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APPLICATION OF A LAYERED COMPOSITE MATERIAL BASED ON ALUMINIUM AND TITANIUM ALLOYS TO PRODUCE WELDED THREE-LAYER HONEYCOMB PANELS

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ABSTRACT

The paper presents the results of studies on production of layered composite materials, based on aluminium and titanium alloys, by vacuum diffusion welding, with a broad range of specific weight values, which is achieved due to different layer ratio in each of the composites. Based on a layered composite material, a procedure was proposed for manufacture of three-layer honeycomb panels by vacuum diffusion welding. It is found that the average compressive strength of the three-layer panel with a filler from a layered composite material based on Al–Ti alloys is equal to 47.3 MPa, that is four times higher than the strength of similar honeycomb elements made from an aluminium alloy. It is shown that the layered material has higher thermal stability as compared to aluminium alloys. Specimen annealing at the temperature of 700 °C for 30 min does not lead to their early destruction or loss of shape.

KEYWORDS: aluminium, titanium, foil, joint, layered composite material, vacuum diffusion welding, three-layer honeycomb panels

INTRODUCTION

Three-layer aluminium panels with a honeycomb filler (Figure 1) have been widely used in aircraft and shipbuilding, construction and other industries due to their unique properties. At a relatively small weight, these structures are characterized by high values of strength and stiffness and, moreover, they have good vibration and radio technical characteristics, sound and thermal insulation properties. Such structures can be used as load-carrying elements in the wing, fuselage, floor, as well as thermal protection elements [1].

One of the methods to produce three-layer panels is vacuum diffusion welding (VDW) [2]. Welding of panels of aluminium alloys is recommended at temperatures higher than 500 °C. However, during heating, the modulus of elasticity of aluminium is rapidly reduced and, therefore, aluminium structures at temperatures of 250–300 °C and higher may lose stability, which causes a difficulty in producing three-layer honeycomb panels during their VDW.

It is possible to increase the resistance of a honeycomb filler in VDW of three-layer panels by the use of a more strength material, such as titanium, but its use as a filler will lead to a significant increase in the total mass of the structure, which when using products in the aircraft industry is not desirable.

In our opinion, the optimal variant between the minimum mass and the maximum strength of honeycomb structures is the use of layered composites. This can significantly improve a number of properties, including specific stiffness and strength, fracture toughness, fatigue characteristics, impact characteristics, wear resistance, corrosion resistance and damping ability, provide an increased ductility of brittle materials and high stability of sizes [3].

In [4], the possibility of producing bimetal Al–Ti by VDW is confirmed.

It can be assumed that the use of layered composite materials (LCM), to which bimetals can also be attributed, can significantly improve the properties of honeycomb structures. Taking into account the possibility of wide regulation of the structure and composition of LCM at the stage of joint formation, studies on the manufacture of such materials is quite relevant. Taken this fact into account, the aim of the work is to develop the procedure of producing three-layer honeycomb panels by VDW from layered composites based on aluminium and titanium alloys.

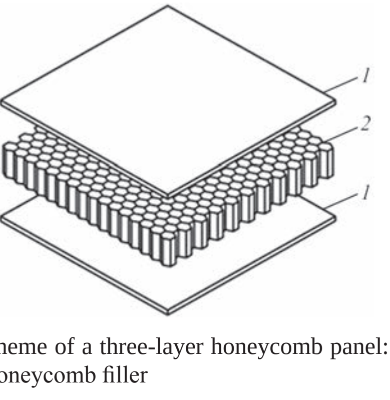

Figure 1. Scheme of a three-layer honeycomb panel: *1* — facial panel; *2* — honeycomb filler

Table 1. Chemical composition of AD1, AMg2 and VT1-0 alloys, wt.%

Alloy	Al	Ti	Fe	Si	Mn	Cu	Mg	Zn	Cr	Amount of impurities
AD1	Base	0.15	0.3	0.3	0.025	0.02	0.05	0.1	–	–
AMg2	Same	0.15	0.5	0.4	0.1–0.5	0.15	1.7–2.4	0.15	0.05	–
VT1-0	–	Base	0.025	0.10	–	–	–	–		0.35

RESEARCH PROCEDURES, MATERIALS

For studies, alloys of AD1 aluminium and VT1-0 titanium alloys in the form of foil respectively of 150 and 30 μm thickness were used. For lids, aluminium AMg2 alloy of 1 mm thickness or LCM based on aluminium and titanium of 480 μm thickness were used. The chemical composition of aluminium and titanium alloys used for the manufacture of three-layer honeycomb panels is given in Table 1.

To manufacture a honeycomb filler, bimetal Al–Ti billets of 130×130×0.180 mm were used, which were previously produced by VDW [5]. From bimetal sheets, strips of 12 mm width were cut, from which in turn in a special equipment, corrugated strips with a step of bending of 10 mm were formed.

In the manufacture of a honeycomb filler, spot welding was used, which was carried out at room temperature in air. Before welding, the contact surfaces of the corrugated strips were cleaned mechanically and degreased. Welding was carried out at constant values of voltage U_w = 10 V and current I_w = 250 mA, the intensity of heating was determined by the pulse duration t_w = 0.5–5.0 s and their number N_w = 1–20.

Unlike welding of homogeneous material, in spot welding of bimetal strips, there may be some complications due to not only the heterogeneity of the material over thickness, but also various physical and mechanical properties of titanium and aluminium. Titanium has a low electrical and thermal conductivity, very active in relation to the gases contained in the atmosphere. Its welding is carried out at relatively low parameters of current, compression force and heating duration. Aluminium has high thermal conductivity, low electrical resistance and refractory oxide film on the surface. Therefore, the surfaces of parts before welding should be carefully treated so that the oxide film was removed to prevent the formation of lacks of fusion.

As is shown in [5], the optimal variant of welding of bimetal Al–Ti strips when producing a honeycomb filler is welding of the aluminium layer to the titanium layer.

Before VDW of panels, end surfaces of a honeycomb filler and contact surfaces on lids were cleaned with a scraper and degreased with alcohol.

Welding was carried out in the vacuum chamber of the installation P115, equipped with a radiation heating system. The heating temperature was monitored by a chromel-alumel thermocouple, fixed in the equipment. The pressure to the specimens was applied from the press through the lower stem. The pressure control was carried out using a dynamometer.

Welding was carried out in the following mode: temperature T_w = 560–610 °C, pressure P_w = = 5–20 MPa, welding duration t_w = 20–30 min.

The structural characteristics of the foil and welded joints were analyzed with the use of the CAMSCAN 4 electron microscope, equipped with EDX INCA 200 system for energy dispersive analysis of a local chemical composition on plane specimens. Cross-sections were prepared according to the standard procedure using grinding and polishing equipment of Struers Company.

Mechanical properties of the specimens were determined during their tests for compression, which corresponds to the research procedure given in [6, 7].

To carry out mechanical tests of the honeycomb structure on compression, a digital pressure controller of the KOLI Company of the brand KhK3118T1 and a sensor of the CAS Company of the brand MNC-1 with a working interval from 0 to 1000 kg were used.

RESEARCH RESULTS

Taken into account that in the aircraft and space industry, materials with low specific weight are used, we produced experimental LCM specimens of different thicknesses and with different number of layers. In Figure 2, *a* the general appearance of LCM specimen, which consists of four layers (2A1 + Ti + Al) is presented. The total thickness of LCM is 480 μm, the specific weight of the produced material is 2.9 g/cm^3.

To reduce the weight of LCM, as a reinforcing element, wire or titanium mesh can be used. The overall appearance of the LCM specimen with the use of the mesh of VT1 titanium alloy is shown in Figure 2, *b*. The specimen consists of three layers: aluminium layer, titanium layer (mesh) and aluminium layer. The total thickness of the specimen is 950 μm (two layers of aluminium is 300 μm and titanium is 650 μm), the specific weight of the produced material is 2.24 g/cm^3.

Generalized results with the parameters of the produced LCM specimens are given in Table 2. Produced LCM have a fairly wide range of specific weight values, which are predetermined by differences in the content of aluminium and titanium in each of the composites.

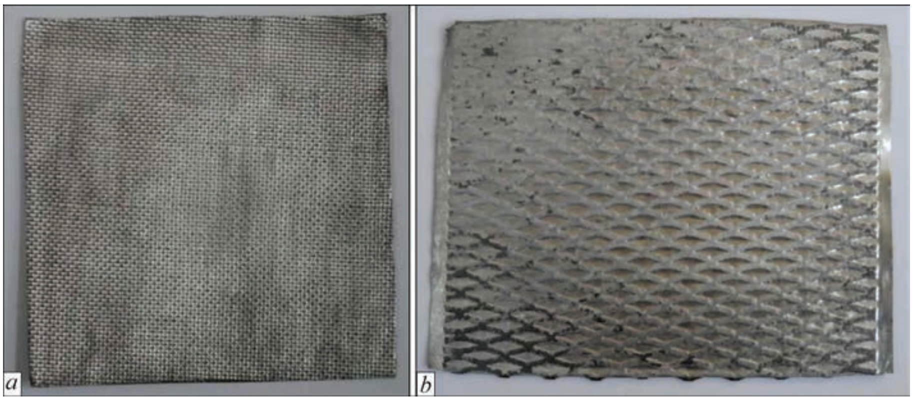

Figure 2. LCM specimens with different thickness and different layer composition: *a* — two aluminium layers, titanium layer, aluminium layer; *b* — aluminium layer, titanium layer (mesh), aluminium layer

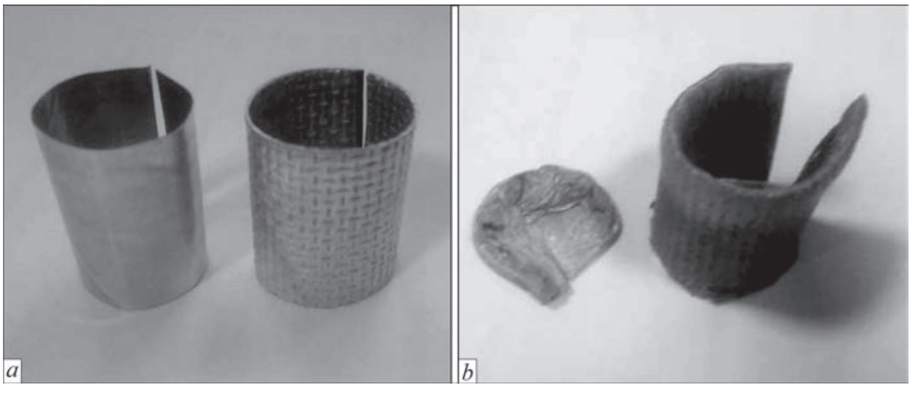

Figure 3. Appearance of aluminium AD1 alloy specimens (left) and Al–Ti LCM (right) in the initial state (*a*) and after heating in the furnace to a temperature of 700 °C for 30 min (*b*)

We have investigated thermal stability of a binary LCM, which consisted of an aluminium and a titanium layer. The carried out studies have shown that as compared to aluminium alloys, it is able to withstand higher temperatures without loss of a design shape, that coincides with the results of other researchers [8]. Figure 3, *a* shows a specimen of aluminium AD1 alloy and LCM, produced from titanium VT1 and aluminium AD1 alloy in the initial state and after heating in the furnace for 30 min at a temperature of 700 °C. As is seen from Figure 3, in the process of heating, the aluminium specimen melts and the LCM specimen retains its design shape.

Obviously, the prospect of using Al–Ti bimetal produced by VDW for the manufacture of three-layer honeycomb panels, as well as the possibility of their operation at elevated temperatures will be determined by the strength and intensity of growth of an intermetallic layer in bimetal during the manufacture of honeycomb structures and their operation.

VDW of honeycomb panels was performed at a temperature T = 560–600 °C, pressure P = 10 MPa, duration of the process t_w = 30 min, vacuum in the chamber was maintained at the level of $1.33 \cdot 10^{-3}$ Pa.

To determine the more specific temperature of welding T-joints of lids with a honeycomb filler, the studies of mechanical properties of three-layer panels, produced at different temperatures of the process were conducted, from the results of which the welding mode was chosen.

For mechanical compression tests, the specimens were selected consisting of a single bimetal honeycomb Al–Ti and lids of AMg2 alloy. The size of a honeycomb filler cell was 10×10 mm, height was 12 mm and cross-sectional area was 18 mm^2. To produce specimens for each of the studied temperatures, two

Table 2. Parameters of specimens of layered composite materials

Number	LCM composition	Number of layers	Material of layers	Layer thickness, μm		Total thickness, μm	Specific weight of LCM, g/cm^3
				Al	Ti		
1	Al–Ti	2	Al, Ti — foil	150	30	180	3.4
2	Al–Ti–Al	3	Al — foil, Ti — mesh	150	650	950	2.24
3	Al–Al–Ti–Al	4	Al, Ti — foil	150	30	480	2.9
4	Al–Ti–Al–Ti–Al	5		150	30	510	3.21

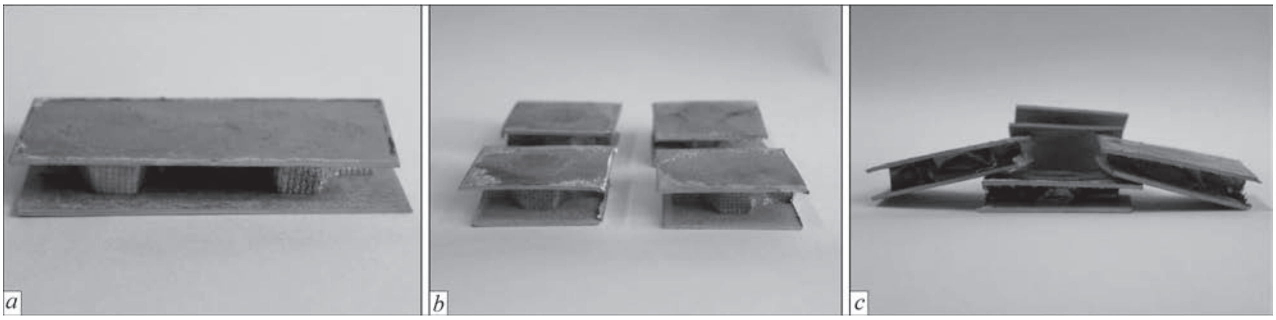

Figure 4. Specimens of the honeycomb panel produced by the method of VDW: *a* — after welding; *b* — elements of a three-layer panel after cutting with an abrasive disc; *c* — after mechanical compression tests

panels were welded, the typical appearance of which is shown in Figure 4, *a*. Then, the panels were cut in half with the use of an abrasive disc (Figure 4, *b*). Upsetting of the honeycombs was set at the level of 50 % of their initial height. It was established that in the specimens produced at a welding temperature of 570 °C, a partial delamination of facial lids occurs already at the stage of their cutting. During the mechanical tests, T-joints are completely destroyed. A poor quality of the joint between the surfaces of facial lids and the ends of a honeycomb filler leads to uneven redistribution of a load, and as a result to a significant decrease in the level of strength of such panels, the average value of which is 2/3 of the strength of the original honeycomb filler (Table 3).

An increase in welding temperature to 580 °C allows increasing the compression strength to 37.2 MPa. At the same time, during deformation of the walls of a honeycomb filler, a single destruction of welding places between filler and lids occurs.

The further increase in welding temperature to 590 °C allows bringing the strength of the three-layer panel to 47.3 MPa, which corresponds to the value inherent in a honeycomb filler after annealing at a temperature of 600 °C for 60 min. Moreover, as is seen from Figure 4, *c*, during compression a deformation of the walls of a honeycomb filler without destruction of places of welding filler with facial lids occurs.

Table 3. Results of mechanical tests on compression of three-layer panel specimens

Welding temperature T_w, °C	Compression strength, MPa	Average compression strength, MPa
570	–	27.1
	–	
	28.0	
	26.1	
580	31.9	37.2
	34.0	
	47.0	
	35.9	
590	52.2	47.3
	43.6	
	44.8	
	48.7	
600	44.3	44.0
	38.8	
	57.6	
	35.2	

The strength of the T-joints produced at a welding temperature of 600 °C is close to the previous results: its slight drop occurs, which is probably related to the diffusion of magnesium of AMg2 alloy to the joining zone.

From the abovementioned, it can be concluded that to produce a high-quality T-joint of a honeycomb filler with facial lids, the optimum welding temperature is 590 °C.

Moreover, according to metallographic examinations of the joints produced at a temperature of 570 °C, some of the specimens are destroyed due to the lack of a physical contact between welded surfaces (Figure 5, *a*). In the specimens produced at a temperature of 590 °C, a sealed joint is formed, in the butt a small number of defects is observed (Figure 5, *b*).

According to the carried out works, the procedure of manufacturing a three-layer honeycomb panel should include the following basic operations:

- diffusion welding of bimetal material;
- cutting of bimetal foil into strips (Figure 6, *a*);
- formation of profiled bands from strips (Figure 6, *b*);
- cleaning and degreasing of the corresponding surfaces and welding of a honeycomb filler;
- cleaning and degreasing of end surfaces of a honeycomb filler block and facial lids of a honeycomb panel;
- VDW of a three-layer honeycomb panel (Figure 6, c).

Welding of bimetal Al-Ti material was carried out at a temperature T_w = 580 °C, pressure P_w = 5 MPa, with the exposure on the mode during t_w = 20 min. The produced plates of 130×70 mm were cut into strips of 70×12 mm (Figure 6, *a*), of which, after the formation of profiled strips by spot welding, a honeycomb filler with the size of honeycombs of 10×10×12 mm (Figure 6, *c*) was manufactured.

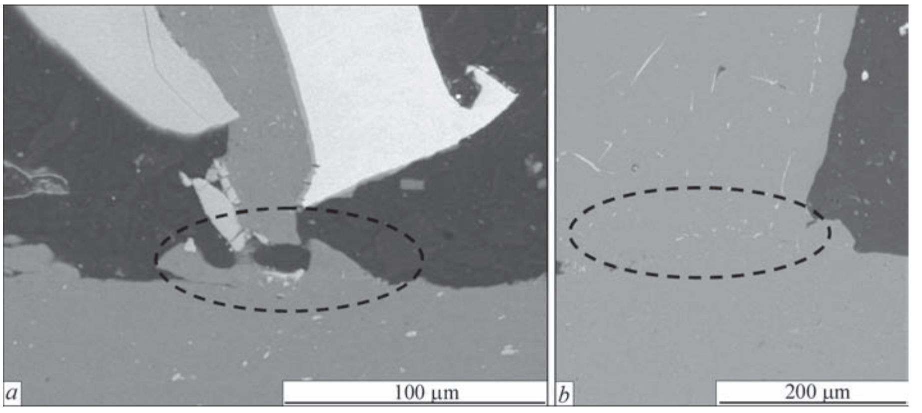

Figure 5. Microstructure of the zone of T-joint specimens produced at a temperature of 570 (*a*), 590 °C (*b*)

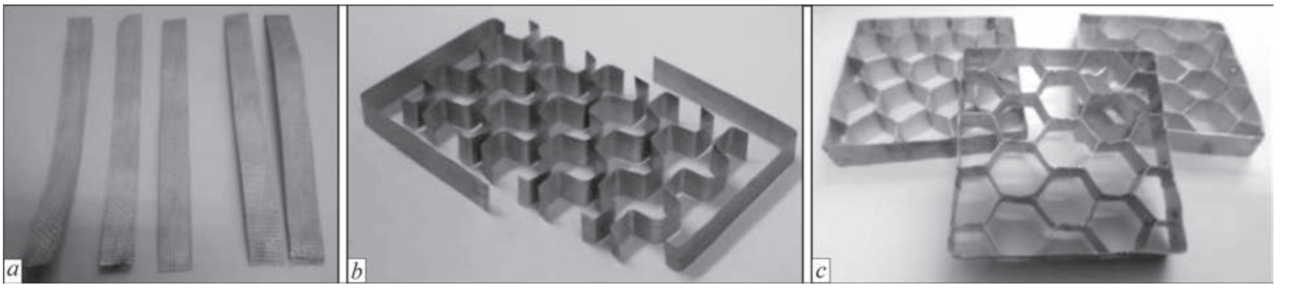

Figure 6. Stages of manufacturing honeycomb filler: *a* — strips of bimetal Al–Ti material; *b* — workpieces of profiled strips for spot welding of a honeycomb filler; *c* — 72×72 mm honeycomb filler

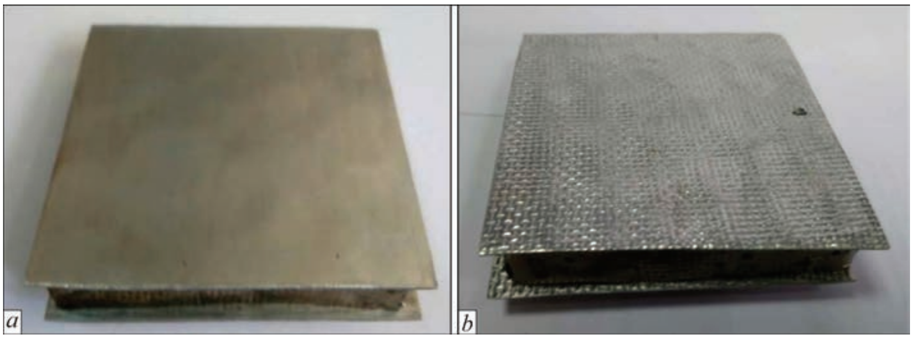

Figure 7. Model specimen of a three-layer honeycomb panel with lids of aluminium AMg2 alloy (*a*) and honeycomb panel with lids of layered composite Al–Ti–Al–Al material

For welding panel of honeycombs on the base of bimetal Al-Ti material and lids of aluminium AMg2 alloy, the equipment was designed and manufactured, consisting of a matrix and a punch and embedded elements that allowed centering of a panel billet on the center of the matrix and regulating the level of plastic deformation of a product. The procedure of producing welded joints was worked out.

On the basis of the developed technology, a batch of model specimens of a three-layer panel of bimetal Al–Ti honeycomb filler and facial lids of aluminium AMg2 alloy were manufactured (Figure 7, *a*). A three-layer panel was also produced, which completely consists of LCM (Figure 7, *b*). A honeycomb filler consists of Al–Ti bimetal, and lids consist of Al–Ti–Al–Al LCM.

As our studies showed, the mass of a three-layer panel produced with lids of aluminium alloy is 46–48 g, and the mass of a three-layer panel with Al–Ti–Al–Al LCM is respectively 24–26 g.

Thus, it can be assumed that the use of LCM for the manufacture of a three-layer honeycomb panel provides a significant reduction in the mass of products.

CONCLUSIONS

1. The fundamental possibility of producing honeycomb three-layer panels with LCM by VDW method is shown.

2. Welding parameters were determined, that allow producing T-joint of a honeycomb filler with LCM based on Al–Ti alloys with lids of aluminium alloy with an average compression strength at the level of 47.3 MPa.

3. It is shown that the use of LCM for the manufacture of three-layer honeycomb panels allows reducing

the mass of products by 2 times as compared to the panels made with lids of aluminium alloy.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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