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STUDY OF THE PECULIARITIES OF THE LASER WELDING OF ALUMINIUM BASED COMPOSITE MATERIALS

The paper considers the problem dealing with the development of the methods of the laser welding of new light composite materials of the increased strength on the base of the aluminum allows, having fiber, dispersive and layered strengthening. Obtaining of their permanent joints requires the application of such innovation solutions, which can be efficiently implemented in industry. One of the solutions may be laser welding process.

The paper studies the characteristic features of the laser welding of the aluminum- based composite materials, necessary experiments for the development of the technological methods for the obtaining qualitative joints were carried out. It is established that among the parameters of the aluminum-based composite materials structure the volume part of the fiber material in the matrix greatly influences the welding process. Analysis of the results of studies shows that when the content of fibers is higher than 30% the welding process becomes more complicated. Main obstacles for the formation of the qualitative joint are high heat input and difference of melting temperatures of the composite materials. As a result of the intensive heating there exists the probability of the fibers destruction and formation of the intermetallidic compounds. The quality of the permanent joints, obtained by fusion welding can be improved by means of strict dosing of the heat input. The studies, carried out allowed to determine the characteristic features of the laser welding of the aluminum-based composite materials, which have matrix filler of different types .It was established that the presence of boron fibers on one hand improves welding properties of the aluminum composite and allows to obtain sound welds but on the other hand-worsens the mechanical properties of the obtained joint. Dispersed alloying of the aluminum composite with the particles of Al_2O_3 leads to the formation of the pores in welded joint, obtained by laser welding. Presence of the steel fibers improves the welding properties but leads to the formation of the intermetallidic compounds. For joining the composites with the binders in the form of the fibers or separate particles it is necessary to use additional technological methods, for instance, welding-soldering. This type of welding is recommended to perform with maximum possible speed (to reduce specific energy intensity). Another special method for welding aluminum composites of all the considered types is the application of the repetitively pulsed radiation with the frequency within the range of 200 – 330 Hz, and relative pulse duration of 1.5 and welding with the aluminum adaptor or welding on the back-up plate with the gap between the ends ~0,6 mm and its filling by means of the filler wire fusion.

Key words: *metal-based composite materials, aluminum-based composite materials, composites with disposed alloying matrix, fiber reinforced composites, laser welding, welding-soldering.*

Introduction

Development of new materials requires the application of the innovation decisions for obtaining their permanent joints. It is stipulated the development of new direction in the field of the dissimilar metals welding – welding of metal-based composite materials (MCM) of different types: fiber, dispersed-reinforced, layered.

As the authors of the works [1 – 5] note, in the process of MCM welding between themselves, there exist peculiarities, regarding the formation of the molded zone, this requires the specification of welding quality criteria, as compared with the criteria for homogeneous alloys.

It is obvious that among other parameters of MCM structure, the volume part of the fiber material in matrix has the greatest impact on the welding process. Analysis of the results of the research, performed in [2, 5] shows that the welding process becomes more complicated if the fiber content is higher than 30%. Main obstacles for making qualitative joint are high heat input and difference of composite materials melting temperature. As a result of the intensive heating, there exists high probability of the fibers distraction and formation of the intermettalidic compounds. Quality of the permanent joints, obtained by fusion welding can be improved in case of accurate dosing of the heat input. As compared with the homogeneous materials, for MCM faults, in the form of the cracks pores, separations, which are the result of the material shrinkage in the zone of welding, are less characteristic.

Aim of the given research was to determine the characteristic features of the laser welding of the aluminum-based composite materials by means of the experimental research, using the additional technological techniques, aimed at obtaining the qualitative permanent joints.

Materials and methods of investigation

For reaching the set aim at the first stage technological equipment and tooling was prepared, the studied material was selected – thin- sheet composites with aluminum matrix and reinforcing filler in the form of separate fibers (Ø150 – 160 µm) or dispersed particles.

While samples preparation the following aluminum-based composite materials were selected: aluminum, reinforced with steel fibers, aluminum,reinforced with boron-fibers, plate-like aluminum-steel composite, aluminum alloys, disperse-doped with silicon carbide SiC or aluminum oxide Al_2O_3 in different percentage rating. Preparation of the samples included accurate fitting of the edges in case of joints welding , elimination of the impurities, elimination of the oxide film from the edges and surfaces of the sample (both in case of joints welding and complete welds penetration).Elimination of the film was performed by means of mechanical scraping directly prior the welding process.

Experiments were carried out, using the laboratory equipment, namely, technological CO_2-laser ЛТ-104 and biaxial manipulator, that moved the laser focusing head relatively the sample, fixed securely in mounting-welding device (clamp). Technological attachment and laser focusing head was manufactured, taking into account the peculiarities of welding the aluminum alloys. Such peculiarities include the necessity of provision the qualitative protection of the welding pool, elimination of the shielding effect of laser emission by argon plasma, formed above the pool, rigid fixation of the welded parts, availability in the mounting-welding equipment the support with the groove for the formation of the backing tile.

Welding clamp was designed and manufactured, it enables to perform butt joints and overlapping joints of the plates of 300×100×δ mm. Samples of the metal aluminum-based composite materials were of flat form and were fixed in the welding clamp, equipped with the system of gas shield of the root of weld and had a possibility to replace this system by the steel support with the groove for the formation of the opposite reinforcing bead.

Fig. 1 presents the general view of the bench for the laser welding of the aluminum- based composite materials which comprises the welding head with the systems for the fixation of the additional equipment (protection of the welding pool), and welding clamp with the system for the shielding the root of the weld.

Results and discussion

Technological studies were carried out, they enabled to determine the characteristic features of welding of aluminum-based composite materials. The presence of boron fibers on one hand improves the welding properties of the aluminum composite and allows to obtain sound welds but on the hand – worsens the mechanical properties of the obtained joint. Dispersed alloying of the aluminum-based composite with aluminum oxide Al_2O_3 leads to the formation of pores in the welds. Presence of the steel fibers improves the welding properties but results in the formation in the remelted metal of the weld the intermetallidic compounds Al-Fe, which are hard fragile needlelike structures with additional alloying of the aluminum matrix with boron or carbon, that leads to the formation of cracks. To minimize this effect the authors used the following technological methods.

Fig. 1. Testing bench for laser welding of the aluminum-based composite materials

Welding was performed at maximum possible speed (to reduce specific energy consumption) during two runs from two sides of the sample so that the material would be welded non-completely but more than for a half of the thickness to obtain the guaranteed overlapping of the root of the weld. Another special method for welding the aluminum-based composites of all the types was the application of the pulse-periodic modulation of the emission with the frequency within the range of 200 – 330 Hz at duty cycle of 1,5.

Experimentally it was established that the supply of the protection gas plays an important role in the process of the aluminum-based MCM welding. From standpoint of increasing the depth of penetration, it is better to supply gas from the front down the welding at the angle of up to 30° to the sample plane. But from the standpoint of the quality improvement of the method zone of the welds and elimination of the oxides it is expedient to realize the gas supply coaxially to laser emission, although such method decreases the depth of penetration to 50%.

As compared with borom and aluminum oxide doping, from the standpoint of mechanical characteristics, absence of the internal faults and welds geometry is silicon and silicon carbide doping.

For jointing composites with the reinforcing filler in the form of fibers it is rational to use the combined methods. One of these methods is the simultaneous welding and soldering, so-called process of welding-soldering.

For the realization of the process welding energy parameters were selected so that to avoid considerable fibers damage. The requirements, typical for laser welding of the aluminum alloys regarding weld formation and depth of welding of the welded pieces were observed. As the additional conditions the provision of the composition of the weld bead, close to the composition of the matrix metal also the minimization of the size of the thermal impact zone were considered.

Welding samples were assembled in the wedding-fabrication device, they were fixed by massive clamps. To provide tight fitting of the welded edges, additional clamps located in the plane of the sample on both sides of the joint at the minimal possible distance one from another were used. As a result, the samples were tightly pressed to the back-up plates, providing reliable heat removal from the heating zone.

Samples were welded long sidewise, parallelly to the direction of reinforcing fibers packing. The aim was to obtain the weld, close by the composition to the composition of matrix metal, with minimal zone of thermal impact. Due to the selected procedure of preparation and butting of the welded samples, conditions, close to the conditions of the homogeneous materials welding were provided, this enabled to obtain high quality joints with the guaranteed dimensions of the opposite bead.

Further technological studies of the laser welding of the aluminum-based composite materials showed that fusion welding without application of the filler material does not provided sufficient quality of joints. In such case certain melting of the matrix of the basic material, destruction of the reinforcing fibers, formation of the intermetallids and rapid growth of the joints brittleness was observed. The structure of the obtained joints had complex phase composition. On the boundary of the joint aluminum-based solid solution was crystalized, separate grains of this solution were located in the middle of the weld. In the intergrain space the degenerated eutectic of the type solid solution-inermetallids was observed.

On the base of metallographic studies of the welded samples it was established that for obtaining of the joints with the strength, close to the strength of the basic material, solid brittle needlelike structures which are formed in the welding pool as a result of aluminum matrix doping with boron or carbon, should be avoided. This is possible using pulse -periodic radiation and minimization of TIZ (thermal impact zone), as well as, while welding with aluminum space plate or welding on the support with the gap between the edges~0.6 mm and its filling by means of melting of the filler wire. That is why, instead of laser welding of the composite materials their laser seam soldering was suggested.

Form of the elements, being melted, was selected, depending on the thickness of the welded samples and type of the edges for welding. Weld formation took place at the expense of the samples edges melting and their fusion with the molten metal of the filler material. For instance, for welding the composite of 2 mm of thickness reinforced with the carbon fibers of 150 – 160 μc of the diameter (with unidirectional location of fibers) the following mode may be recommended: power of the emission, focused on the sample is 2.5…2.7 kW; speed is 200 m/h; space plate is made of aluminum alloy AMr5 (δ=2.5 mm); gas protection – by means of the coaxial nozzle with the consumption of argon 20 l/min. Analysis of the weld structure in Fig. 2 showed that in case of laser welding-fusion in the argon environment the fusion of composite edges with the metal of insert takes place without the destruction of the composite material. The contact of the fibers with the molten metal is reduced to minimum. In the zone of the weld the carbide phases are not present.

It is established that to provide stable and satisfactory formation of the weld metal the portion of the filler material in the weld must be not less than 90%. Reinforcing fibers in the metal of the weld are not present. The best method of MCM edges preparation is the machining by means of diamond – abrasive wheel without application of the emulsions, as their drop on MCM leads to the formation of pores in the process of welding and poor welding penetration in the welding joint.

Fusion welding of the dispersive-reinforced composite materials has a number of characteristic features:

1.As a result of presence of uniformly spaced particles in the material the viscosity of the metal of the molten weld pool is rather high. This leads to under mixing of the weld puddle in case of the presence of the filling material (wire).

2. At high temperature the reactions of the interaction on the boundary particle-matrix occur; decomposition of the particle is possible (if this is a carbon particle – before joining $A1_4C_3$) and its dilution in the matrix. Phase $A1_4C_3$ is brittle and is disposed to corrosion; it has acicular form, that may be the cause of strain concentration at load application.

3. Segregation of the reinforcing material is observed in the joints, welded in the shielding gases. In the process of the laser welding this phenomenon is not observed due to high rate of cooling.

For butt welding of the dispersed -reinforced composites Al+8%Si and Al+15%SiC (alloy 6063) of 1 mm of thickness by the continuous emission of CO_2-laser the following mode is selected: speed of welding 72 m/h; power of the focused on the sample emission 1.5 kW; deepening of the focus to 1 mm; shielding gas – argon. Worsening of the mechanical properties in case of laser welding of the composite are connected with the formation of the cast structure and dissolution of Si. Thermal machining after welding must promote the saving of strength and plasticity of the welded joints.

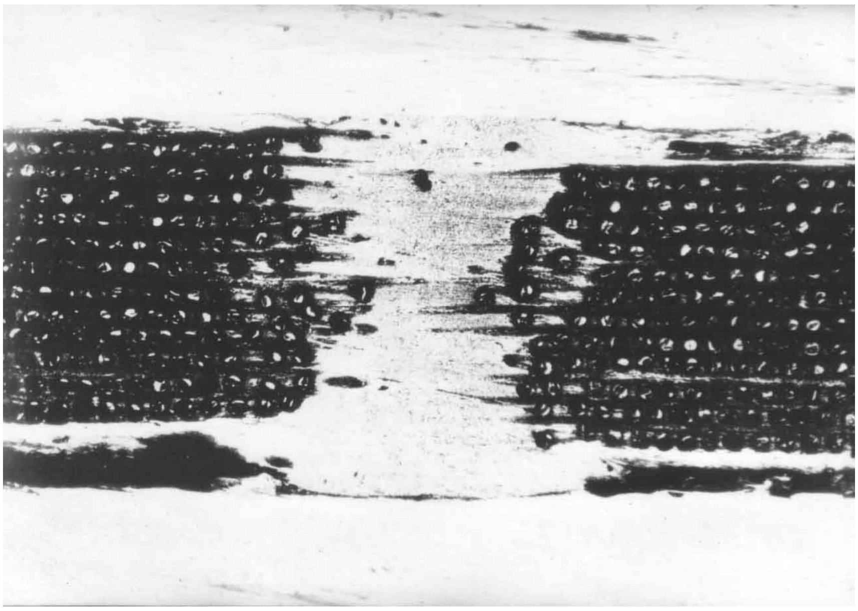

Fig. 2. Structure of the composite with the aluminum matrix (δ=2 mm), reinforced with carbon fibers (∅150 – 160 μm), obtained by laser welding with the spacer plate AMг5 (δ=2.5 mm),×25

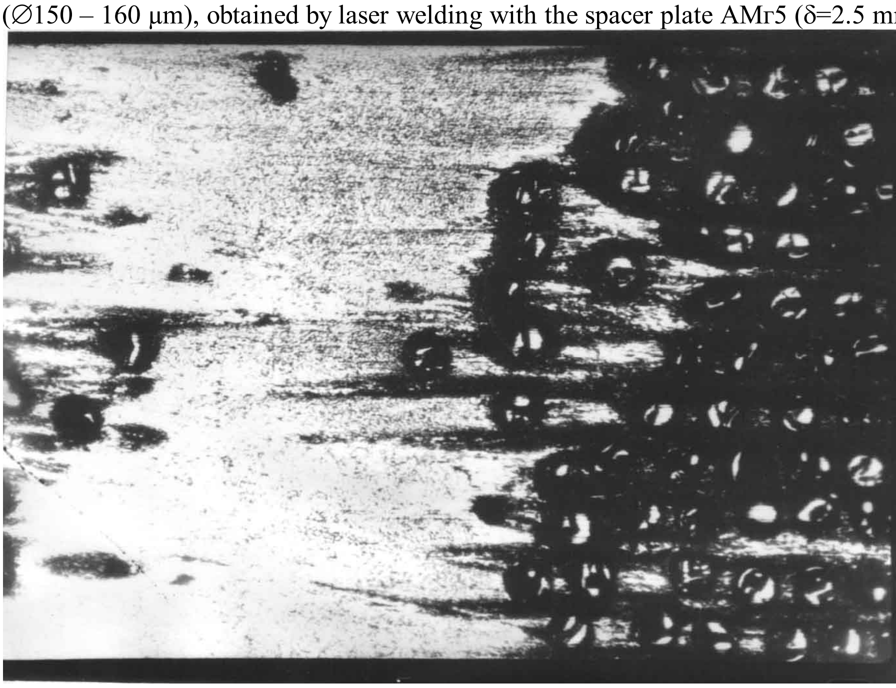

Fig. 3. Structure of the transition zone of the composite joint with the aluminum matrix (δ=2 mm), reinforced with C-fibers (∅150 – 160 μm), obtained by laser welding with spacer plate of AMг5 (δ=2.5 mm), ×64

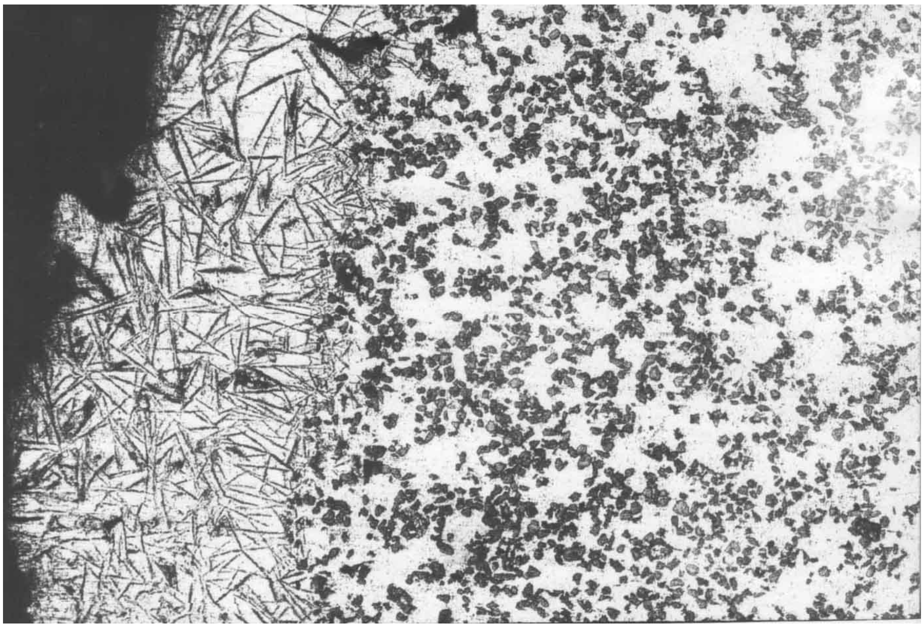

Fig. 4. Structure of the transition zone of the welded joint of the composite with the aluminum matrix (δ=1 mm), reinforced with SiC-dispersed particles (∅150 – 160 μm),×150

Among measures, aimed at improvement of the butt joints formation the following measures were used: change of the heat input, repeated penetration, change of edges machining for welding, composing of the edges with the gap for welding, additional argon protection of the welding zone from below.

Analysis of the results of metallographic studies of the welded joints showed that laser welding-fusion, in the complex with the rational method of edges preparation and with efficient protection of the welding zone enables to obtain good-quality joints.

Conclusions

1. Technological studies, enabling to establish characteristic features of aluminum-base composite materials welding, were carried out. Presence of boron fibers, on one hand, improves the welding properties of the aluminum-based composite and enables to obtain the sound welds but on the other hand – worsens the mechanical properties of the obtained joint. Dispersed doping of the aluminum-based composite with aluminum oxide Al_2O_3 leads to the formation of pores in the welds. Presence of the steel fibers improves the welding properties but results in the formation of intermetallidic compounds.

2. For joining composites with reinforcing material in the form of the fibers or separate particles it is necessary to use additional technological methods. One of these methods is simultaneous realization of welding and fusion processes so-called welding-fusion process. Welding-fusion is recommended to perform at maximum possible speed (to reduce the specific heat input). Another special method, used for welding aluminum-based composites of all considered types is the usage of pulse-periodic modulation of the emission with the frequency within the limits of 200 – 330 Hz at relative pulse duration 1.5, and welding with the aluminum-space plate or welding on the support plate with the gap between edge~0.6 mm and its filling by means of melting the filler wire.

REFERENCES

1. Latest development sin modeling and characterization of joining metal based hybrid materials / S. Khoddam, L. Tian, T. Sapanathan [et al.] // Advanced Engineering Materials. – 2018. – Vol. 20, №. 9. – P. 1800048. https://doi.org/10.1002/adem.201800048.

2. Properties of metal-based and nonmetal-based composite materials: A brief review / N. Y. Makhkamov, G. U. Yusupov, T. Tursunov [et al.] // IOP Conference Series: Earth and Environmental Science. – IOP Publishing, 2020. – Vol. 614, №. 1. – P. 012068. https://doi.org/10.1088/1755-1315/614/1/012068.

3. Zhang Y. Analysis on the Development Status of Automobile Light weight Welding Technology / Y. Zhang // Journal of Physics: Conference Series. – IOP Publishing, 2021. – Vol. 1750, №. 1. – P. 012001. https://doi.org/10.1088/1742-6596/1750/1/012001.

4. Laser-arc and laser-plasma welding and coating technologies / V. D. Shelyagin, I. V. Krivtsun, Yu. S. Borisov [et al.] // Paton Welding Journal C/C of Avtomaticheskaia Svarka. – 2005. – Vol. 2005, №. 8. – P. 44.

5. Compression brazing of SiC p/Al composite using a semisolid Zn-Al-Cu filler metal based on the strain-induced meltactivation process / J. Xiao, S. Li, S. Bai [et al.] // JOM. – 2019. – Vol. 71, №. 12. – P. 4931 – 4939. https://doi.org/10.1007/s11837-019-03791-3.

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