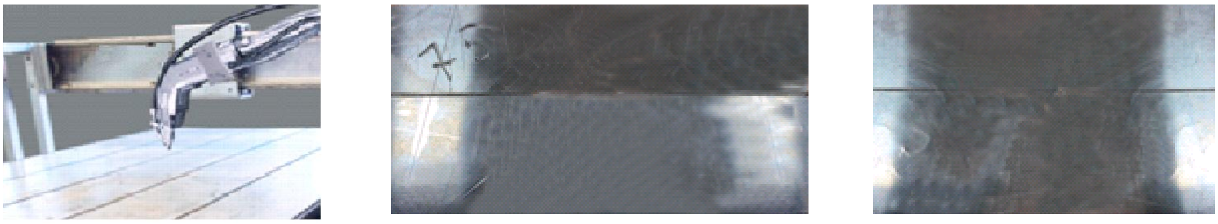
Equation (2) describes the relationship between the maximum heating temperature of the material with the parameters of laser radiation and the optical-physical characteristics of the material.

To determine the relationship between the surface temperature of the workpiece T and the speed of the laser beam, it is necessary to reduce equation (2) taking into account expression (1) to the following form: π

$$\mathrm{T} = \frac{2q_0 A\sqrt{\dfrac{2ar_0}{V}}}{k\sqrt{\pi}} + \mathrm{T}_H \tag{3}$$

Analysis of expression (3) shows that even small changes in the speed of the laser beam lead to significant changes in the heating rate of the metal surface, which causes the instability and irreproducibility of the welding process.

With the aim of experimental verification of this position, a comparative study of the dependence of the quality of the welded joint of the AD33 aluminum alloy on the change in the speed of the laser beam for the conditions of manual and automatic laser welding was carried out.



a *b* *c*

Fig: 1. To study the dependence of the quality of the welded joint: gantry installation with CNC (a); a sample of the welded joint of alloy AD33, made in the manual laser welding mode (b); sample of the welded joint of AD33 alloy, made in the automatic laser welding mode (b).

The experiments were carried out using a manual laser welding unit "Sekirus P0313M-SVR". Power of fiber optic Nd: YAG-laser 1 kW. Wavelength 1.06 µm. The type of radiation is continuous / modulated.

To carry out laser welding in an automatic mode, a portal installation with CNC with a linear displacement of 0.01 mm was used. In this case, the portable head of manual laser welding was rigidly fixed on the support of the automatic portal installation (Fig. 1a).

Practice shows that a significant difference in the results of welding can be observed when receiving butt joints, therefore, during the experiments, the butt welding joint of samples of plates of alloy AD33 with a size of 1.5×50×300 mm was studied both in manual (Figure 1b) and automatic welding modes. (Fig. 1 c).

The sides of the plates to be welded were face milled with a finish of Ra 12.5 µm and chamfered. Immediately before welding, the surfaces to be joined were washed and cleaned. The maximum size of the gap between the plates, pre-assembled end-to-end on tacks, did not exceed 0.1 mm.

Measurement of geometric dimensions and study of macro- and microstructures were carried out using a video measuring microscope VM-150 and a software-computing complex "ProfVision" on thin sections. The preparation of the sections was carried out according to the standard technique: grinding, repeated polishing and etching. The study of the microstructure was carried out on an optical microscope "METAM LV-41" at various magnifications.

The appointment of rational parameters of the technological mode of laser welding ensures the required quality of the welded joint. The parameters of the technological regime were set based on the parameters for typical cases of laser welding of an aluminum alloy sheet with a thickness of 1 ÷ 1.5 mm:

- Laser beam diameter d_0 = 0.3 mm.
- Welding speed 2.5 m / min.
- Argon consumption 0.7 ÷ 0.9 l/s.
- Type of radiation: pulse.

In this case, proceeding from relation (1), the duration of the pulsed radiation is τ ≥ 7 10-3 s.

The power density of laser radiation during welding of aluminum by pulsed action is easily determined from the expression (2):

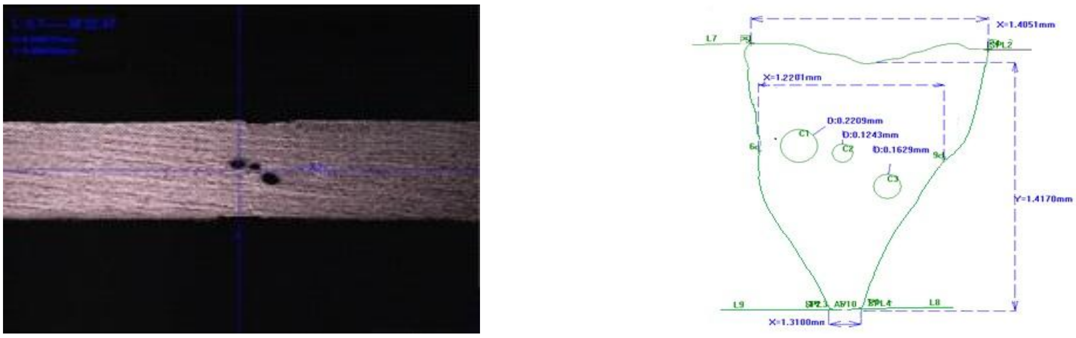
$$q_0 = \frac{(\mathrm{T} - \mathrm{T}_H) k \sqrt{\pi}}{2(1-R)\sqrt{\alpha\tau}} \geq 7{,}5 * 10^6 W \;/\; cm^2$$

where for aluminum:

- the reflection coefficient of the material R = 0.93;
- coefficient of thermal conductivity k = 233;
- coefficient of thermal diffusivity α = 0.094;
- the final temperature of the metal surface T = Tm = 660°C;
- the initial temperature of the metal surface T_H ≈ 18 ÷ 20°C.

Installation of manual laser welding "Sekirus P0313M-SVR" allows providing the required parameters of the laser welding mode: d_0 = 0.3 mm, τ ≥ 7 10-3s and q_0 ≈ 7.5 W / cm^2.

Investigation of the macrostructure of butt welded joints of AD33 alloy plate specimens showed that the designated welding modes provide through penetration of the material, while for both automatic and manual welding methods, the seam as a whole has an equiaxial structure; on all specimens, the heat-affected zone does not exceed the weld bead boundary. seam.



a *b*

Figure: 2. Sample of butt welded joint of ad33 alloy by automatic laser welding: macrostructure × 50 (a); geometric parameters of the heat-affected zone (b).

The width of the welded seam formed for the conditions of automatic laser welding of samples is on average ~ 1.25÷1.6 mm (Fig. 2), for manual laser welding ~ 1.1 ÷ 2 mm (Fig. 4)

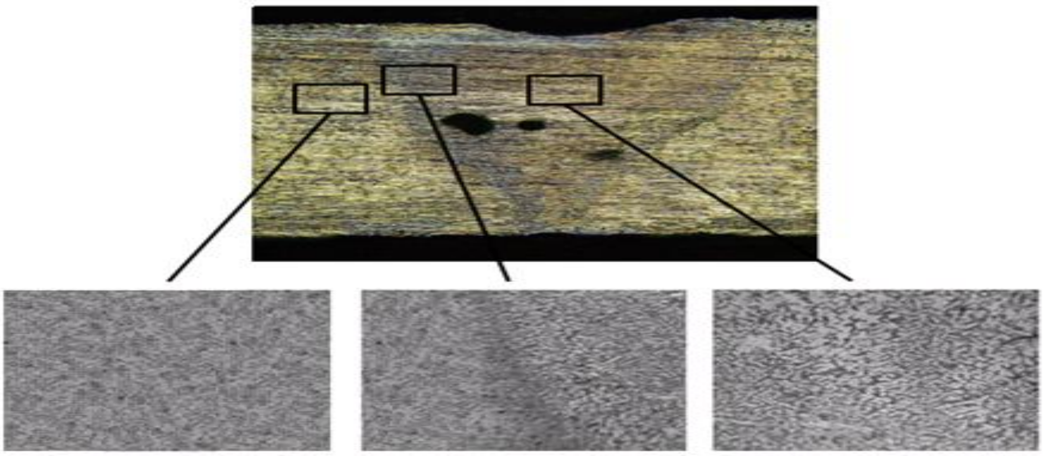


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Figure: 3. The structure of the butt welded joint of the AD33 alloy sample in automatic laser welding: the microstructure of the base metal (a), the heat-affected zone (b) and the seam (c) (× 150).

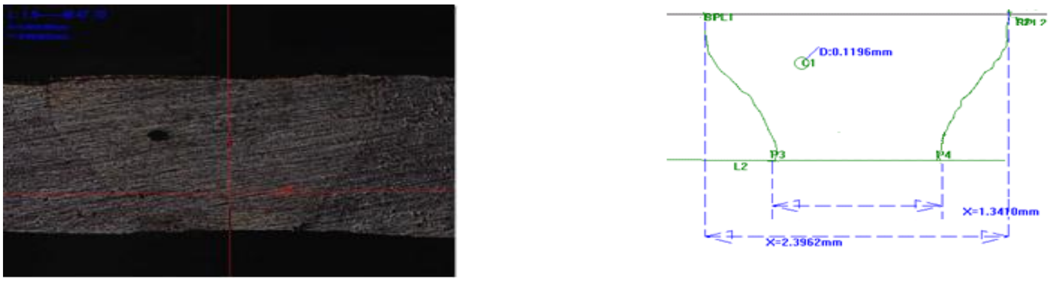

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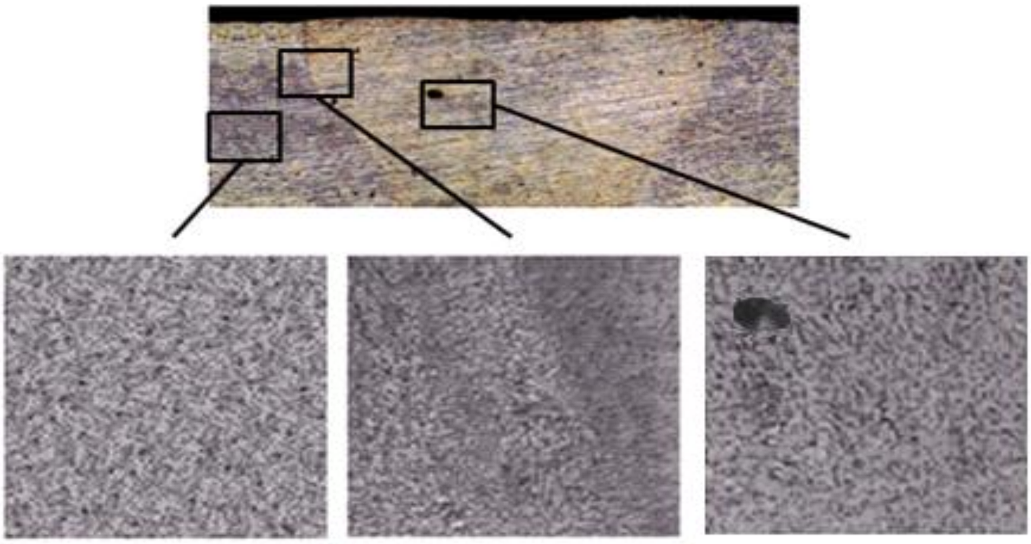
Figure: 4. Sample of butt welded joint of ad33 alloy by automatic laser welding: macrostructure × 50 (a); geometric parameters of the heat-affected zone (b).

In the course of studies of the macrostructure of butt welded joints, made by both automatic and manual laser welding, a few near-weld spherical pores with an average size of 0.1944 mm to 0.0254 mm were revealed. Such violations of the continuity of the metal are mainly found in the fusion zone of the weld metal, and in some cases are scattered in the root part of the weld.



a *b* *c*

Figure: 5. The structure of the butt welded joint of the AD33 alloy sample during manual laser welding: the microstructure of the base metal (a), the heat-affected zone (b) and the seam (c) (× 150).

The microstructure of the weld metal and the heat-affected zone of welded joints of the AD33 alloy after laser welding differs significantly from the nature of the microstructure of the surface of the base material (Fig.3-5) both in phase composition and in crystal structure.

The microstructure of the weld metal of all samples consists of an a-solid solution, against which the dendritic network crystallized. General analysis of the obtained microstructures shows that on the samples welded in automatic mode (Fig. 3) the cast weld metal has a finer-grained structure and a rather thin cellular branched dendritic structure. It was noted that the weld is difficult to pickle. Obviously, this is due to the presence (increased content) of alloying elements.

On some samples welded manually (Fig.5), the central part of the microstructure consists of dendrites of a larger structure, the grain size in it is 30–50 μm, and towards the periphery the weld metal becomes even more heterogeneous. The most heterogeneous structure is formed at the root of the suture.

An inhomogeneous structure, also consisting of large dendrites and gradually transforming into a fibrous structure of the base metal, is also observed near the fusion zone. In this case, the size of the fusion zone of the weld metal with the base unmelted metal is no more than 70 ÷120 μm.

Conclusion

Metallographic studies of AD33 alloy samples performed in manual and automatic modes of laser welding show that welding in automatic mode provides a minimum zone of softening of the welded joint compared to manual welding mode.

The calculation of the magnitude of the area of the heat-affected zone, carried out on the basis of the results of metallographic examination of samples of alloy AD33 in manual and automatic modes of laser welding, are presented in Table №1. As can be seen from Table №1. more than for automatic laser welding mode.

Table № 1.

Results of calculating the area of the heat-affected zone for AD33 alloy samples made in manual and automatic modes of laser welding.

№ sample	HAZ area, mm^2, manual welding mode.	№ sample	HAZ area, mm^2, automatic welding mode.
1	1,8304	6	1,5230
2	2,2056	7	1,4062
3	2,0015	8	1,5548
4	1,1052	9	1,6875
5	1,6205	10	1,6017

Thus, the experimental verification showed that, other things being equal (the same reflection coefficient, the same technological modes of welding, the same gaps and bevels of the welded edges), the process of automatic laser welding gives better opportunities for improving the quality of the welded joint.

When laser welding in manual mode, an increase in the weld pool and an increase in weld heterogeneity are observed, which predetermines unfavorable changes in the properties of the weld metal and the heat-affected zone. Obviously, this is due to the instability of the speed of movement of the portable laser head, therefore, in order to improve the quality of the welded joint, an automatic system is needed that allows for operational regulation of the technological parameters of manual laser welding, depending on the change in the speed of the laser beam. The study of the method opens up the possibilities of using and studying welded joints in different conditions and under extensive types of load.

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