FLASH BUTT WELDING OF PRODUCTS OF HIGH-STRENGTH ALLOYS BASED ON ALUMINIUM

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The generalized data of technologies and equipment for flash butt welding of products of aluminium alloys and also types of products being welded using this method in rocket construction are given. The main directions of investigations for modernization of technologies of welding of high-strength aluminium alloys are considered: technology of welding using pulsed flashing as a method of heat intensification, and also effect of deformation degree at upsetting on the structure and properties of welded joints. The optimal degree of deformation of forming devices was determined allowing increase the elongation of welded product by 1.5 times at simultaneous preserving of high values of strength. In welding of thick-wall heat-hardened aluminium alloys the postweld thermomechanical treatment allows producing joints, equal in strength to base metal. Technology of welding of thick-wall T-profiles of high-strength hard-to-weld alloys was developed. The mechanical characteristics of welded joints of high-strength aluminium alloys are at the level of not less than 90 % of the strength of base metal. 10 Ref., 3 Table, 10 Figures.

Keywords: *flash butt welding, flashing, aluminium alloys, welded joint, thermomechanical treatment, mechanical properties, strength, ductility*

The wide application of aluminium alloys for manufacture of critical structures in aircraft and rocket construction predetermined the need in development of reliable and high-efficient technologies of their joining [1]. To manufacture these structures different methods of welding are applied: arc, electron-beam, flash butt, friction, etc. [2–4]. During manufacture of critical structures of hard-to-weld alloys the permanent joints are produced using riveting. The service characteristics of the products depend greatly on the selected method of their joining [5].

Table 1. Equipment for FBW of parts of aluminium alloys

Machines for FBW	Maximum sections being welded, mm^2	Minimum inner diameter of ring semi-products, mm	Rated power at duty cycle of 50 %, kV·A	Efficiency, welds/h
K617	600	320	150	20
K724	600	250	100	36
K607	5000	500	350	8
K393	6000	1300	150	10
K756	15,000	900	860	6
K566	26,000	1400	930	4
K831	40,000	1700	6000	2
K754	60,000	5000	4800	4
K767	64,000	1800	4800	2
K825	90,000	1800	6000	2

The flash butt welding (FBW) is successfully applied at the enterprises of Ukraine and Russia for joining of different parts of high-strength aluminium alloys. The many-year experience of application of FBW evidences of high and stable quality of joints. The technological FBW process combines assembly and welding operations, does not require auxiliary consumables (electrodes, wire, fluxes, shielding gases) and easily adapted to automation and robotization. In flash welding the precision preparation of edges of parts is not required [6–8].

At the E.O. Paton Electric Welding Institute of the NAS of Ukraine (PWI) the technologies and equipment for FBW of different products of alloys based on aluminium with the cross section area of up to 90,000 mm^2 (Table 1) were developed. The technology and specialized equipment are implemented at the plants of rocket industry in Ukraine and Russia.

The FBW technology is applied for joining of:

• products of closed shape (frame rings) of pressed profiles with intricate and different-thickness cross section of up to 60,000 mm^2 area (the examples of profiles being welded are given in Figure 1);

• longitudinal welds of shells of bodies of fuel tanks with section of up to 2000 × 32 mm of alloys AMg6NPP, 1201, and 2000 × 45 mm of alloy AMg6M;

• longitudinal load-carrying set (stringers, fittings) of thickness from 2 mm of aluminium alloys of different alloying systems (V95, D16, AK6) in similar and dissimilar combinations.

FBW of frame rings with cross section area of 2500 mm^2 using machine K393 and FBW of a shell with cross section area of 64,000 mm^2 using machine K767 are shown in Figure 2.

Figure 1. Examples of aluminium alloy profiles welded by FBW

In connection with wide application in welded structures of high-strength aluminium alloys, relating to the category of hard-to-weld, the need in modification of FBW technology arises. It was found that to obtain high values of mechanical properties of welded joints it is necessary first of all to optimize the heat input in welding and to control the temperature distribution in HAZ metal. In welding of heat-hardened alloys it is especially important to optimize the temperature and time of heating [9]. Alongside with this the sufficient influence on mechanical properties of joints is exerted by the conditions of deformation of near-contact layers of metal subjecting to intensive deformation.

As a result of many-year investigations at the PWI the methods of heat intensification were developed (program decrease of voltage, pulsed and pulsating flashing) [6]. At the present time the technologies of heating using pulsating flashing of aluminium alloys with application of modern powerful hydraulic drives and computer control systems are developed at the PWI. The principle of the method of heating using pulsating flashing consists in maintenance of welding current in the range, at which the highest efficient power is generated in the contact between two parts. The given mode is provided by control of welding speed depending on the values of welding current. The application of pulsating flashing instead of preheating by resistance heating allows producing uniform high-concentrated heating

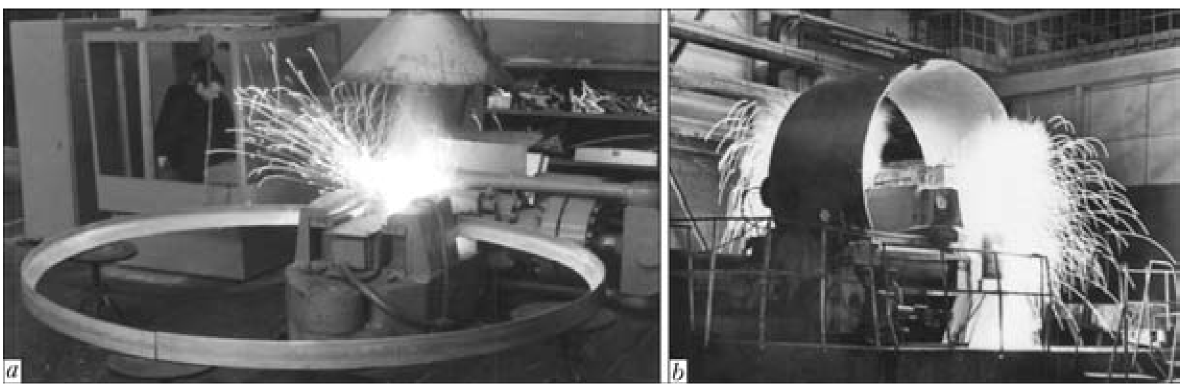

Figure 2. FBW of frame rings in machine K393 (*a*) and shells in machine K767 (*b*)

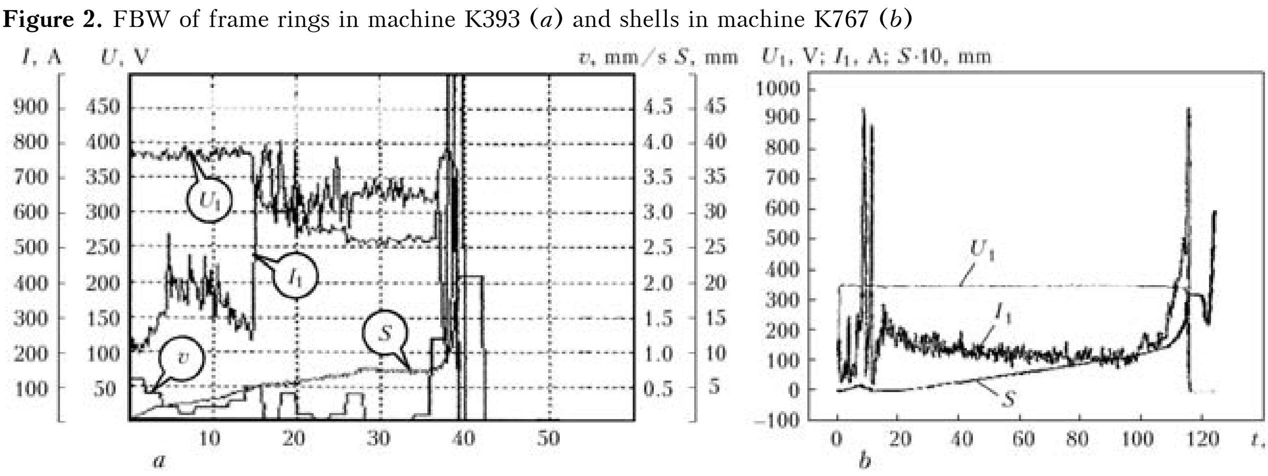

Figure 3. Program of change of main parameters of process in welding of aluminium alloy parts of cross section area 30 × 140 mm by pulsating (*a*) and continuous (*b*) flashing

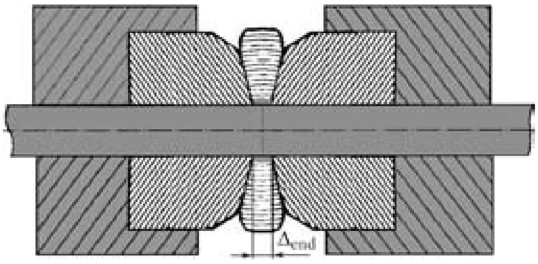

Figure 4. Scheme of formation of welded joint with end gap Δ_{end}

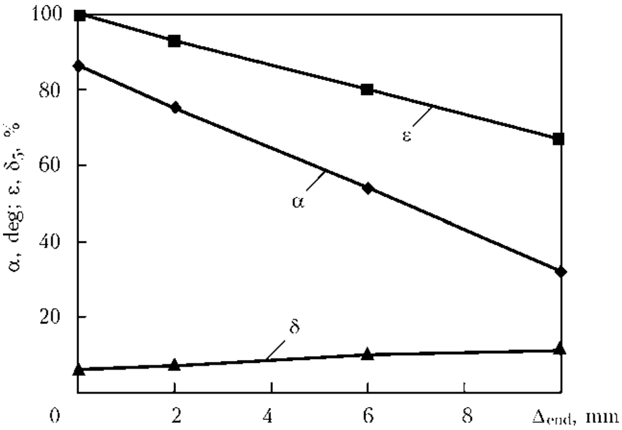

Figure 5. Dependence of deformation degree, bending angle of fiber and elongation on end gap

across the welded section, decreasing tolerances for flashing and duration of heating.

The carried out investigations showed that the possibility of smooth control of welding voltage in heating using pulsating flashing allows presetting the mode of heating with the most optimal welding parameters (Figure 3).

To increase the plastic characteristics of welded joints the influence of deformation degree on mechanical properties of welds during formation of welded joint was investigated.

In welding with forming devices (Figure 4) the metal of thickness δ is extruded into the gap Δ_g during upsetting, the value of which is changed with time, the deformation degree ε is also changed with time [10]:

$$\Delta_g(t) = \Delta_{end} + \Delta_{ups} - v_{shr}t, \quad \varepsilon(t) = \frac{\delta - \Delta_g(t)}{\delta}\, 100\ \%,$$

where Δ_{ups} is the tolerance for upsetting; v_{shr} is the speed of shrinkage.

With the increase of end gap between the forming devices the deformation degree and bending angles of fibers under the edges of knives decreases. It was found that in flash welding the decrease of deformation degree in welded joint due to increase of end gap allows increasing the elongation δ_5 from 7 to 10–11 % at simultaneous preserving of high values of strength (Figure 5). The macrostrucutres of the zone of welded joint with different end degree of deformation are given in Figure 6. The results of mechanical tests of welded joints obtained in FBW, specimens of 1201 alloy of 30 mm thickness at different conditions of extrusion are given in Table 2. The application of thermomechanical treatment after welding allows producing welded joints close to the strength of base metal (Table 3).

The development of welding technology was accompanied with modification of design of FBW equipment. The systems of quick-response hydraulic drives of machines on the base of modern complexes, computerized systems of control of parameters of flashing process were developed. They allow reproducing the welding modes (see Figure 3, *a*) at high accuracy, providing stable flashing at higher densities of current than at continuous flashing (see Figure 3, *b*).

In the process of optimizing the welding modes the criterion for quality evaluation under industrial conditions is the bend test of welded joints, having preliminary notch in the weld, up to fracture (quality express-analysis). This method allows visual detecting of defects directly in the

Table 2. Mechanical properties of base metal and welded joints of alloy 1201 of 30 mm thickness

Material	ε, %	σ_t, MPa	δ_5, %	$K = \sigma_{t\,WJ}/\sigma_{t\,BM}$
Base metal	–	433	15	–
Welded joint	93	411	7	0.95
	80	427	10	0.98
	67	430	11	0.99

Table 3. Mechanical properties of base metal and welded joints without and with postweld thermomechanical treatment

Alloy (analog)	Without heat treatment			Postweld thermomechanical treatment			K
	σ_t, MPa	$\sigma_{0.2}$, MPa	δ_5, %	σ_t, MPa	$\sigma_{0.2}$, MPa	δ_5, %	
1201 (2219)	176/177	86/100	23/23	441/432	325/345	25/8	0.98
V95 (7075)	217/219	103/128	21/13	487/479	419/406	12/9	0.98
AD33 (6061)	132/131	67/73	32/27	281/301	276/297	19/15	1

Note. In numerator the values for base metal are given, in denominator — for welded joint.

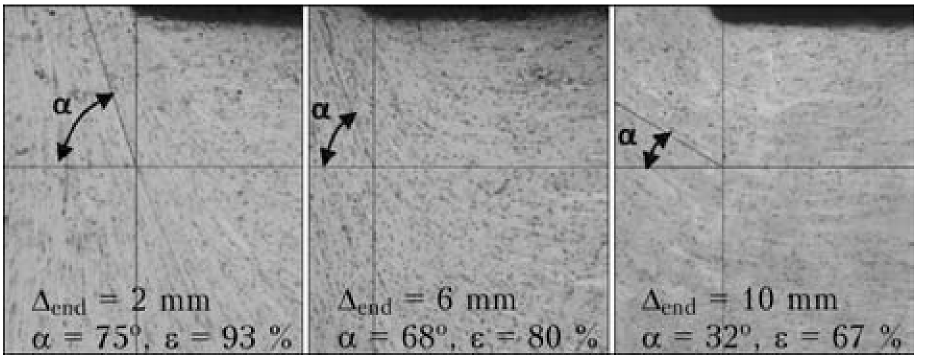

Figure 6. Macrostructures of zone of welded joint (*a*–*c*) in welding alloy 1201 of 30 mm thickness at different final degree of deformation

weld. The example of fracture is given in Figure 7.

In the structure of welded joints the following is distinguished:

• base metal with large grains elongated along the line of rolled metal and large clusters of intermetallics along their boundaries;

• HAZ which consists of areas with different level of recrystallized and deformed metal that leads to sharp decrease of grains size and their orientation relatively to the direction of grains of base metal up to 90°;

• weld metal with dense fine-grain structure.

The examples of microstructure of welded joints, produced using FBW method, of speci-

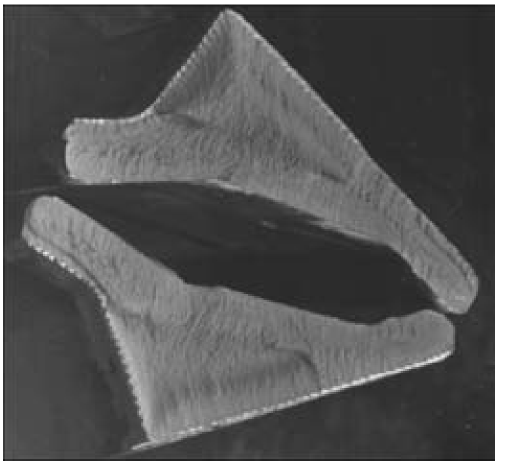

Figure 7. Fractures of welded joints

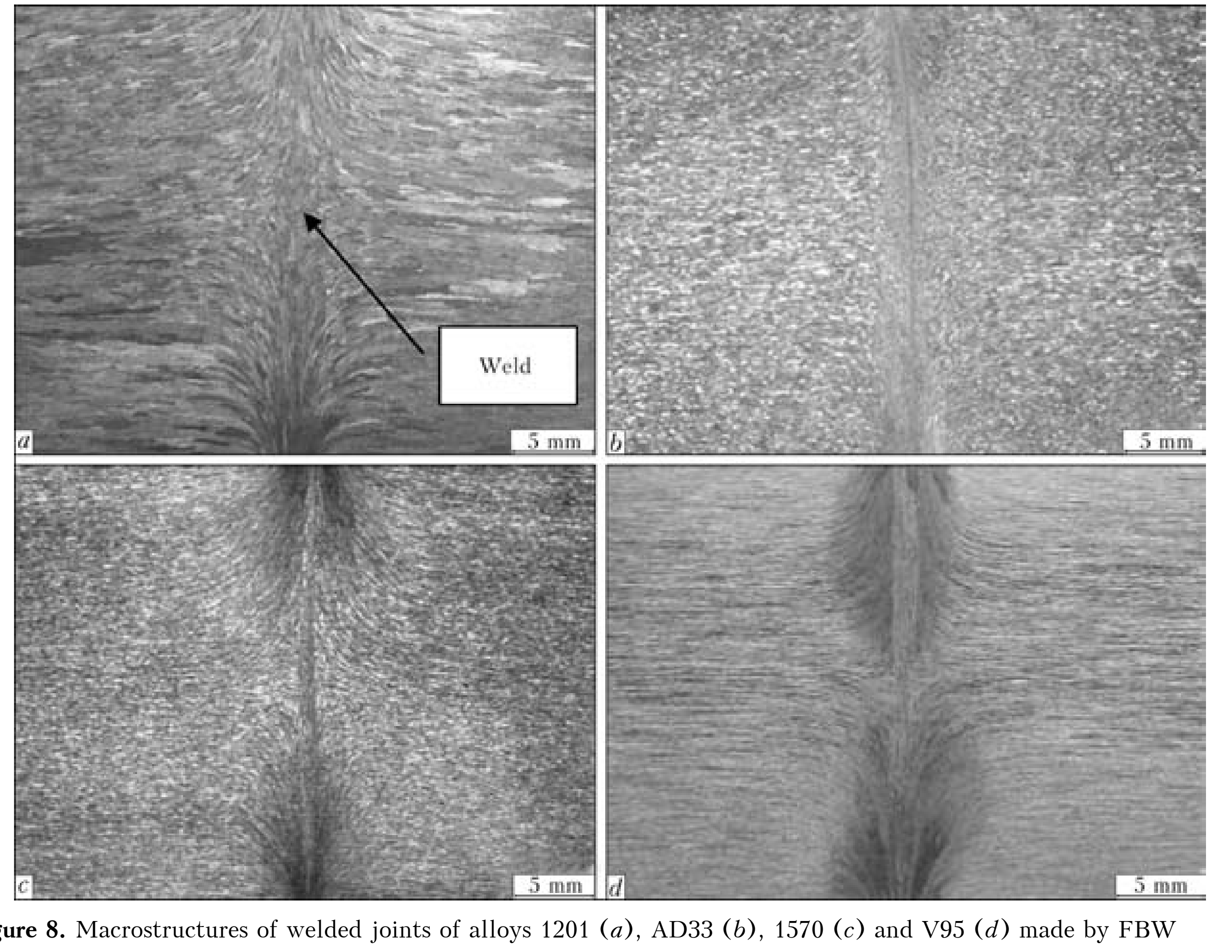

Figure 8. Macrostructures of welded joints of alloys 1201 (*a*), AD33 (*b*), 1570 (*c*) and V95 (*d*) made by FBW

Figure 9. Riveted and welded joint of dissimilar alloys on aluminium base of fitting–stringer elements used in aerospace industry

mens of 30 mm thickness of alloys 1570, AD33, 1201 and V95 are given in Figure 8.

The application of welding instead of riveting is one of the efficient methods of solution of problem of decrease of weight of flying vehicles (Figure 9).

As a result of conducted investigations the FBW technology of thin-wall heat-hardened T-profiles of V95-T1 alloy was developed applied in manufacture of assemblies of longitudinal load-carrying elements of the last stage at efficient loading of rocket-carriers (fitting–stringer and stringer–stringer). This technology provides coefficient of strength of welded joints $K \geq 0.9$. The average values of mechanical properties of base metal (numerator) and welded joints (denominator) of profile 2.5 mm thick of V95-T1 alloy are given below: $\sigma_t = 580/536$ MPa; $\sigma_{0.2} = 505/426$ MPa; $\delta_5 = 15/6$ % ($K = 0.92$).

Basing on the FBW technology of thin-wall profiles of high-strength aluminium alloys the new machine for welding of stringer–fitting, stringer–stringer elements (Figure 10) was developed providing welding of profiles of high-strength aluminium alloys of up to 300 mm^2 cross section area.

The application of this technology in production for welding of fitting–stringer joints instead of riveted ones, being used at the moment, will allow sufficiently increasing the weight of useful load delivered to the orbit by domestic rocket-carriers.

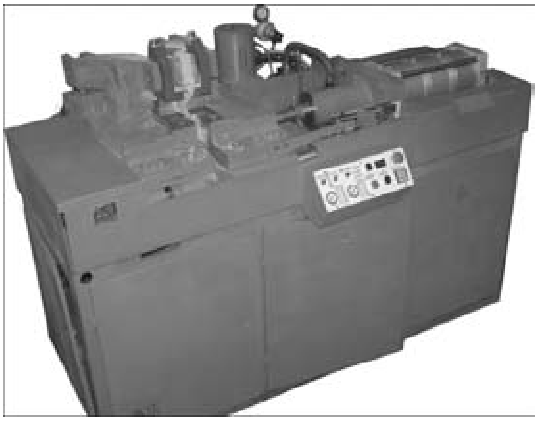

Figure 10. Machine for FBW of thin-wall profiles of high-strength aluminium alloys

Conclusions

1. The use of flash butt welding technology for joining of parts of high-strength alloys based on aluminium provides mechanical properties of welded joints at the level of not lower than 90 % of strength of base metal.

2. The optimal degree of deformation at upsetting using forming devices was developed, which allows increasing the elongation of welded product by 1.5 times at simultaneous preserving of high values of strength.

3. In welding of thick-wall heat-hardened aluminium alloys the postweld thermomechanical treatment allows producing joints, equal in strength to the base metal.

4. The technology and equipment for FBW of thin-wall profiles of high-strength heat-hardened alloys based on aluminium were developed.

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Received 10.06.2013