anode and comparison of obtained results with available experimental data performed in this study on the whole are an evidence of adequacy of the self-consistent model proposed in study [13] for processes of heat-, mass- and electric transfer in the anode region and column of welding arc in nonconsumable electrode welding and plasma welding in inert gas.


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# EFFICIENCY OF ELECTRODYNAMIC TREATMENT OF WELDED JOINTS OF AMg6 ALLOY OF DIFFERENT THICKNESS

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Influence of design features of fastening the samples of AMg6 alloy and its welded joints in the grips of testing machine on decrease in deformation resistance at electrodynamic treatment is shown. It is established that the effectiveness of electrodynamic effect is decreased with increase in thickness of metal being treated.

**Keywords:** *welded joints, aluminium alloy, electrodynamic treatment, initial stresses, current discharge, charge voltage, system of specimen fastening, efficiency of treatment, decrease of deformation resistance*

The methods of treatment of metallic materials by pulse electromagnetic fields are ever more widely used in control of stressed state of elements of welded structures [1, 2]. One of the methods of pulse effect by electric current on metals and alloys is electrodynamic treatment (EDT). The investigations of mechanisms of influence of EDT on stressed state of aluminium alloys [3], structural steels [4, 5] and also welded joints of these materials were conducted. The results presented in the works [1, 3–5] were obtained using developed experimental methods based on tension of flat specimens, their treatment by current discharges with in-process control of change in tension force which was taken as evaluation characteristics of EDT.

At the same time it is known [6] that conditions of fastening of specimens being investigated in the grips of testing machine have considerably greater influence on resistance of metallic materials to deformation at dynamic loads than at static ones. The same concerns the deformation processes initiated in the metals and alloys by passing of charges of electric current [7].

Thus, it is obvious that during evaluation of EDT process efficiency it is necessary to consider the design system of fastening the specimens being treated. Moreover, basing on the analysis of fractograms of fractures of AMg6 alloy it is assumed that the efficiency of electrodynamic effect is deceased with increase in thickness of metal being treated [8]. The quantitative evaluation of EDT efficiency depending on thickness of treated material allows distinguishing the range of values of power parameters of electrodynamic effect defining the applicability of this method of treatment in the engineering practice.

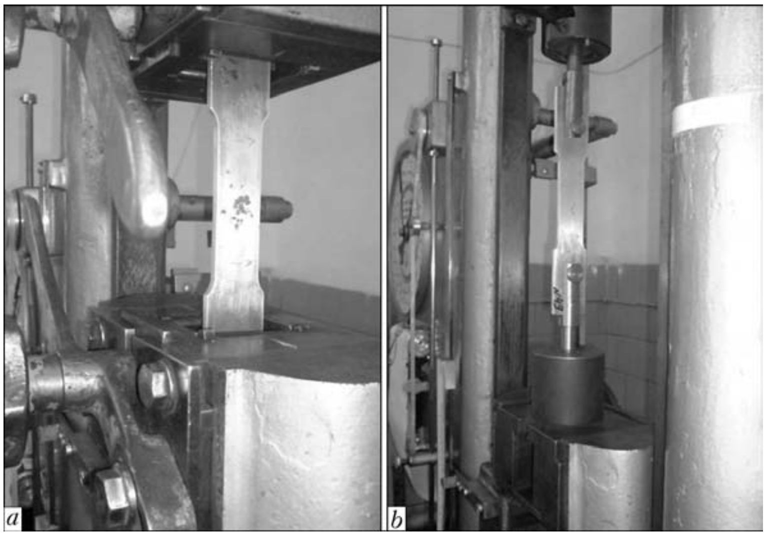


**Figure 1.** Appearance of assemblies of fastening of specimens in TsDM-10 machine using wedge-type grips (*a*) and pins connected with П-shaped cramps (*b*)

The aim of this work was the investigation of influence of thickness of specimens of welded joints of aluminium AMg6 alloy and also design features of their fastening in testing machine on the efficiency of electrodynamic effects.

To evaluate the EDT effect on decrease of level of initial stresses in the material, the tests were carried out after preliminary tension of flat specimens of AMg6 alloy of rectangular section with sizes of a test part and head of, respectively, 150 × 30 and 120 × × 40 mm and thickness from 2.5 to 10 mm. To generate the pulse current the installation was used described in the work [5], and EDT was performed by the contact of a copper electrode with the surface of metal on the test part of the specimen, as is shown in the work [3].

The tension of specimens was performed in the rupture machine TsDM-10 of class 2 with a maximal load at tension of 98,000 N, speed of deformation was 0.1 mm/s and temperature 293 K. The machine was completed with a mechanical drive of tension, a manual system of precise adjustment of load, a pendulum force meter and relates to the devices with a closed loading system. The choice of given type of machine excludes possibility of uncontrolled deformation and fracture of specimen at dynamic loading which in number of cases occurs while using loading devices with an automatic maintaining of deformation speed [7].

The EDT was conducted by series in 5–6 pulses at charge voltage $U$ = 500 V and capacity of capacitor battery $C$ = 6600 μF which corresponded to the energy of accumulated charge of 800 J. The treatment of specimens of base metal and butt welded joints of AMg6 alloy, preliminary loaded up to the values of initial stresses $\sigma_0$ from 50 to 140 MPa, was performed.

The investigations of influence of design peculiarities of fastening of specimens in the grips of machine for decrease of $\sigma_0$ values in EDT were carried out on the basis of comparison of two variants of design of assembly for fastening the heads of specimens (Figure 1). In the first variant the fastening was performed by wedge-type grips, the jaws of which were matched with the area of contact surface of heads of specimen (Figure 1, *a*). In the second variant the specimen was fastened by cylindrical pins joined by П-shape cramps of the machine traverse (Figure 1, *b*). The cross sections of working platform and heads of test specimens were in compliance with the requirements of GOST 1497–84.

The comparative evaluation was carried out in EDT of specimens of 5 mm thickness after tension to

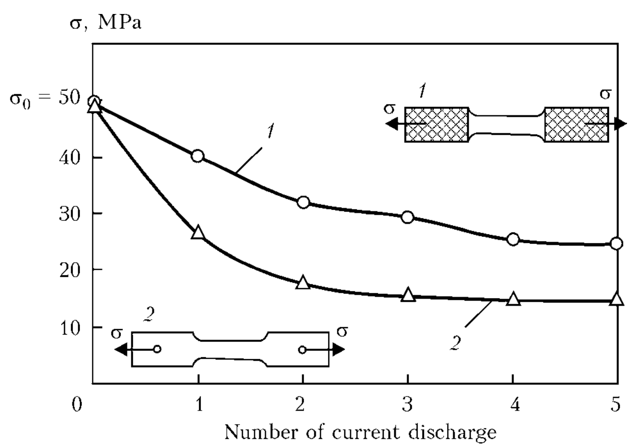


**Figure 2.** Influence of design features of fastening of specimens of AMg6 alloy on decrease of stresses σ in EDT: *1* — fastening using wedge-type grips; *2* — the same, but with П-shaped cramps

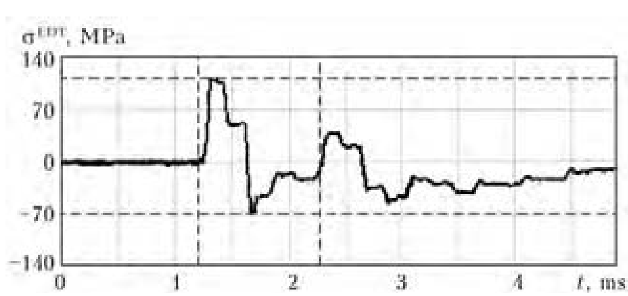


**Figure 3.** Wave of dynamic stresses $\sigma^{EDT}$ in the specimen of AMg6 alloy at single electrodynamic effect with charge energy of 800 J

the values of $\sigma_0$ = 50 MPa. The treatment of specimens was performed by the series of five current pulses. The changes in values of stresses in EDT for both variants of fastening of specimens are presented in Figure 2, where it is seen that fixation of specimen using pin (curve *2*) is characterized by more intensive decrease of values of stresses as compared to the fastening using the wedge-type grips (curve *1*). Here, the difference of values of stresses in curves *1* and *2* after five current pulses amounted to 40–50 % , which is connected with difference in design features of specimen fastening. In case of the specimen fastening using pin, at the moment of electrodynamic effect the conditions of interaction occur, defined as a contact of pin–hole pair [9] on the surface of their matching. The area of the contact corresponded to the print of a pin on the surface of a head hole, matched with it after single electrodynamic effect, and was equal to 5 mm$^2$. In case of fastening using wedge-type grips the interaction of specimen head with two jaws of a traverse grip occurs along the lines of matching of total length of 80 mm (width of specimen head is 40 mm), that determines the area of contact interaction of 200 mm$^2$.

To evaluate the dynamic load influencing the specimen in the fastening zone, the distribution of longitudinal waves of stresses initiated by electrodynamic effect caused by treatment was investigated. The flat specimen of rectangular section of AMg6 alloy was used after tension to the values of initial stresses corresponding to 50 MPa. On the front and reverse surface of test part of the specimen along the central longitudinal axis two tensors ($r$ = 200 Ohm) with 10 mm base were positioned. The sensors were positioned at the distance of 70 mm from the centre of specimen, the surface of which was treated by a single current discharge under the conditions corresponding to the charge voltage of 500 V. The record of values of sensors was carried out by two-channel digital oscillograph PCS Welleman at the scanning of 0.5 ms.

During calculation of dynamic stresses the dynamic modulus of elasticity $E_d$ for aluminium alloys was taken equal to static one of $E$ = 70,000 MPa [10]. The amplitude values of stress wave, averaged across the thickness of metal, are presented in Figure 3. It is seen from the Figure that the range of amplitude is 178 MPa, from which 108 MPa are valid for tensile stresses. Moreover, the residual plastic deformation in the zone of measuring by tensors was not recorded. This fact is proved by the works [3, 11] where it is pointed out that area of plastic deformation in EDT is localized in the area of energy release of electrodynamic effect.

Coming from the experimentally obtained maximal values of stress of load wave, presented in Figure 3, the approximate evaluation of stressed state of metal of specimens in the places of their fastening on traverses of testing machine was carried out. In accordance with the work [6] it is necessary to account for the correlation of conditional yield strength at dynamic loads $\sigma_{0.2}^{d}$, the value of which is determined by the relation [10]

$$\sigma_{0.2}^{d} = \chi\sigma_{0.2}^{st},$$

where $\sigma_{0.2}^{st}$ is the conditional yield strength in static tension, MPa; $\chi$ is the coefficient of dynamics.

According to the work [10] the $\chi$ value for aluminium alloys was taken equal to 2, and $\sigma_{0.2}^{st}$ of AMg6 alloy, obtained from the results of tests of metal in initial state, was 140 MPa. Considering $\chi$, the value of dynamic yield strength $\sigma_{0.2}^{d}$ was 280 MPa.

In case of fastening using wedge-type grips the values of dynamic tensile stresses are 81 MPa. In addition of dynamic stresses with initial stresses of specimen $\sigma_0$ = 50 MPa, their summed value does not exceed 131 MPa, which is considerably lower than $\sigma_{0.2}^{d}$.

In pin-type fastening the values of dynamic stresses are 324 MPa, that during addition with initial stresses is 374 MPa, which exceeds $\sigma_{0.2}^{d}$. According to the carried out evaluation using the pin-type system of fastening, in the area of a hole the local yielding is developing, leading to its deformation. It imposes certain restrictions to applicability of pin fastenings during development of experimental methods of investigation of influence of dynamic and pulse loads on stressed state of structural materials.

The investigations of influence of thickness of metal on efficiency of EDT during treatment of specimens of AMg6 alloy and its welded joints with thickness of test part of 30 mm were carried out. Here, the thickness of specimens of base metal was preset 2.5 and 10 mm and welded joints — 2.5, 4, 5 and 10 mm. The latter were produced by cutting from plates of 400 × 400 mm sizes TIG-welded with a filler in the installation ASTV-2M. The welding conditions of specimens of AMg6 alloy are given in the Table.

Conditions of automatic welding of plates of AMg6 alloy of different thickness used for EDT ($U_a$ = 18 V)

| Plate number | $\delta$, mm | $I$, A | $v_w$, mm/s |
|---|---|---|---|
| 1 | 2.5 | 170 | 5.55 |
| 2 | 4 | 200 | 3.33 |
| 3 | 5 | 250 | 3.33 |
| 4 | 10 | 480 | 2.50 |

It should be noted that section area in the region of weld reinforcement during increase of thickness of metal being welded can change, that is due to the technology of welding. This can have a negative influence on validity of results in comparison of values of efficiency of EDT of specimens of different thickness treated at equal power parameters of electrodynamic effects. To increase the accuracy of measuring results the reinforcement on the specimens was removed by machining to the value of thickness of base metal.

Before the treatment the specimens were subjected to static tension up to the value of initial stress $\sigma_0$ = = 140 MPa which corresponds to maximal value of a longitudinal component of residual welding stresses in AMg6 alloy.

The treatment of surface of central part of specimens was performed by a series of six pulses ($n$ = 6) at the parameters of electrodynamic effect corresponding to energy of accumulated charge of 800 J. After each pulse the decrease of level of initial stresses $\Delta\sigma$ was recorded. The evaluation characteristic of influence of thickness of treated metal on EDT efficiency was relative efficiency $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ %.

Dependence of influence of thickness of metal being treated on EDT efficiency is presented in Figure 4, *a*, from which it is seen that maximal values of $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % are achieved after the first pulse current in the whole range of thicknesses being examined ($n$ = = 1). During comparison of values of efficiency of EDT of base metal and welded joints for minimal thicknesses of 2.5 mm (Figure 4, *a*, curves *1′* and *1*) and maximal 10 mm (Figure 4, *a*, curves *4′* and *4*) it can be seen that $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % values for base metal are 10–12 % lower than those for the welded joints. It is connected with the presence of residual stresses in the specimens of welded joints. In a number of works, for example [3, 7], it is shown that direct dependence of efficiency of electrodynamic effects on the values of elastic tensile stresses applied to the specimen in the process of EDT is observed.

During comparison of parameters of efficiency of electrodynamic effect in EDT of welded joints of 2.5 and 4 mm thickness (Figure 4, *a*, curves *1* and *2*) the values of $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % are differed by 2–5 % during the whole cycle of treatment. The maximal values of EDT efficiency during increase in thickness of specimens from 4 to 10 mm (curves *2*–*4*) are decreased, respectively, from 25 to 15 %, i.e. the $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % values are decreased as a whole with increase in thickness of metal. As is seen from Figure 4, *a*, the values of EDT efficiency with charge energy of 800 J are close to maximal ones in the range of thicknesses of 2.5–4 mm.

The evaluation of decrease of resistance of metal to deformation in EDT of specimens of welded joints of AMg6 alloy of thickness from 2.5 to 10 mm after the first ($n$ = 1) and finishing ($n$ = 6) pulse currents (Figure 4, *b*, curves *5* and *6*) was made. If maximal value $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % at $n$ = 6 to take for each of sections

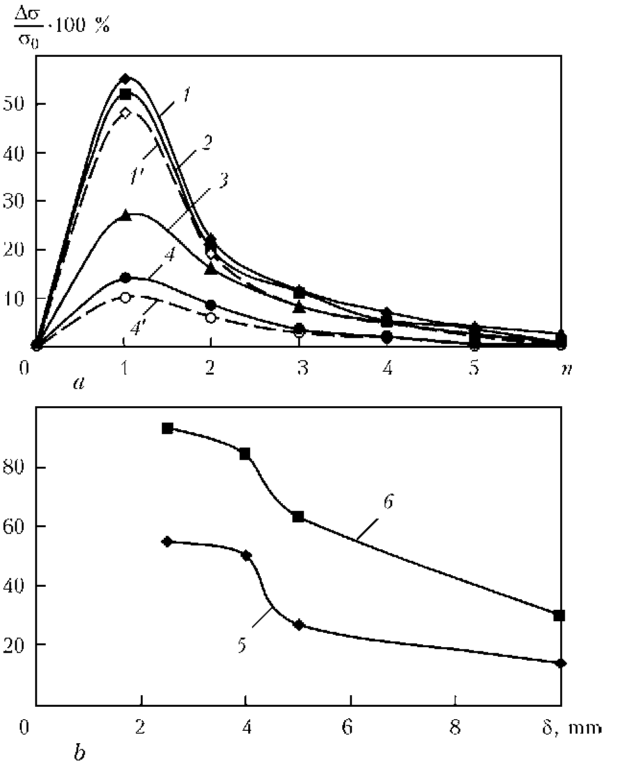


**Figure 4.** Dependence of EDT efficiency on number of current discharges $n$ for specimens of base metal (BM) and welded joints (WJ) of AMg6 alloy (*a*) and on the thickness of specimens (*b*): *1*, *1′* — $\delta$ = 2.5 mm for BM and WJ; *2* — 4 mm for WJ and BM; *3* — 5 mm for WJ; *4*, *4′* — 10 mm for WJ and BM; *5* — $n$ = 1; *6* — 6

being investigated as 100 %, then it is seen during comparison of curves *5* and *6* at the regions corresponding to the thicknesses 2.5 and 4 mm that influence of the first current pulse (curve *5*) on EDT efficiency is 60 %.

The similar values of influence of the first current pulse for the thicknesses of 5 and 10 mm were, respectively, 0.50 and 0.35. Having analyzed the data of Figure 4, it can be concluded that in the range of thicknesses of 2.5–4 mm the increase in values of EDT efficiency during comparison with specimens 5–10 mm thick takes place. The values of efficiency for the thicknesses of 2.5 and 4 mm are very close. It evidences that processes of deformation of metal as a result of electrodynamic effect for the thicknesses of 2.5–4 mm and 5–10 mm are different. It can be assumed that linear character of decrease in values of $\frac{\Delta\sigma}{\sigma_0}\cdot 100$ % with increase in thickness from 5 to 10 mm is connected with elastic-plastic deformation of metal during treatment. With increase of thickness of specimens the fraction of plastic component of deformation is decreased with accompanied growth of elastic one. Deformation of specimens of 2.5–4 mm thickness takes place under the conditions when metal has almost exhausted the elastic properties and close to plastic yielding, that is proved by steep areas of curves *5* and *6*.

To confirm the abovementioned assumption about difference of processes of deformation of welded joints of AMg6 alloy in the ranges of thicknesses of 2.5–4 and 5–10 mm, the approximate evaluation of specific dynamic load, corresponding to stored charge energy of 800 J, was performed. According to the results of tests on longitudinal tension, it was established that value of static yield strength $\sigma_{0.2}^{st}$ for welded joints of AMg6 alloy of 2.5–10 mm thickness in initial state is 130 MPa. Considering the accepted dynamics coefficient value $\chi = 2$ based on the work [10], the value of dynamic yield strength $\sigma_{0.2}^{d}$ was 260 MPa. In the work [12] the experimental evaluation of dynamic load was carried out, corresponding to the accumulated energy of 800 J, the value of which was 20,461 N, and the period of increment up to maximal value was 0.0013 s. The value of dynamic stresses $\sigma^{EDT}$ at the thickness of specimens of 2.5 mm is equal to 273 MPa which exceeds $\sigma_{0.2}^{d}$. At the thickness of 4 mm the relation $\sigma^{EDT} = 0.75\sigma_{0.2}^{d}$ is valid which proves that maximal values of dynamic stresses are close to dynamic yield strength. The obtained relations $\sigma^{EDT}$ and $\sigma_{0.2}^{d}$ determine the steep nature of curves *5* and *6* in Figure 4, *b* within the range of thicknesses 2.5–4 mm. During treatment of specimens of 5 and 10 mm thickness the electrodynamic effect is in the area of elastic dynamic loads which correspond to monotonous area of curves *5* and *6* in Figure 4, *b*, and efficiency of EDT is determined by the area of plastic deformation in the area of current pulse energy release [3, 11].

## CONCLUSIONS

1. It was established that in case of pin-type fastening of heads of specimens of AMg6 alloy in testing machine the values of tensile stresses, decreased by 50 % during electrodynamic effects, were recorded as compared with those obtained in fastening by wedge-type grips.

2. It is shown that values of EDT efficiency of welded joints of AMg6 alloy are decreased with increase in thickness of metal being treated.


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