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Formation of A Non-detachable Welded Titanium-aluminium Compound by Laser Action

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Abstract. Progressive in the welding of dissimilar materials is the use of laser technology. With the use of the ROFIN StarWeld Manual Performance laser, an aluminium alloy AK4 and a titanium alloy VT5-1 were welded. Processing regimes have been determined, the realization of which during melting of materials in the zone of thermal influence makes it possible to obtain a homogeneous structure without voids and shells, which indicates a potential sufficiently high serviceability of the welded joint. To create the required power density distribution in the cross section of the laser beam, it is expedient to use diffractive optical elements.

1. Introduction

Materials based on aluminium are widely used in aircraft designs. The receipt of their high-strength and reliable welded joints with other metals and alloys is one of the topical tasks of the aerospace industry. Welding of aluminium and its alloys with other materials is accompanied by a number of difficulties: a large difference in thermal conductivity leads to intense heat removal towards aluminium, which prevents the formation of a quality welded joint. The use of so-called traditional methods for the production of integral welded joints of these materials presents significant difficulties and, often, does not provide the required quality of the connection. The intermetallides formed during the crystallization of such seams lead to embrittlement of the material [1]. For dissimilar metal materials, several welding methods are known: argon-arc welding with a non-consumable electrode [2], welding using an intermediate metal [3], welding with pressure [4], diffusion welding [5]. However, none of the above methods, as well as the use of a combination of different types of welding, do not exclude the appearance of intermetallic interlayers [6]. Welding by explosion allows to weld only sheet materials.

Laser welding is an attractive technique in comparison with the traditional methods of joining dissimilar metals, because the processing speed and accuracy are high, while the heat supply is very low, this method does not require the use of additional materials, special processing of the edges [7, 8]. This method provides the opportunity to obtain an ultrathin diffusion zone and avoid the appearance of defects. Redistribution of the radiation power density with displacement of its maximum value towards one of the welded metals makes it possible to obtain the required structure of the welded joint [9, 10]. Locality is provided for the depth and area of the physical processes flowing in the thermal effect zone while maintaining the original properties of the material in the remaining volume and the absence of significant deformations of the machined parts [11, 12]. To create the required power density distribution in the cross section of the laser beam, it is advisable to use diffraction optical elements [13-15]. At the same time, a high rate of melting and crystallization of the material is achieved, which is caused by intensive heat removal from a small-volume molten bath into the surrounding material of the article. The purpose of this study is to study the features of the formation of high-strength and reliable titanium-aluminium welded joints by laser action using diffractive optical elements.

2. Results and discussion

The main reason complicating the welding of titanium alloys with each other and with other materials is the active interaction of titanium with atmospheric gases at elevated temperatures, especially in the liquid state. In addition, during the welding thermal cycle structural transformations in the seam and the weld zone lead to the formation of brittle intermetallic and carbide phases. Using the known methods of fusion welding, it is difficult to obtain high-strength and reliable compounds of titanium alloys with each other and with aluminium. Sufficient strength and heat resistance of all-in-one joints does not allow soldering of titanium alloys. The physical and mechanical properties and heat resistance of solders are much lower than in titanium alloys, which leads to a lowered thermomechanical reliability of the compound. When soldering titanium and aluminium alloys, the choice of solder, an equally good wetting contacting surface, is complicated. In the welding of high-temperature corrosion-resistant titanium alloys with products made from aluminium-based materials, the use of laser technologies is progressive.

In the quality of the materials to be welded during the pilot studies, sheet materials were chosen: aluminium alloy AK4 and titanium alloy VT5-1 2 mm thick. The chemical composition of materials is presented in tables 1 and 2. This combination of materials is used in the manufacture of a number of aircraft units.

Table 1. Chemical composition of the alloy AK4,%

Al	Fe	Si	Mn	Ni
basis	0.8…1.3	0.5…1.2	unto 0.2	0.8…1.3
Ti	Cu	Mg	Zn	Impurities
unto 0.1	1.9…2.5	1.4…1.8	unto 0.3	Other, each 0.05; Only 0.1

Table 2. Chemical composition of alloy VT5-1,%

Ti	Fe	C	Si	V	N
basis	unto 0.3	unto 0.1	unto 0.12	unto 1.0	unto 0.05
Al	Zr	O	Sn	H	Impurities
4.,3…6.0	unto 0.3	unto 0.15	2.0…3.0	unto 0.015	Other 0.3

The deformable alloy AK4, belonging to the group of high-temperature aluminium alloys of special purpose, is used for manufacturing deformable semi-finished products. Alloy VT5-1 refers to deformable titanium alloys. Immediately before welding, the bonded surfaces of the parts were thoroughly washed in solvents in order to remove various kinds of contaminants (dust, grease films, etc.) from them.

Laser welding was performed on the ROFIN StarWeld Manual Performance, the applied system "Sweet Spot Resonator" provides the output of constant power beam to the material being processed. During welding to improve the parameters of the material processing process, the shape and duration of the radiation pulse can be changed using the "Pulse Shaping" program. Processing modes are determined, at which minimal thermal loads are achieved, the thermal cycle of heating and cooling of the processed material improves, which ensures a high quality of welding. The beams transport and formation system was used including diffractive optical element [16-19].

The structure of the seam of the butt joint without the bevel of the edges of the aluminium alloy AK4 and the titanium alloy VT5-1 was studied. For metallographic studies, a Phenom-ProX scanning electron microscope was used, with an integrated energy-dispersive analysis system and a CeB6 (cerium hexaboride) electron source. The range of magnifications of the electronic microscope is in the range of 80-45000x. The energy dispersive analysis system for determining the elemental composition at a point (Elemental Identification) is built into the image acquisition module. The device uses a silicon drift detector SDD with thermoelectric cooling without liquid nitrogen. The active area of the detector is 25 square millimeters. The energy resolution (Mn Ka no more than 140 eV) allows to determine the elements from C (carbon) to Am (americium) with high accuracy. Multichannel analyzer, 2,048 channels (energy 10 eV per channel). Reading speed 300000 pulses per second. In figure 1 shows the structure of the weld metal in the cross-section of the laser welding zone between the aluminium alloy AK4 and the titanium alloy VT5-1.

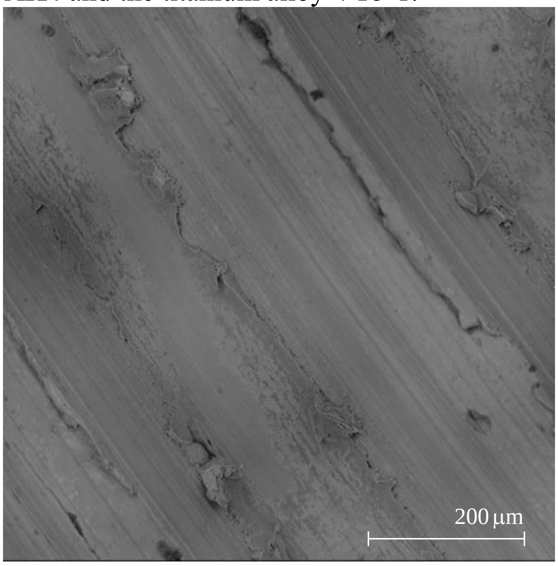

Figure 1. The structure of the weld metal in the cross section of the laser welding zone between the aluminium alloy AK4 and the titanium alloy VT5-1; Zoom. x380.

It is determined that the cast weld zone formed after melting has a homogeneous structure without voids and shells, which indicates a potential sufficiently high serviceability of the welded joint. The weld metal zone of dissimilar materials formed during welding is characterized by an individual structure, crystal orientation, and phase distribution.

The seam break was investigated. As a result of studying the structure of the kink, the following is established. Formed in the process of destruction, the fibers are stretched along the main crack. The microstructure of the fracture zone is characterized by the presence of large and small pits, and fibrousness is observed at the bottom of the wells. An image of the fracture surface of a welded joint is shown in figure 2. When studying the fracture surface in the field of view of an optical microscope at various magnifications, it is established that the structure of the fracture is homogeneous. The surface area of the fracture is characterized by fibrousness. The surface of the fracture does not have a metallic luster, there are no defects in the form of pores, nonmetallic inclusions. Fine-grained fibrous fracture without gloss characterizes the potentially good enough ductility and high impact strength of the metallic material. Metallographic studies of microsections make it possible to draw a conclusion about the formation of an actual contact between welded surfaces.

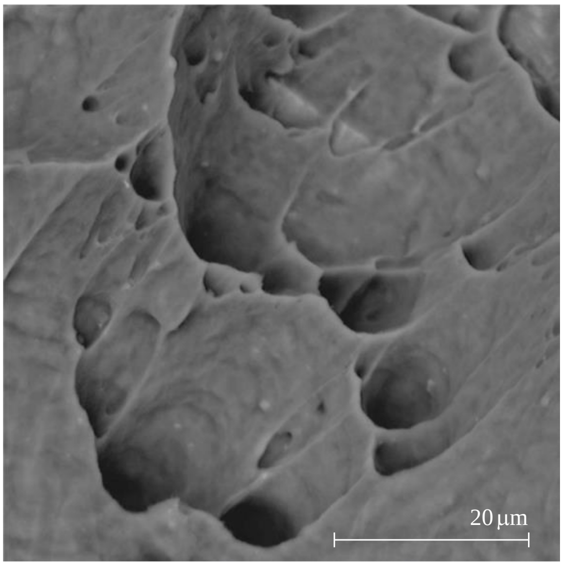

Figure 2. An image of the fracture of a welded joint obtained by means of an analytical scanning electron microscope Phenom-ProX; Zoom. x4700.

The chemical composition of the welded joint was studied on the material sections in the cross section of the laser welding zone. Figure 3 shows the designation of zones of investigation of the chemical composition on the section of material in the cross section of the laser welding region. In Fig. 4 presents the results of an analysis of the elemental composition of the material in the zone adjacent to the titanium alloy. The presence of oxygen in the diagram of the percentage of chemical elements is due to the oxidation of the surface of the thin sections when they are exposed to air for a long time after welding. The results of the analysis of the elemental composition in the zones on the section of the material in the cross section of the laser welding region of the aluminum alloy AK4 and the titanium alloy VT5-1 are shown in table 3.

Figure 3. Designation of zones of investigation of the chemical composition on the section of material in the cross section of the laser welding region.

As a result of the conducted investigations, it has been established that during the laser welding, the weld metal is mixed. In this case, the concentration gradient of the chemical composition remains in the cross section of the laser welding zone. In the process of welding, a new material is formed in which chemical elements of both welded alloys, such as the aluminium alloy AK-4 and the titanium alloy VT5-1, are present.

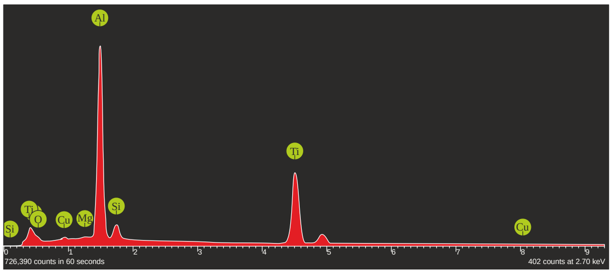

Figure 4. Results of analysis of the elemental composition of the material in the zone adjacent to the titanium alloy.

Table 3. Results of analysis of elemental composition in% in zones on the section of material in the cross section of the laser welding region of aluminium alloy AK4 and titanium alloy VT5-1

Study area number	Al	Ti	Si	Mg	Cu
1	60.8	36.7	1.4	0.5	0.5
2	63.6	32.4	1.3	1.0	1.5
3	75.2	21.6	1.0	0.5	1.6

As a result of metallographic studies it was determined that the diffusion zone formed during the laser action has a homogeneous structure without voids and shells, which indicates a potential sufficiently high performance of the welded joint. The weld metal zone of dissimilar materials formed during welding is characterized by an individual structure, crystal orientation, phase distribution. The laser action with its clearly defined and precise localized energy input makes it possible to largely control the growth of intermetallic compound layers.

3. Conclusions

The obtained results of experimental studies have shown the expediency of forming high-strength and reliable welded joints of materials based on aluminum with other metals and alloys by laser action. Due to the much more precise control of the parameters of the thermal source in the heat affected zone, laser welding of dissimilar materials can have significant advantages. The use of laser welding of aluminium-based materials avoids the formation of an Al_2O_3 oxide film, which is a fairly common defect in fusion welding. A feature of the application of laser welding technologies are high achievable speeds, which makes it possible to reduce the size of the intermetallic interlayer formation zones and minimize the thermal impact zone in materials with high thermal conductivity. However, the predictability of the wetting behaviour, diffusion processes and the thickness of the resulting intermetallic phase layer leaves much to be desired. Additional efforts are needed to better understand the physical mechanisms of laser welding of dissimilar materials. It is promising to carry out modelling of laser welding of dissimilar materials, which should allow increasing the reliability of the process with a view to its introduction into industrial production.

Integration of laser welding of dissimilar materials into industrial production lines remains a difficult task due to the need for an accurate local energy supply, as well as increasing requirements for sample preparation, systems for fixing and positioning the samples. Nevertheless, the use of compounds of dissimilar materials in a wide range of numerous industrial applications is constantly increasing because of the potential for reducing the weight of structures and saving material costs. To implement such technological processes, special optics should be used. More accurate metering of the laser beam energy supply is required locally in the thermal effect zone with the possibility of power density redistribution. Such a redistribution of the energy of the laser beam can be obtained with the help of diffractive optical elements, the use of which in the technological operations of welding heterogeneous materials opens the prospects not only for solving the specific problems described, but also for other applications.

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