EFFECT OF ELECTRIC PULSE TREATMENT ON RESIDUAL CHANGE IN SHAPE OF THIN-SHEET WELDED STRUCTURES (Review)

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It is shown that treatment of thin-sheet welded joints by electric current pulses is an efficient method for regulation of residual deformations of welded structures. With electric pulse treatment of butt welded joints on steel 30KhGSA and aluminium alloy AMg6, the values of sags of plates are decreased from 3 to 9 times. An advantage of this treatment consists in mobility of the equipment used, thus allowing its application for straightening of separate elements of large-sized thin-sheet welded structures, including those in service.

Keywords: *arc welding, high-strength steel, aluminium alloy, welded structures, butt joints, straightening of welded joints, residual change in shape, sagging, preliminary tension, forming, pressing, electroplastic effect, current pulse treatment, plastic deformation*

One of the urgent problems of welding manufacturing is need in regulation of residual change in shape of welded structures. In manufacture of new types of structures the advanced consumables and welding technologies are applied, for which the conventional methods of providing preset accuracy of manufacture are not always suitable.

The purpose of the present work is generalization of modern conceptions about the ways of control of change in shape of metallic products under the influence of electric current pulses. The possibility of use of such effect for straightening of thin-sheet metallic structures is offered and experimentally checked.

The conventional ways of control of residual change in shape of structures can be divided into thermal and mechanical ones depending on the character of effect on the structure in the process of its welding or postweld treatment.

Nowadays the application of thermal methods of treatment considering the expenses for energy carriers increases greatly the cost of manufacture of metallic structures, especially of large-size bridge [1] and ship hull [2] ones, as well as products of light alloys with high heat conductivity. At the same time the automation of process [3] in combination with modern calculation methods, optimizing heat effect on the structure, allows successful use of this method of treatment in modern production. The mathematic models of heat straightening have been developed for such types of structures as thin-wall shells, shafts [4], ship-building panels [5–7], allowing minimizing the heating of product at maximum efficiency of straightening operation.

In heat treatment by tempering in clamping fixtures [1], based on heating of workpiece together with assembly outfit, the high heat energy is consumed for heating of massive assembly devices, applied for fixation of a workpiece. Taking into account that efficiency of tempering is proportional to specific amount of heat per 1 t of a mass of structure (considering the outfit), the application of different heating schemes for treatment of large-size welded structures becomes not profitable. The compromise solution is local tempering of separate assemblies of welded structure, however it is limited in application and not efficient for the products of metals with high heat conductivity.

The force methods of straightening are based on applying the mechanical loads to the structure at different stages of its manufacture compensating its residual change in shape caused by welding.

The reverse bending is an efficient method of compensation of welding deformations in the products with a relatively small bending rigidity, for example, in welding-in of flanges into thin-sheet shell structures [8]. It complicates the welding technology, but in a number of cases it is the more rational solution than postweld treatment. Here, the application of the above-mentioned method is not rational due to high cost of assembly fixture.

Welding with a preliminary tension is one of methods of reducing the welding deformations of thin-sheet structures, which is used in manufacture of large-size panels of light alloys [9, 10]. Its drawback is high cost of a special equipment for tension of elements being welded.

The main drawbacks of the above described methods of straightening is the high level of power and metal consumption. In this connection the need is appeared in search for the new approaches to the assurance of a preset accuracy of manufacture of welded structures.

The promising approach, characterized by the simplicity of application, low power consumption and not requiring the metal-intensive equipment is the pulsed method of treatment realizing the shock-wave effects applied to metal structures in the process of their manufacture.

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Thus, the traditional method of peening of welded joints found its development as far back as the 1980s by application of ultrasonic impact tool [11, 12], possessing large capabilities of control.

Fundamental and applied investigations, carried out since the 1960s [13], allowed stating the abrupt increase in ductility and decrease in metal resistance to deformation due to simultaneous effect of mechanical stresses and electric current of high density. This phenomenon was called electroplasticity [14]. Its practical application has opened the new possibilities for deforming metals and alloys, including refractory metals, and also for improving their properties after mechanical shaping.

This regularity of current effect is differed from the known heat effect, being a basis of an electric contact heating, by the fact that it is manifested only in the metal being deformed, i.e. in specimens under the effect of elastic mechanical stresses [15, 16] or under load of higher than yield strength [17]. In this case, at the moment of current pulse effect the material is characterized by a non-stationary stress-strain state influencing the change in geometric characteristics of part being treated [18].

The common feature of all these methods of pulsed treatment of metals is the supply of high-density currents directly into the zone of metal deforming and localizing the area of current effect. These types of treatment based on electroplastic effect (EPE) are differed from electric contact heating used in drawing and rolling. In advanced technologies of shaping the structural materials the processes of intensification of deforming the semi-products are used by using the non-thermal effect of pulsed current, namely the realization of EPE. Here, the expenses are decreased for heating in operations of forging, stamping and drawing and also the heating of technological fixture is eliminated.

Basing on EPE the technologies of producing super-conducting wires, strips and stamped parts of brittle materials (cast iron, beryllium, rhenium) with a minimum level of technological residual stresses by applying high-density currents in the zones of drawing, rolling, stamping and after pressure treatment of parts are realized [19]. The mentioned methods of shaping the metallic materials have a number of common regularities which should be taken into account in use of electric pulse treatment for straightening of deformations caused by welding.

The results of investigations on electric plastic drawing of structural steels [19] showed that the current effect allows increasing the rate of deformation in drawing. The electric pulse effect on deforming steel 08G2S leads to the increase of homogeneity of fragmented structure of metal, and plastic deforming of metal is manifested at earlier stages of loading at concurrent increase of a volume fraction of a plastic component. This is confirmed by data obtained in electric dynamic treatment under the conditions of an uniaxial tension of specimens of carbon steel and its welded joints [20]. In this case the intensive plastic yielding of metal, which is expressed by the formation of Chernov–Luders bands, began in the elastic region of deformation of specimens.

Results of investigations [19, 21] showed that EPE can be applied for intensification of the process of metal forming in manufacture of parts of vehicles. The current effect makes it also possible to prevent the fatigue cracks and to extend the service life of parts operating at cyclic loading.

The thermal intensification and also the electric contact heating, used in technological operations of forming thin-walled parts of a load-carrying structure and lining of vehicles, have a number of disadvantages, such as high power consumption, high temperature of forming leading to the growth of a grain and deterioration of service characteristics of produced parts, need in post operation heat treatment. These drawbacks are eliminated by using the electric pulse effects during forming. Single- and multi-pulse effect was used at different stages of forming of vehicle parts. Here, the definite level of specific electric power supplied to the semi-product, number of current pulses, degree of preliminary deformation of semi-product and rate of cooling after forming finishing were preset.

It was found that at optimum electric pulse effect the ultimate strength of product material, the fatigue limit and service life are increased without decrease in ductile properties of the material. The electric pulse effect allows in many cases increasing in service life of vehicles by increasing their corrosion resistance. It was determined that the time before the corrosion cracking of specimens of aluminium alloy D16 is 3 times increased, and the rate of corrosion of aluminium alloy AMg3M is reduced by one order. It was found that the electric pulse effect influences the anisotropy of mechanical properties of semi-products for vehicle parts which is taken into account in designing of products of aeronautical engineering.

To study the influence of electric pulse effects on ductile properties of semi-products used for forming of vehicle parts, the specimens were subjected to tensile tests at different degree of relative deformation [22]. It was determined that multiple electric pulse effect in the process of forming leads to 3.5–4 times increase in ductility of alloys at the expense of combined effect of EPE and heat effect. Here, the single effect by current pulses after deformation (instead of post operational heat treatment) contributes to a complete recovery of ductility margin that cannot be attained using traditional furnace heat treatment. The single electric pulse effect before the deformation beginning leads to increase of elongation up to 45 %.

The evaluation of technological capabilities of electric pulse effect in change of shape was made in rolling-out and rolling-up, flanging, sheet bending for small radii and also in operations of cut-off and bending of profiles, specific for aircraft manufacture, using tension, longitudinal and transverse stretch-wrap forming of a sheet. It was found on the basis of results obtained [22] that the electroplastic effect can be used for intensification of processes of sheet forming of metals and alloys. At different stages of forming it is rational to use the single- and multi-pulse effect at which the definite level of electric power, supplied to the semi-product, and number of current pulses, as well as degree of preliminary semi-product deformation is preset. At optimum electric pulse effect the static strength of product material and fatigue strength without deterioration of its ductile properties are increased in the process of forming, while the level of residual technological stresses of the product is decreased. Specific features of an electric pulse effect were tested on steels of grades 12Kh18N10T, 30KhGSA, titanium alloys VT8, OT4, VT20 and aluminium alloys D16, 1420, V95T, AMg6.

Basing on the analysis of studied processes of shaping the structural steels, the presence of common regularities in them such as change in parameters of technological stresses or plastic deformations due to EPE stimulation under the current pulses effect can be noted. Here, the deforming forces at concurrent increase of ductility of the material treated are decreased.

Coming from works [13–23] on plastic shaping and regulation of stressed state of metals under conditions of current effects, it can be concluded that the technology of shaping on the basis of treatment by current pulses can be realized for straightening of welded structures.

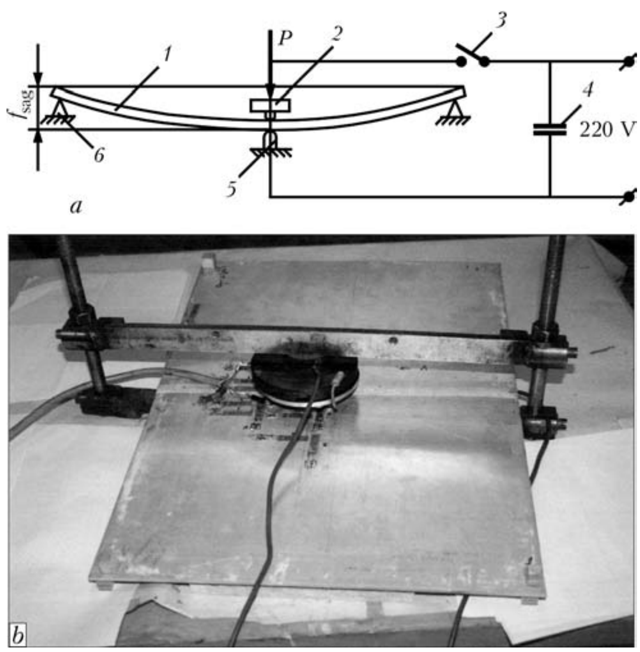

Figure 1. Electric pulse treatment of specimens of welded joints: *a* — scheme of current supply and three-point bending of plates (*1* — specimen; *2* — electrode; *3* — electric switch; *4* — bank of capacitors; *5* — current connector; *6* — support); *b* — specimen of butt joint of alloy AMg6 fixed in a loading device

In treatment of the welded joint by current pulses the elastic component of residual deformation of shaping is transformed into plastic component that has a positive effect on geometric characteristics of metal structures.

The electric pulse treatment can increase the efficiency of such methods of preliminary force effect as the rigid fixing [1] or preliminary elastic tension [9, 10] of elements being welded. At force schemes realized in listed methods of treatment the external loads are applied to the welded structure, at which the treatment of welded joints by current pulses gives the maximum effect. This is due to the EPE realization by transformation of elastic deformations in structure elements into plastic ones in their treatment in fixture. Here, the assembly force contours used for realization of these methods provide geometric characteristics of product, fixed in them, at a sufficient accuracy.

To treat the specimens of welded joints by current pulses, a laboratory equipment was designed and manufactured, where the main element was a bank of capacitors, completed with a charge and discharge devices and also a recording equipment.

List and purpose of devices included into the laboratory equipment, as well as a principle of its operation are described in detail in [23].

The investigations of effect of current pulses on the regulation of residual change in shape of welded joints were carried out on specimens of butt joints of steel 30KhGSA and aluminium alloy AMg6. External loading was realized by the scheme of a three-point bending of plates along the weld line (Figure 1). Sagging of plates f_{sag} was preset to provide the level of preliminary stresses in specimens in the zone of treatment within the 10–30 MPa range. The bending was performed in contact of electrode tip of a capacitor machine with a plate surface. After reaching the preset values of sagging the batteries discharged and then the parameters of treatment condition were recorded and discharge energy was determined. After completion of current pulse effect the changes in geometric characteristics of plates as a result of treatment were defined.

The measure of sagging was made along the longitudinal and transverse edges of welded plates of steel 30KhGSA of 200 × 200 size and 3.5 mm thickness, treated with current pulses. Before the treatment, the initial sags were measured, then a single effect of current pulse at energy E = 300 J was made and sagging was measured again. Figure 2, *a, b* shows the change in shape of welded plates after welding and electric pulse treatment. It is seen from the Figure that before the treatment the plate had longitudinal sags of a typical saddle with 4.3–6.5 mm sag at edges and 6.7 mm sag on the weld. After treatment the residual sags along the longitudinal edges 3–5 times decreased (to 1.2–1.3 mm) and on weld — 8–9 times decreased (to 1.1–1.4 mm). Here, the deviations from plane along one diagonal of the plate reached zero values, while along the second diagonal they 2–3 times de-

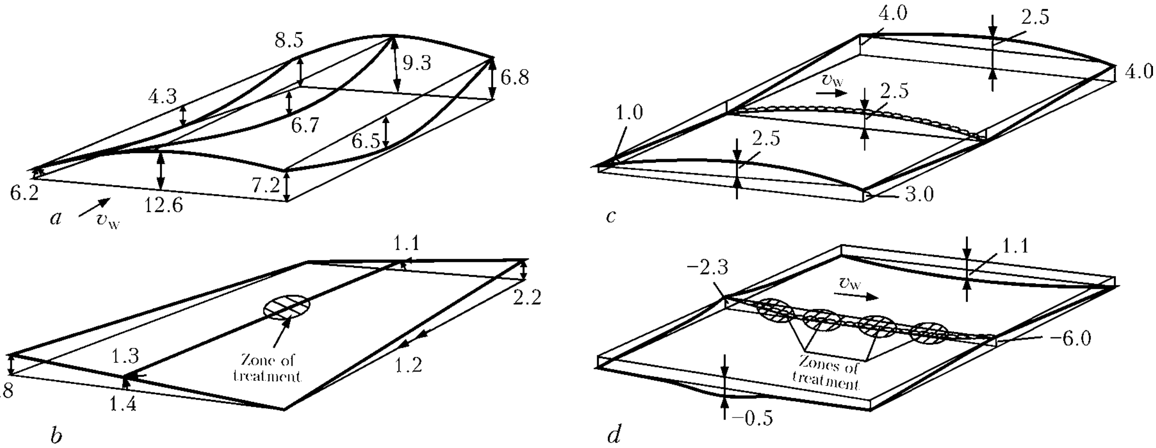

Figure 2. Residual changes in shape of butt joints of steel 30KhGSA (*a, b*) and aluminium alloy AMg6 (*c, d*) after welding (*a, c*) and electric pulse treatment (*b, d*)

creased (from 6.2–6.8 to 2.2–2.8). This proves that maximum effect of treatment due to EPE is attained at that weld area, where the values of residual welding stresses are maximum, that is confirmed by data of works [20] on electric stimulation of low-carbon steel.

To evaluate the efficiency of process of electric pulse treatment, the measurements were made of general sags of plate of alloy AMg6 of 400 × 350 mm size and 4 mm thickness with a butt weld, treated by a series of current pulses consisting of four electric discharges at $E = 300$ J in the direction from its middle to edges. It is seen from Figure 2, *c, d* that after current pulse effect the sign of sagging is changed for opposite one, and a sag is decreased by 4–5 times (from 2.5 to −0.5 mm). Here, the treatment by a series of current pulses is more effective than by a single electric discharge.

The advantage of electric pulse treatment consists in mobility of used equipment that makes this method suitable for straightening of separate elements of large-size thin-sheet welded structures including also those in service. To perform the electric pulse treatment there is no need in powerful units as the electric discharges of 0.005–1 s are used, and the used element base provides the following operation parameters: pulse current is $I_p \leq 10$ kA, voltage is $U_p \leq 3$ kV.

Thus, the analysis of advanced technologies of change in shape of metal structures under conditions of electric pulse effect gives premises for application of current pulse treatment for straightening thin-sheet welded structures.

After pulse current treatment of specimens of butt joints of steel 30KhGSA the longitudinal sags along weld decreased by 8–9 times, along the edge — by 3–5 times, the deviation from plane — by 2–3 times.

In treatment of specimens of butt joints of alloy AMg6 by a series of current pulses the values of longitudinal sags along the weld line 4–5 times decreased with a change of sign.

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