EFFECT OF PRELIMINARY DEFORMING AND ELECTRODYNAMIC TREATMENT ON STRESSED STATE OF CIRCUMFERENTIAL WELDED JOINTS OF AMg6 ALLOY

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At the present time the methods of control of welded and technological stresses based on preliminary deforming of elements being welded and also electrodynamic treatment (EDT) of welds using pulsed current become ever more developed. The aim of the work is the investigation of influence of preliminary unclamping of edges being welded and EDT on control of stressed state of circumferential welded joints specimens of aluminium alloy AMg6, made using automatic welding in argon. Control of stressed state of specimens was performed using method of electron speckle-interferometry with use of a specialized rigging. The preliminary unclamping of edges was performed using original device for force loading. The values of preliminary tensile stresses reached the yield strength of AMg6 alloy. The EDT was conducted at the surface of deposited metal in the direction «from middle to edges» at a charged voltage of capacitive storage up to 450 V. As a result of carried out investigations it was established that preliminary unclamping and EDT allow significant decreasing of level of residual stresses in circumferential welded joints. 10 Ref., 6 Figures.

Keywords: *electrodynamic treatment, preliminary unclamping of edges being welded, aluminium alloy, tensile stresses, compressive stresses, circumferential welded joint, automatic welding, capacitive storage, current discharge, plane inductor*

Welded structures of aluminium alloys find ever wider application in different branches of modern industry. One of the factors negatively influencing the service efficiency of welded joints is residual stresses, high level of which decreases the service life of structures at fatigue and dynamic loads, characteristic of products of transport machine-, air- and ship-building. Therefore the problem of control of welding residual stresses is challenging in welding of circumferential butt joints of light alloys.

The existing methods for control of stresses of large elements of structures, for example, preliminary deforming of parts assembled for welding, have the certain limitations, connected with the presence of a specialized fixture and not always can be realized under the conditions of unit-by-unit or module-block assembly-welding of a product [1].

At the present time the methods for control of welding and technological stresses based on treatment of metallic materials and structures using pulsed electromagnetic fields of different duration and configuration find the ever more spreading [2–6].

It is shown in work [7] that interaction of mechanical and electromagnetic pulses influences the movement of dislocation clusters in crystalline materials which causes change in their stressed state.

One of the methods of realization of mutual interaction of pulse electric field of a plane inductor and dynamic loading on welded joint is electrodynamic treatment (EDT) [8]. The EDT equipment, characterized by compactness and mobility, allows using this type of treatment to control the stressed state of welded joints in erection or repair large-size thin-wall products. The application of EDT showed its efficiency in repair welding of ship-hull structures of AMg6 alloy and allowed prolonging their service life [9].

The aim of this work is the investigations of efficiency of control of residual stresses in circumferential butt joints of aluminium AMg6 alloy at their preliminary deforming and EDT.

As the object for investigations, the authors used specimens of circumferential butt-welded joints of AMg6 alloy. Before welding the specimens were subjected to heat treatment to eliminate technological stresses in them caused by mechanical treatment.

The specimens of circumferential joint, butt-welded, (Figure 1, *a*) were assembled of two cylindrical billets of AMg6 alloy of 100 mm diameter, 150 mm height and wall thickness of

3 mm. To provide preset assembly gaps, complete penetration and formation of reverse bead the specialized assembly device was applied, the appearance of which is presented in Figure 1, *b*. The principle of operation of the device is based on transformation of forward movement of screw pair into radial force of distance levers of unclamping hinge system, where at the places of coupling the cut out backing rings with forming groove were mounted. The value of unclamping force of backing rings was controlled by loading nut which provided the guaranteed mutual alignment of cylindrical billets, backing rings and optimal orientation of assembly gap, relative to the welding head.

In the zone of edges being welded of circumferential butts two levels of values of initial stressed state σ_0 were preset using their radial unclamping. The level of component of initial stressed state in the circular direction at the distance of 10 mm from the butt was controlled by mechanical deformation meter.

In the specimens of the first type the values of initial stresses did not exceed 10–15 MPa, which allowed providing both necessary accuracy of assembly of circumferential butt for welding as well as distribution of residual stresses characteristic of full-scale structures welded without application of force devices.

In the specimens of the second type the initial stresses reached the value $\sigma_{0.2}$ for AMg6 alloy which provided formation of plastic tensile deformations in welding and, as a consequence, fields of compressive stresses in a weld.

The welding of circumferential butts using non-consumable electrode was performed in the installation «MAGIC WAVE-3000» (Figure 2) at the «backward welding» position of torch with 60° angle to horizontal. At the smaller values of angle the instable arc burning takes place accompanied by periodic splashes of metal from the weld pool. The angle between the longitudinal axes of non-consumable electrode and bunch with filler wire amounted to 90°. The process was performed at the linear speed of 5.4 mm/s, welding current of 165 A and arc voltage of 18 V.

The initial stressed state of specimens of circumferential welded joints was measured using contact-free method of electron speckle-interferometry. The method was used, which is based on measurement of deformations at elastic unloading of metal volume in the investigated spots at the surface of specimen caused by drilling of blind holes of 1.0 mm diameter [10]. The optical scheme of interferometer was applied in the places where investigated area of the specimen

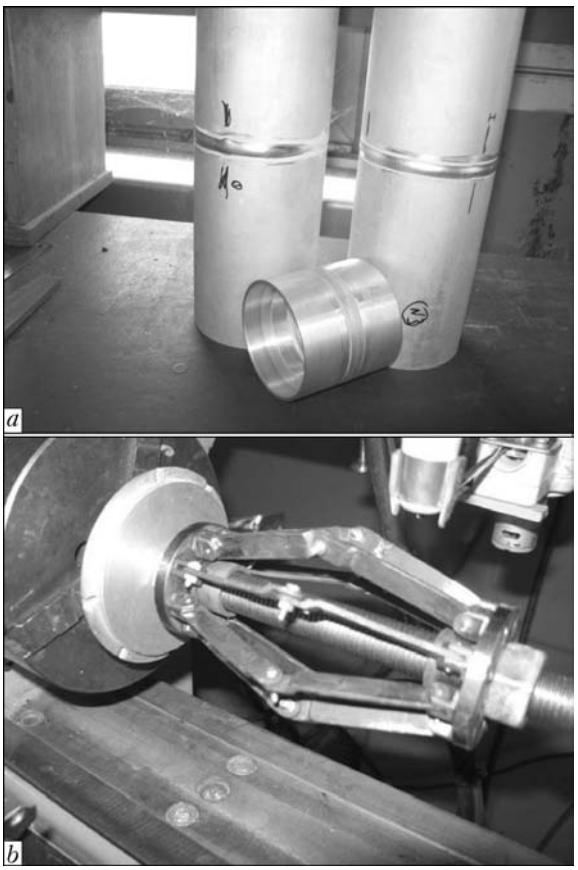

Figure 1. Appearance of specimens of AMg6 alloy circumferential butts (*a*) and assembly device for their welding (*b*) (*on the right* — loading nut)

was illuminated by the laser beam at the same angle from the both directions and, thus, plane components of movement vector were determined, characterizing deformation of specimen in the plane. The angle between the normal to the spot of investigated surface and illumination direction was 57°. The choice of this method was predetermined by need in preserving integrity of specimen after registration of its initial stressed state. The specimens with known level of initial stresses were subjected to pulse treatment and then the resulting values of stresses were repeat-

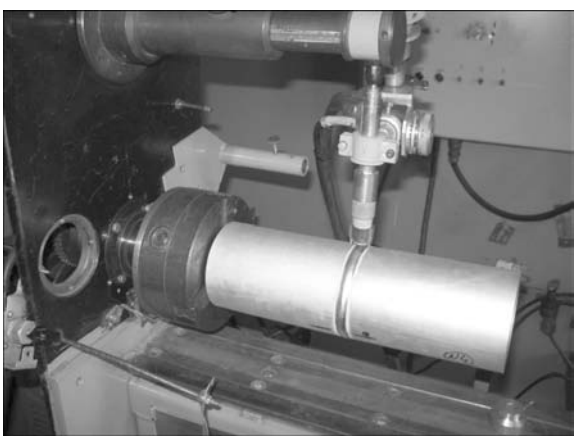

Figure 2. Argonarc welding of specimens of AMg6 alloy circumferential butts

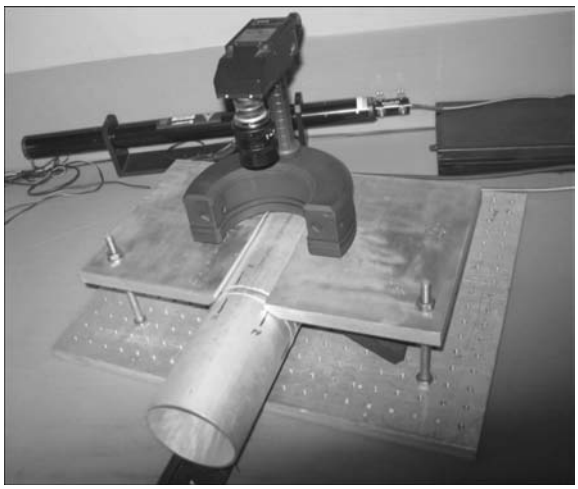

Figure 3. Device and specialized fixture for measurement of residual stresses of welded circumferential joints of AMg6 alloy using method of speckle-interferometry

edly measured. Having combined the parameters of stressed state before and after the pulsed treatment on the specified specimen of welded joint it is possible to judge about efficiency of EDT process. To determine changes of level of stressed state of welded joints using speckle-method the small interferometer was used which was installed directly at the surface of investigated specimen (Figure 3). The device is composed of such basic components as speckle-interferometer, CCD-camera, light-guide, basement with three cone supports. For quality mounting of device on the cylindrical surface of circumferential weld a specialized fixture was designed. The parameters of stressed state of specimens of circumferential welds were recorded only at the external surface of joints.

Measurement of stresses using speckle-interferometry method was performed after mounting of interferometer on the surface of the specimen. The reflected light wave characterizing the initial stressed state of metal was entered to the memory of computer. Later in the specified spot of the surface of welded joint the blind hole of diameter and depth of 1.0 mm was drilled. After elastic unloading of stresses caused by drilling, the reflected light wave was also entered to the memory of computer. After computer processing of light waves received before and after the local elastic unloading of residual stresses, in the vicinity of a hole the fringe pattern was obtained by visualization means containing the information about parameters of stressed state in the controlled spot at the surface of specimen. During treatment of metal of welded joint using current pulses the stressed state is changed in it, the parameters of which are determined in the following measurement cycle. The cycle includes record of parameters of reflected light wave before and after the drilling, obtaining of fringe pattern containing the characteristics of stressed state. Difference in values of stresses obtained in the first and second measurement cycles is the value of efficiency of EDT process as-applied to the welded joints.

Distribution of stressed state was studied on the external surface of circumferential joints by change of values of two its components — along σ_x and perpendicularly to σ_y of a weld line.

To treat the specimens using current pulses the installation was used, the basic element of which is a capacitive storage, and working device was a plane inductor coupled with a disc of non-ferromagnetic material and cylindrical electrode, the spherical edge of which is the zone of energy generation at the contact with treated surface of welded joint at the moment of discharge. The disc is intended for realization of dynamic component of electrodynamic effect on the metal. The principles of operation of the installation are given in the work [8], based on the transition electrodynamic processes which run in the metal of specimen at the discharge of the capacitive storage.

For EDT of specimens the assembly device was used (Figure 4) designed for positioning of inductor relatively to the specimen being treated and also for fixed contact of electrode edge with the surface of metal at the pressing force of up to 60 kg.

The device (Figure 4, *a*) is composed of a support beam *2* with a cradle of electrical copper of grade M1 which is the element of discharge circuit. The cradle, located on the face side of beam and coupled with a contact wire of capacitive storage, is designed for guaranteed clamping of specimen *1* at the moment of current discharge. To fix the plane inductor *6*, a pressing beam *5* was used, the positioning of which relatively to the specimen was performed by guiding pins and vertical clamping force was created by loading nuts *4*. The magnified fragments of positioning zone of electrode on the treated surface in EDT of circumferential joints are presented in Figure 4, *b*, where arrangement of plane inductance coil *7* is shown relatively to the disc of non-ferromagnetic material *8* and electrode *9*. The force control of vertical loading of nuts *3* was performed using dynamometric key. It was established that the optimal pressing force providing the guaranteed contact of electrode edge in the absence of damage of the surface being treated, is the loading value close to 40 kg.

The EDT of butt welds of circumferential joints was performed at charge voltage of 450 V

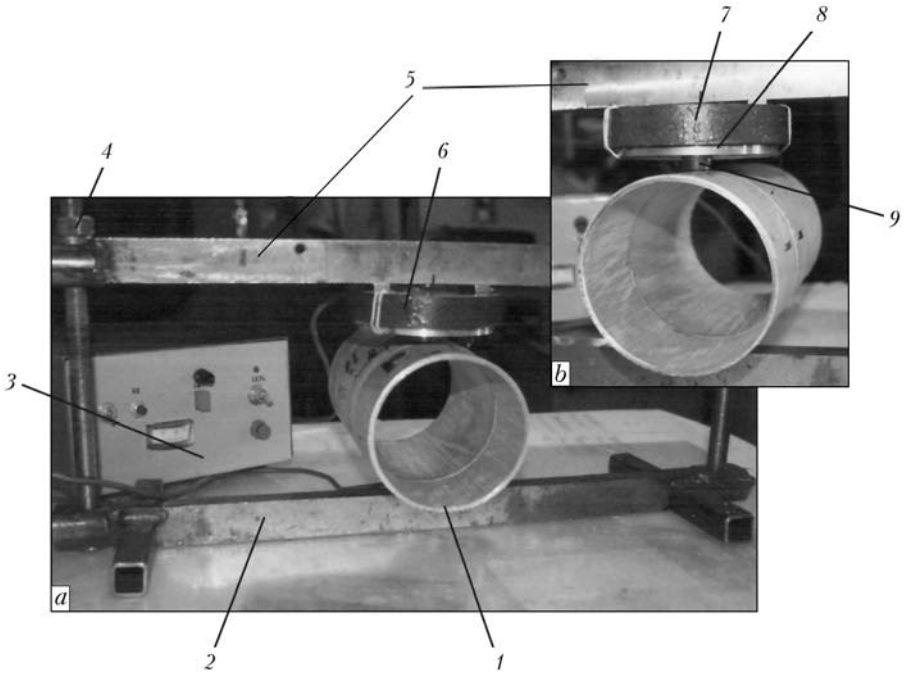

Figure 4. Assembly device for EDT of welded circumferential joints of AMg6 alloy (*a*) and inductor positioning (*b*): *1* — specimen; *2* — support beam; *3* — EDT power source; *4* — guiding pin with loading nut; *5* — pressing beam; *6* — inductor; *7* — inductance coil; *8* — disc; *9* — electrode

and in the storage capacity of 6600 μF. The treatment was performed along the weld centre in the direction «from the middle to the edges» at a pitch of 10 mm in such a way that the first two zones of pulse effects were arranged on both opposite sides of a circumferential weld and the next two ones — within 90° as applied to the previous ones. Each area of the surface near the fusion line was exposed up to five electrodynamic effects.

At the circumferential welded butts, made without elastic-plastic unclamping of edges, the residual stressed state was recorded which is characterized by maximum values of longitudinal σ_x = 175 MPa and transverse component σ_y = = 125 MPa (Figure 5, *a*). Here, if the tensile stresses σ_x are monotonously decreased almost to zero values in near-weld zone, then for σ_y stresses the non-monotonous distribution of values in weld area varied from 0 to 50 MPa is characteristic.

In the specimens welded applying the preliminary unclamping of edges, the stressed state is characterized by transformation of longitudinal component of tensile stresses σ_x to the compression area up to the values of 125 MPa at some lowering of tensile stresses σ_y down to 75 MPa (Figure 5, *b*). Thus, the preliminary force effect on the circumferential joint edges being welded results in increase of their diameter, positively influencing the distribution of σ_x at practically negligible influence on σ_y. It can be explained by the similarity of mechanisms of preliminary unclamping of circumferential elements and tension of plane plates and panels [1].

In the specimens welded without unclamping of edges with the further EDT the longitudinal component σ_x also changed not only the value, but also the character and, as a result, its values amounted down to –100MPa, whereas values σ_y decreased to 100 MPa (Figure 6) which is comparable with the variant of welding under the conditions of edges unclamping (see Figure 5, *b*).

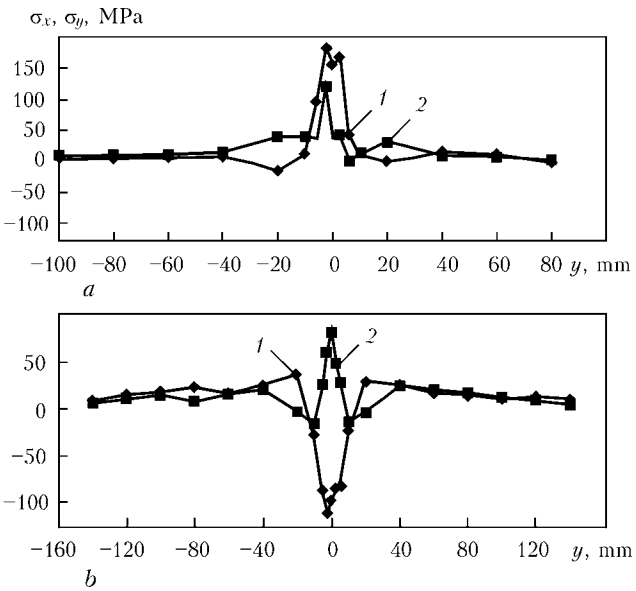

Figure 5. Residual stressed state in AMg6 alloy circumferential welded joint of longitudinal (*1*) and transverse (*2*) component of stresses without elastic-plastic unclamping (*a*) and after welding with preliminary unclamping of edges (*b*)

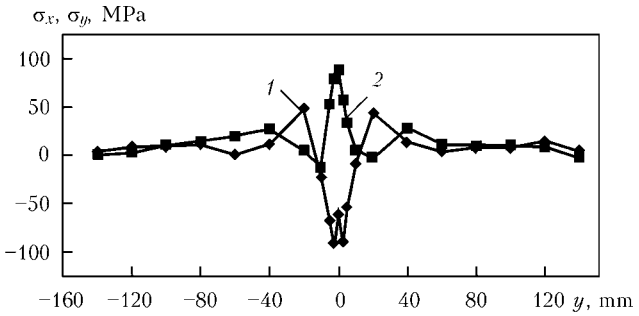

Figure 6. Stressed state in the specimen of circumferential joint after EDT of longitudinal (*1*) and transverse (*2*) stress component

It should be noted that the peculiar feature of unclamping method is the fact that it is the complex of technological effects on the joint, made both before welding as well as in the process of its performance. To realize the method, it is necessary to provide an access for fixture of unclamping device inside the edges being welded, performance of unclamping and removal of device.

The EDT is applied after producing a welded joint and for its realization the access to inner hollows of welded circumferential joint is not required. The labor consumption of EDT of circumferential joints is compatible with those, consumed in use of device for unclamping.

Thus, comparing the distribution of σ_x and σ_y for both variants of producing specimens of circumferential joints, shown in Figure 5, b and 6, one can conclude that EDT can be applied under the conditions when the method of preliminary unclamping of edges can not be realized.

Conclusions

1. The experimental method for evaluation of effect of preliminary unclamping of edges and electrodynamic treatment on change of residual stressed state of circumferential welded joints was developed.

2. It was established that in preliminary unclamping of welded edges of AMg6 alloy circumferential joints, when circumferential stresses reach the yield strength, transition of tensile stresses occurs at the external surface of circumferential weld of up to 175 MPa into compressive ones, the values of which reached 125 MPa.

3. It was shown that in electrodynamic treatment the decrease of longitudinal component of stresses reaches more than by 100 %.

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