PECULIARITIES OF FLASH BUTT WELDING OF HIGH-STRENGTH ALUMINIUM ALLOY 2219

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Peculiarities of flash butt welding of high-strength heat-hardening alloy 2219 were studied. It was shown that welded joint have no defects of the type of oxide films and delaminations. Optimal conditions for heating of the plastic deformation zone in upsetting were determined. A 15–20 % weakening of the heat-affected zone in the welded joints can be fully eliminated by postweld heat treatment (hardening and subsequent artificial ageing). Tensile strength of the welded joints is at a level of 93–95 % of that of the base metal.

Keywords: *flash butt welding, high-strength aluminium alloy, heating, defects of joints, mechanical properties, weakening, heat treatment of joints*

High-strength aluminium-base alloys have found wide application in aerospace engineering for manufacture of different-purpose parts and structures used in aircraft. In particular, many load-carrying elements of structures are produced from high-strength heat-hardening alloy 2219 of the Al–Cu alloying system. They are manufactured by using various welding methods (arc, electron beam, flash butt, friction, etc.), which determine to a considerable degree the welded joint performance [1].

Continuous flash butt welding is one of the most economically and technically viable methods for manufacture of straight-lined and annular billets. This method provides a high and consistent quality of the joints, combines assembly and welding operations in one cycle, and requires no consumables (electrodes, wires, fluxes, shielding gases, etc.) [2].

In this connection, it was of interest to study weldability of high-strength aluminium alloy 2219 in continuous flash butt welding, degree of weakening of the joints and probability of formation of defects in them.

Investigations and development of the technology for continuous flash butt welding of parts of alloy 2219 (composition, wt.%: 6.45 Cu, 0.31 Mn, 0.14 Zr) were carried out on samples with a cross section of 20 × 100 mm in the T851 state (hardening, cold deformation and artificial ageing). It was taken into account that in continuous flash butt welding of parts of aluminium-base alloys the joints are usually formed during upsetting (Figure 1). Considering thermal-physical properties of this alloy and its thickness, resistance preheating was used prior to continuous flashing to achieve optimal heating of the plastic deformation zone in upsetting.

High sensitivity of alloy 2219 to thermal cycles required that comprehensive investigations be performed to identify heating parameters to be used in welding.

Optimal conditions of formation of a welded joint in upsetting can be created provided that the material to be welded has equal yield stress and tensile strength values in the deformation zone. In this case, the resulting welded joints have minimal internal stresses and are free from cracks or other defects.

In flash butt welding with formation, the intensive deformation zone is almost equal to the upsetting allowance. Mechanical characteristics (tensile strength σ_t and yield stress σ_y) of alloy 2219 at increased temperatures were studied to identify optimal heating prior to upsetting (Figure 2).

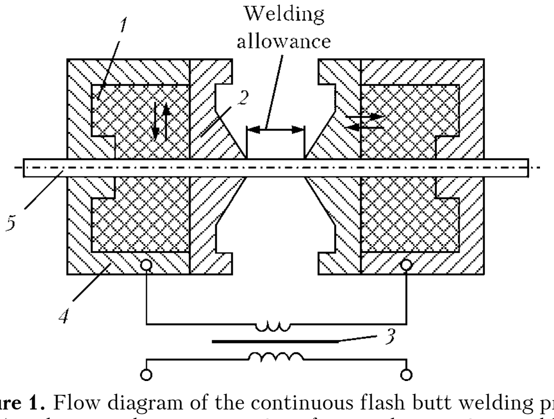

Figure 1. Flow diagram of the continuous flash butt welding process: *1* — heat-insulating insert; *2* — forming knives; *3* — welding transformer; *4* — current conductor; *5* — workpiece

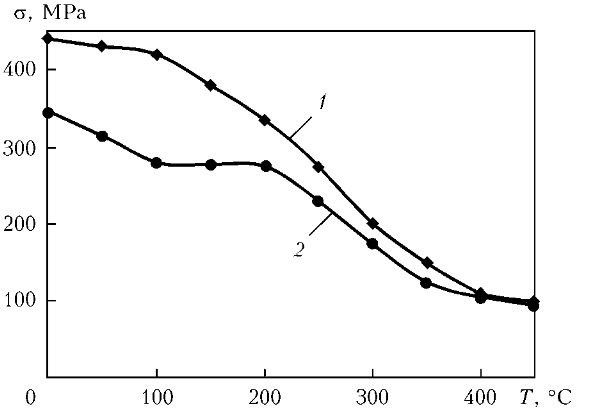

Figure 2. Mechanical properties of alloy 2219 at increased temperatures: *1* — σ_t; *2* — σ_y

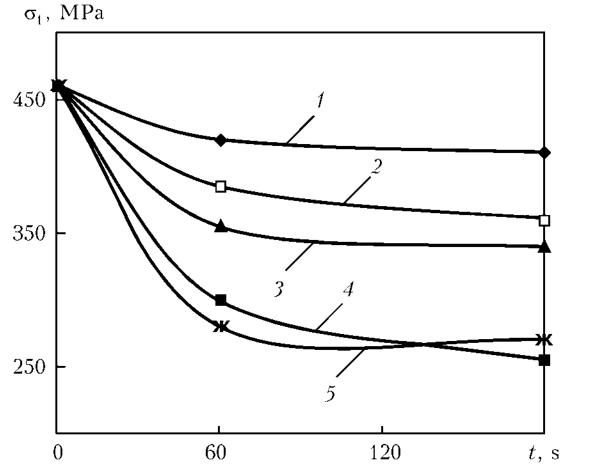

Figure 3. Tensile strength versus heating temperature and holding at this temperature: *1* — 250; *2* — 300; *3* — 350; *4* — 400; *5* — 450 °C

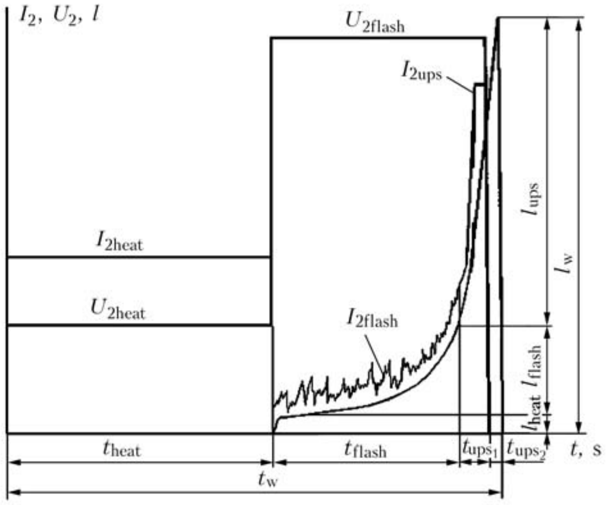

Figure 4. Cyclogram of the flash butt welding process with preheating: I_{2heat}, I_{2flash}, I_{2usp} — current in welding circuit for heating, flashing and upsetting; U_{2heat}, U_{2flash} — voltage in welding circuit for heating and flashing; l_w, l_{heat}, l_{flash}, l_{ups} — welding, heating, flashing and upsetting allowances; t_w, t_{heat}, t_{flash}, t_{ups} — welding, heating, flashing and upsetting times

It can be seen from the Figure that the optimal conditions for deformation can be created at a temperature of about 400 °C. These data allow a conclusion that to produce sound welded joints it is necessary to provide heating of the near-contact zone in the intensive deformation region to a temperature above 400 °C.

The effect of the heating temperature and time of dwelling at this temperature on mechanical properties

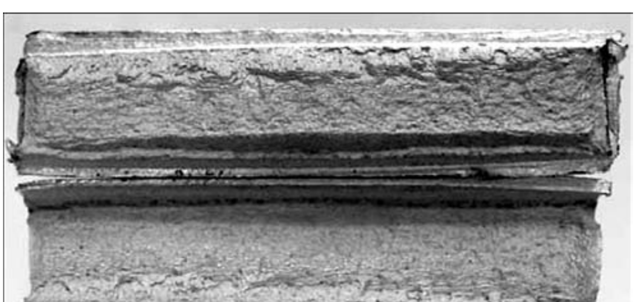

Figure 5. Appearance of fractures in welded samples with notch along the joining line

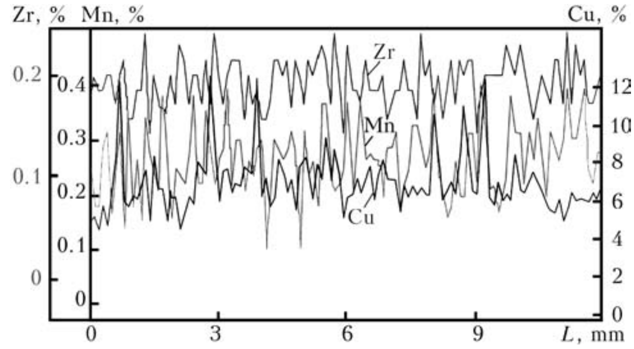

Figure 6. Distribution of alloying elements in welded joint (base metal HAZ–joint–base metal HAZ)

of the alloy was investigated to identify the optimal thermal cycle of flash butt welding.

The base metal samples were resistance heated in a laboratory welding machine to a preset temperature and held for a certain time. After heating, holding at the preset temperature and air cooling, the samples were subjected to tensile tests (Figure 3).

Analysis of the test results shows that mechanical properties of the samples greatly depend upon the heating temperature and time of holding at this temperature. Even a relatively short holding for 20–30 s at a temperature of 400–450 °C leads to a 15–25 % decrease in strength values.

This high sensitivity of the alloy to heating requires that the welding parameters be as rigid as possible, ensuring a minimal heating time. Such parameters provide the sound welded joints (almost without weakening) only on small thicknesses (up to 12 mm). Welding of larger thicknesses at the above parameters fails to ensure the required heating, this leading not only to formation of defects in the welded joints and HAZ metal (e.g. the required deformation in upsetting is not achieved, and probability of formation of oxide films grows), but also to a 20–30 % decrease in the strength values. The above defects can be avoided by increasing the heating time in welding, this causing an increased weakening of the weld and HAZ metals.

In such cases it is necessary to use postweld heat treatment to improve strength of the welded joints.

Welding was performed by using the laboratory flash butt welding machine with a modified secondary

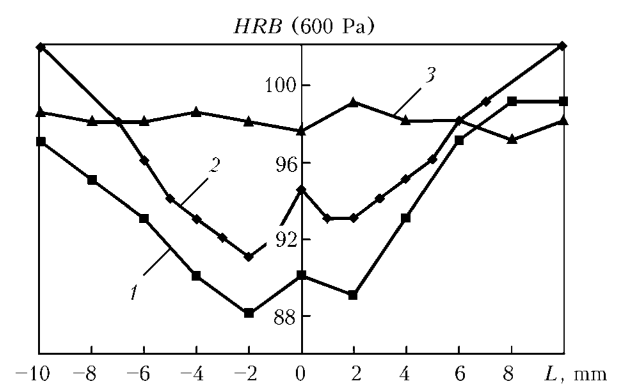

Figure 7. Distribution of hardness in welded joint after welding (*1*), ageing (*2*) and heat treatment (*3*)

Results of mechanical tensile tests of base metal and welded joints before and after heat treatment

Specimens	Mechanical properties			
	$\sigma_{0.2}$, MPa	σ_t, MPa	δ, %	ψ, %
Base metal	339	430.5	11.2	21
Welded joint	$\frac{200-214}{208}$	$\frac{347.4-350.8}{350.0}$	$\frac{4.7-5.8}{5.2}$	$\frac{13-17}{14}$
Welded joint after heat treatment	$\frac{266-297}{278}$	$\frac{380-422}{402}$	$\frac{4.7-8.4}{6.4}$	$\frac{5.2-15.6}{8.6}$

circuit at a power of 75 kV·A under the following conditions: flashing voltage U_{2flash} = 6.5–8.0 V, initial flashing speed — 2 mm/s, final flashing speed — 16 mm/s, welding time t_w — up to 60 s, including flashing time t_{flash} — up to 15 s. Total welding allowance l_w is 60 mm. The process cyclogram is shown in Figure 4.

After welding, part of the samples was heat treated under the following conditions: hardening (heating to 535 °C, holding at this temperature for 2 h, water cooling) and subsequent artificial ageing (heating to 180 °C, holding at this temperature for 24 h).

Fractures of the welded samples with a notch along the joining line exhibit no defects (Figure 5).

Mechanical tensile tests of the base metal and welded joints before and after heat treatment were conducted on flat specimens. Results of the tests are given in the Table.

No substantial redistribution of main alloying elements along the joining line and in the HAZ metal is seen in flash butt welding of alloy 2219. In the majority of the welded joint the content of alloying elements is almost identical to that in the base metal (Figure 6).

As shown by the Rockwell hardness measurements, the length of HAZ is 20–25 mm. A considerable decrease in hardness is detected in the joining zone after welding (Figure 7, curve *1*), which is an indirect indication of weakening of this zone. Artificial ageing allowed increasing hardness of the weld and HAZ metals, although leaving the anneal regions located symmetrically about the joining line (Figure 7, curve *2*). Postweld heat treatment performed under the above conditions provides the distribution of hardness in the HAZ metal close to that in the base metal (Figure 7, curve *3*).

Metallographic examinations show that the welded joints are fully free from such defects as oxide films, delaminations, etc. (Figure 8, *a*). Microstructure of the base metal contains different-size oriented grains of solid solution of copper in aluminium. Structure of the alloy also contains intermediate phases formed during the heat treatment process (Figure 8, *b*).

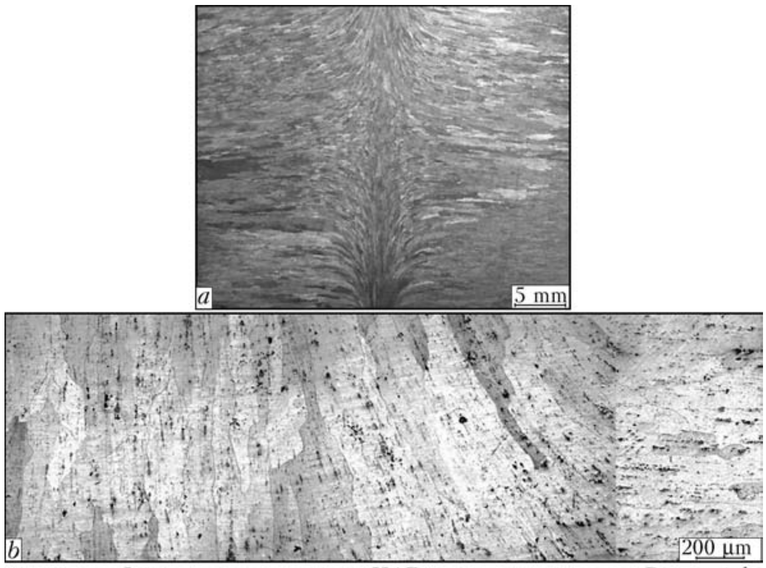

Figure 8. Macrostructure (*a*) and microstructure (*b*) of welded joint after heat treatment

Orientation of grains in the weld metal and adjoining HAZ regions gradually changes by 90° relative to the initial orientation of grains of the base metal, and coincides with orientation of deformation of metal in upsetting. Intermetallic phases are also oriented to a direction of metal flow in upsetting.

CONCLUSIONS

1. The flash butt welded joints on alloy 2219 are free from defects of the type of oxide films, delaminations, etc.

2. The minimal temperature of the deformation zone in alloy 2219 should be about 400 °C. Short-time heating to this temperature within 20–30 s leads to a 15–25 % decrease in strength characteristics.

3. Decrease in hardness accompanied by a 15–20 % weakening takes place in the HAZ metal of the welded joints.

4. Ageing provides increase in hardness of the weld and HAZ metals, leaving the weakening regions.

5. Postweld heat treatment (hardening and subsequent artificial ageing) provides the distribution of hardness close to that in the base metal, as well as strength at a level of 93–95 %.

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