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PECULIARITIES OF PRODUCING Al–Ti BIMETAL SHEET JOINTS BY THE METHOD OF VACUUM DIFFUSION WELDING

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Given are the results of investigation of the effectiveness of application of vacuum diffusion welding technology to obtain aluminium-titanium bimetal sheets of 120×120 mm size. The effect of welding parameters on the joint microstructure and mechanical properties was studied. It is established that welding of foil materials is complicated, because of its low deformability. Application of thermally stable SiC and WC powders as «activators» in welding does not allow producing sound joints, because of hard particles embedding into the material being welded, and formation of defects in the form of through-thickness holes. It is shown that application of steel net for activation of plastic deformation on the foil contact surfaces, allows a significant lowering of welding pressure and producing defect-free joints between titanium and aluminium, with 1.7 times higher strength values, compared to layered Al+Ti joints, produced without using the net. 12 Ref., 1 Table, 6 Figures.

Keywords: aluminium, titanium, foil, bimetal joints, diffusion welding

Owing to low specific weight and corrosion resistance under atmospheric conditions, panels from aluminium alloys have become widely accepted in aerospace and mechanical engineering sectors. Prior research by the authors of work [1] showed that strength of three-layer aluminium panel is limited by that of the honeycomb core. In order to widen the possibilities for application of such structures, there is the need to replace the core material by the one more resistant to compression. So, in [2], it was proposed to replace the core from ATs5K5 aluminium alloy by VT6S titanium alloy 3–4 mm thick. However, considering the fact that the specific weight of titanium is two times greater than that of aluminium, its application as the core will lead to an essential reduction of overall weight of the structure that is undesirable when used in the aerospace sector.

Development of new materials, having higher mechanical properties, for working under the specific loading conditions in aircraft, and rocket construction, chemical industry, etc., is urgent. Over the recent years, layered composite materials (LCM) have attracted a lot of attention of scientists, due to the ability to combine the properties of the metals present in their composition [3–5]. Owing to its low density, high heat conductivity and corrosion resistance, aluminium is widely used in different sectors. Titanium at relatively low density has anticorrosion properties and high strength. Light layered Al–Ti composite materials that combine the properties of both the metals, have high values of strength, rigidity and impact toughness [6, 7]. Hence, the need to develop the technology of producing such LCM for further use in manufacture of the honeycomb core.

In the previous work by the authors [8], it was shown that joining foil with Al and Ti in the welding modes lower than the aluminium melting temperature (660 °C) prevents formation of a continuous intermetallic interlayer between these metal layers. From this viewpoint, it is rational to apply the methods of solid-phase joining, in particular, vacuum diffusion welding (VDW) is promising. It is known that in order to improve the welding quality, it is necessary to create in the butt joint the conditions for increase of shear deformations that can be achieved due to application of plastic deformation activators in the form of perforated interlayers, net or powder mixture. Authors of work [9] in welding thin bimetal foil propose applying mobile backing from powdered material.

In view of the above-said, the objective of this work was studying the features of vacuum diffusion welding of sheet materials from aluminium and titanium, using plastic deformation activators in the form of powder or steel net.

Foil from aluminium alloy AD1 and titanium alloy BT1-0 of 150 and 60 μm thickness, respectively, was used as material for investigations. The sheet size was 120×120 mm. Chemical composition of the materials is given in the Table. Before welding, samples were cleaned using a scraper and were degreased with alcohol.

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Chemical composition of AD1 and VT1-0 alloys [10]

Alloy	Element content, wt.%								
	Al	Ti	Fe	Si	Mn	Cu	Mg	Zn	Sum of impurities
AD1	Base	0.15	0.3	0.3	0.025	0.02	0.05	0.1	–
VT1-0	–	Base	0.025	0.10	–	–	–	–	0.30

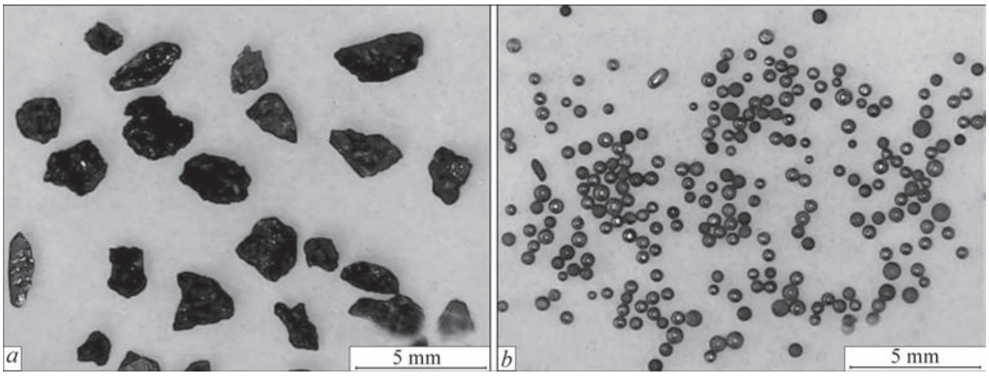

Figure 1. Appearance of SiC (*a*) and WC (*b*) powder, which was used in the investigations in welding aluminium foil to titanium

Welding was performed in a free state in the vacuum chamber of P115 unit, which is fitted with radiation heating system. The assembly with the samples was mounted between the massive steel rods with ground surfaces.

Heating was performed by molybdenum heaters, located around the samples. Heating temperature was controlled by chromel-alumel thermocouple, fastened to the fixture. Pressure was applied to the samples from the press through the lower rod. A dynamometer was used to control the pressure.

Backing from SiC or WC powder, or metal net from 12Kh18N9T stainless steel 1 mm thick with 4×4 mm cell size was used to localize the deformation on the foil surface in welding.

Powder was selected proceeding from the fact that it should be thermally stable at the welding temperature. SiC powder of irregular shape with particle size of 2–3 mm, and WC spherical powder with particle size of 0.5–1.0 mm, respectively, were used (Figure 1).

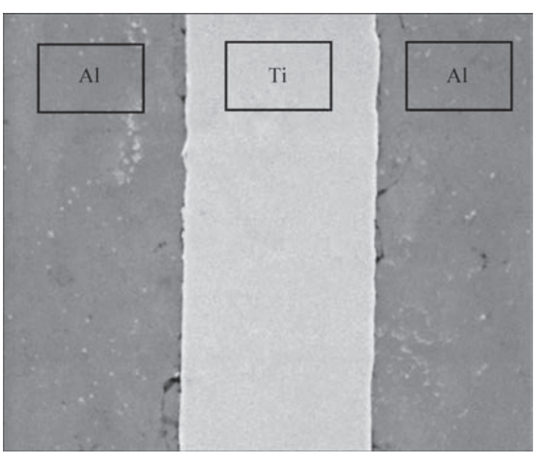

Figure 2. Microstructure of Al+Ti joint produced in the free state in the following mode: T_w = 580 °C, P_w = 20 MPa, t = 20 min

Welding was performed in the following mode: temperature T_w = 580 °C, pressure P_w = 5–20 MPa, welding time t_w = 20 min.

Analysis of structural characteristics of the foil and welded joints was conducted using scanning electron microscope CAMSCAN 4, fitted with a system of energy-dispersive analysis EDX INCA 200 for local chemical composition on flat samples, as well as optical microscope Biwyily USB 500. Transverse sections of welded joints were prepared by the standard procedure, using grinding-polishing equipment of Struers Company.

Digital pressure controller of KOLI Company of XK3118T1 grade and pressure sensor of CAS Company of MNC-1 grade with working interval from 0 to 1000 kg was used, when studying the mechanical properties in compression.

Our literature review [8] showed that it is rational to apply vacuum diffusion welding, in order to obtain the layered material from Al and Ti foil without formation of a continuous intermetallic layer in the butt joint.

In welding thin foil from aluminium alloys it was necessary to take the following factors into account:

- aluminium has a dense, thermally stable oxide film on the surface;
- the foil proper as a material has a work-hardened surface due to manufacturing by rolling methods;
- with reduction of foil thickness its welding becomes more complicated, as a result of reduction of the volume of metal, capable of plastic deformation.

Our investigations in welding thin materials in the form of aluminium foil (Al+Al) 50–200 μm thick in the modes recommended in reference books [11] showed that defects in the form of pores are observed in the butt joint. In order to eliminate the defects, in

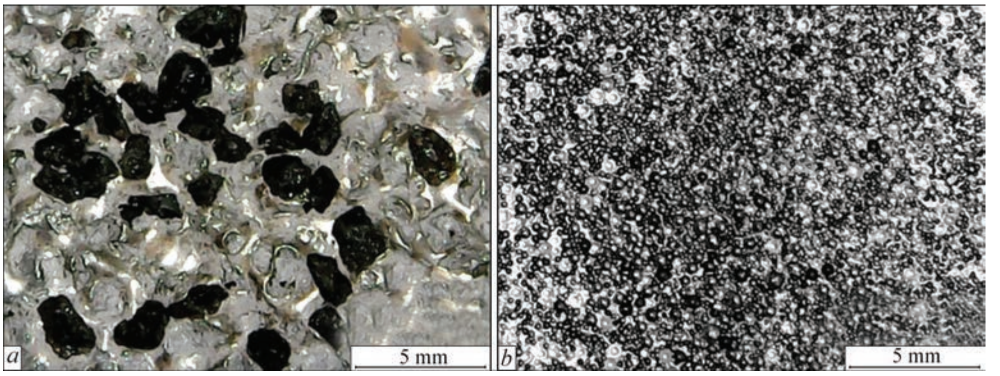

Figure 3. Appearance of the surface of Al+Ti joint after welding using SiC (*a*) and WC (*b*) particles produced in the following mode: T_w = 580 °C, P_w = 5 MPa, t = 20 min

foil welding it is necessary to increase the values of process parameters, namely temperature from 500 to 600 °C and welding pressure from 10–15 up to 40 MPa [1]. However, in welding aluminium and titanium foil this technological measure does not yield any results, although massive materials from these alloys have satisfactory weldability even at lower welding parameters T_w = 560 °C, P_w = 20 MPa [12].

As shown by our investigations, welding of sheet Al+Ti bimetal materials (up to 200 μm thickness) at higher pressure values up to 20 MPa is difficult, because of the low deformability of the foil. A dense contact between titanium and aluminium with individual pores and cracks is observed in the joint zone (Figure 2). Taking into account the sample dimensions, application of such forces leads to deformation of the welding fixture and its quick failure.

According to the technique, described in [9], an interlayer from SiC or WC powder was additionally placed between the foil and fixture for welding that created shear deformations in individual points, and enabled increasing the foil deformability on the whole. Powder application allowed lowering the welding pressure from 20 to 5 MPa.

As shown by the conducted studies, when using SiC powder, its particles are embedded into the bimetal material being welded, with formation of through-thickness irregular holes of considerable dimensions (Figure 3, *a*). Moreover, under the impact of thermodeformational welding cycle, individual SiC granules are partially enveloped by aluminium that makes impossible their further removal without damaging the bimetal material.

Replacement of SiC powder by WC with particles of spherical shape, allows lowering the defect level of the joint surface: the hole dimensions are reduced, and sharp corners disappear in them (Figure 3, *b*). However, reduction of particle dimensions and their regular shape promote a more intensive «absorption» of the powder by aluminium foil surface.

General disadvantages at application of both the «powder–activators» are as follows:

- high values of surface roughness;
- nonuniform distribution of particles over the foil surface;
- embedding of hard particles in the material being welded;
- formation of defects in the form of through-thickness holes;
- increase of bimetal sample weight.

The above-said may lead to the conclusion that application of powder to produce sheet bimetal material does not allow producing the joints suitable for further application.

In order to improve the deformability of foil with simultaneous lowering of pressure value in welding, steel net was furtheron used as plastic deformation activator. This technique allows uniformly localizing plastic deformation over the entire foil surface. No defects were found between aluminium and titanium in the microstructure of the joints produced using the net (Figure 4).

Mechanical compressive testing was conducted for evaluation of strength of the produced bimetal material. For this purpose, 70×12 mm strips were cut out of the bimetal plates and they were rolled into cylinders with 5 mm overlapping of the edges. In order to prevent cylinders unrolling during testing, two tacks were placed

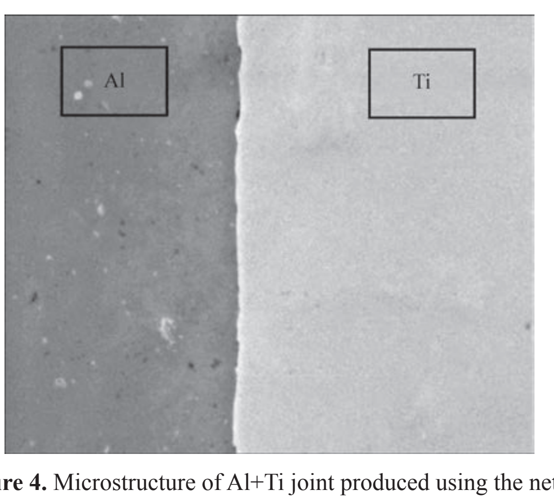

Figure 4. Microstructure of Al+Ti joint produced using the net in the following mode: T_w = 580 °C, P_w = 5 MPa, t = 20 min

Figure 5. General view of cylindrical samples before (*a*) and after (*b*) compressive testing

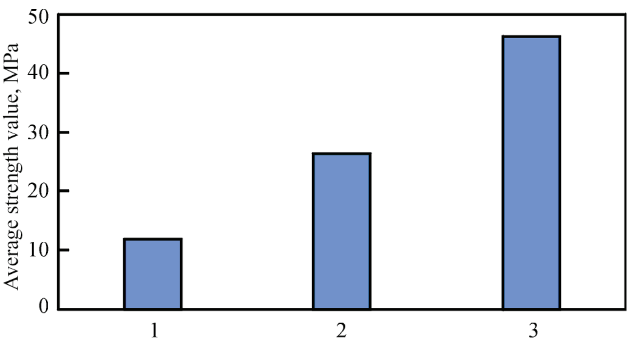

Figure 6. Results of mechanical compressive testing of cylindrical samples: *1* — foil of initial aluminium; *2* — Al+Ti bimetal; *3* — Al+Ti bimetal, produced using the net

in the material overlapping region by resistance welding method. Then, the thus formed samples were compressed with a controlled degree of upsetting to 50 % of the initial height. Figure 5 gives the sample appearance before and after compressive testing.

Obtained results showed that the strength of Al+Ti bimetal joints produced using the net is 3.8 times higher than that of the joints of pure aluminium (46.3 against 12.1 MPa), and is 1.7 higher than that of Al+Ti joints, produced without application of the net (46.3 against 26.5 MPa) (Figure 6).

It was further established that no foil delamination occurs on the bimetal samples produced using the net at compressive testing.

Conclusions

1. Welding of sheet Al+Ti bimetal materials is complicated because of the low deformability of the foil. Separate pores and cracks are observed in the joint zone.

2. Application of plastic deformation activators from refractory SiC and WC powders does not allow producing sound bimetal joints, first of all, due to introduction of hard particles into the material being welded, and formation of defects in the form of through-thickness holes.

3. Application of a steel net as plastic deformation activator on the foil contact surfaces allows an essential reduction of welding pressure and producing defectfree joints of titanium and aluminium, with higher strength levels, compared to layered Al+Ti joints, produced without the net application.

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