EFFICIENCY OF ELECTRODYNAMIC TREATMENT OF ALUMINIUM ALLOY AMg6 AND ITS WELDED JOINTS

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The evaluation of parameters of pulsed current and dynamic pressure at electrodynamic treatment was performed, based on the developed experimental procedure. The influence of charge voltage and capacitance of capacitors on relative effectiveness of electrodynamic treatment was studied. It was established that maximum values of pulsed current and its increment rate are directly dependent on applied charge voltage, while the rate of dynamic pressure increment is the power function of a pulsed current.

Keywords: *welded joints, aluminium alloy, electrodynamic treatment, primary stresses, decrease of resistance to deformation, relative efficiency of treatment, pulsed current, dynamic pressure, charge voltage, capacitance of capacitors,, welding stresses*

The electrodynamic treatment (EDT) based on the combined pulsed effect of electric current and dynamic load on current-conducting materials is a challenging method to control the stressed state of metal structures [1].

Up to now the investigations of mechanisms of the EDT effect on stressed state of aluminium alloys [2], structural steels [3, 4], and also welded joints of these materials were carried out. The peculiarities of changes of micro and macrostructures [5], plastic deformation [6] and residual shape changing [7] of metals and alloys under influence of a pulsed current, initiated at EDT, were studied. The results of investigations, presented in the works [1–7], were obtained using the developed experimental procedure based on tension of flat specimens of «blade» type, their treatment by current pulses with in-process control of dropping the tension force, which was taken as an evaluative characteristic of EDT.

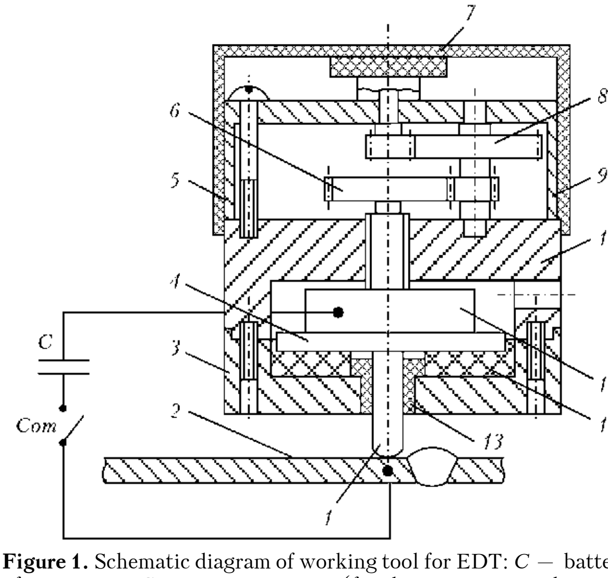

Figure 1. Schematic diagram of working tool for EDT: *C* — battery of capacitors; *Com* — commutator (for designations see the text)

However, no attention was paid to the study of effect of such parameters of EDT as values of pulsed electric current and dynamic force on efficiency of this process.

The aim of this work is investigation of efficiency of eletrodynamic effect during treatment of aluminium alloy AMg6 and its welded joints depending on electric and dynamic parameters of EDT.

To form the pulse of electric current, the pilot-industrial installation was used presented in the work [4]. The supply of a pulsed current to the surface of metal was performed using copper electrode in the way that the specimen being treated is connected to the discharge circuit of the capacitor storage. Here, in the process of passing the discharge current the electric pulsed processes in the current-conducting material being treated are initiated, connected with the mechanism of electric plasticity [1]. Besides, a special design of electrode device transfers impact effect into the material being treated.

The working tool includes a current-conducting striker *1* with a hemispheric edge (Figure 1). The design peculiarities of the tool allow changing the length of electrode stickout *1* by adjusting gears *6*, *8* and screw *7* relatively to the surface of welded joint *2* which is the receiver of the electrodynamic effect. The working tool includes also an inductance coil *11*, connected to the discharge circuit of the capacitor storage and defining the duration of a current pulse. The coil is arranged in the working tool above the disc *4* of non-ferromagnetic material.

The interaction of magnetic field of inductance coil and field of induced currents, caused by passing the current pulse along the winding, leads to the appearance of electrodynamic force trying to push out the disc from the coil, here the current-carrying electrode, rigidly connected to a disc, transfers the electrodynamic effect to the surface of material being treated. The superposition of electric plastic and dynamic processes during passing of the pulsed current through the product being treated determines the intensity of electrodynamic effect.

Working tool body components *3*, *5*, *9*, included into composition of the working tool, provide the required rigidity of the design, and the damping *12* and guiding *13* elements reduce the negative effect of impact action of the disc on the body *10*.

One important peculiarity of EDT should be noted, consisted in difference of character of electrodynamic effect of working tool from characteristic diagrams of a mechanical impact. The rate of increment of dynamic force in our case is determined by leading front of a current pulse and, evidently, can be controlled using hardware.

To evaluate the effect of EDT parameters on the efficiency of the process, the treatment of flat specimens of rectangular section of AMg6 alloy after tension and its welded joints cut out across the weld of plates of 500 × 500 × 4 mm sizes was carried out. Butt welds were performed by the automatic welding using non-consumable electrode in argon in the installation ASTV-2M at the voltage 18 V and current 220 A at the speed of 14 m/h.

The tension of specimens was performed in the rupture machine TsDM-10 with a closed power loop and maximal force of tension 9800 N at the rate of deformation of 0.1 mm/min and temperature of 293 K.

The influence of electric parameters of EDT process such as discharge voltage U and battery capacitance of capacitors C on decrease in resistance of material to deformation $\Delta\sigma$ (difference of values of initial stresses σ_0 and after EDT σ_{EDT}) was studied. For this purpose the specimens of base metal and welded joints of AMg6 alloy were subjected to tension up to preset value of σ_0 and single current discharge was performed with control of stress drop to σ_{EDT}, presetting here the different U and C values.

At the first stage of investigations the $\Delta\sigma$ values at discrete increase of charge voltage U from 200 to 300 and 500 V at constant charge of capacitors C = = 6600 μF were measured. At the second stage the C value was changed, being discretely increasing from 1400 to 2800 and 6600 μF at invariant U = 500 V. The σ_0 values of specimens were preset equal to 55, 130 and 270 MPa. The dependencies of influence of parameters U and C on relative efficiency of EDT $\Delta\sigma/\sigma_0$ are presented in Figure 2. Having analyzed the dependencies $\Delta\sigma/\sigma_0 = f(U)$ at C = const (Figure 2, *a*) and $\Delta\sigma/\sigma_0 = f(C)$ at U = const (Figure 2, *b*) it is seen that parameters U and C are different according to the level of influence on resistance to deformation $\Delta\sigma$ and, as a consequence, on relative efficiency $\Delta\sigma/\sigma_0$ of EDT of AMg6 alloy.

Thus, if to achieve maximal values of efficiency (see Figure 2) the charge voltage U is enough to be increased by 2.5 times, then to achieve the similar

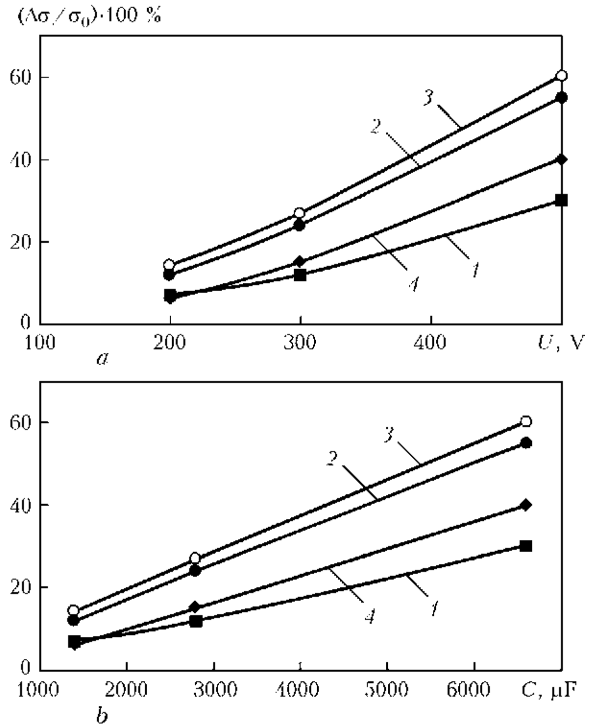

Figure 2. Effect of charge voltage U (*a*) and capacitance of battery of capacitors C (*b*) on relative efficiency of EDT $(\Delta\sigma/\sigma_0)\cdot 100$ % of alloy AMg6 and its welded joints at different values of initial stress: *1* — σ_0 = 55; *2*, *3* — 130; *4* — 270 MPa; *1*, *2*, *4* — base metal; *3* — welded joint

values of $\Delta\sigma/\sigma_0$ it is necessary to increase the capacitance C by 5 times. Basing on the data of Figure 2, it can be concluded that efficiency of EDT is directly proportional to the capacitance of C at U = const and square of voltages U^2 at C = const, which gives grounds to present it as a function of accumulated energy of the capacitor [8].

The values of efficiency for welded joints are by 5–10 % higher than for base metal, which is explained by the higher sensitivity of weld metal structure to electrodynamic effects [2].

Basing on the dependencies, presented in Figure 2, it can be concluded that increase of $\Delta\sigma$ values at EDT by adjustment of charge voltage U is preferable as compared with the variation of capacitance C. However, the application of capacitors with charge voltage U higher than 500 V is limited, as it is connected with working out of safety rules in operation with high-voltage manual tool. At the same time the increase of the battery capacitance C due to a number of capacitors leads to increase of mass and sizes of equipment for EDT. It causes the necessity of searching for compromising solutions based on use of modern element base and new design schemes of the discharge loop.

The influence of electrodynamic effects at different levels of primary stress σ_0 on relative efficiency EDT $\Delta\sigma/\sigma_0$ determined after single current discharge was evaluated. U values were preset in the range of 200–250 V, and value of σ_0 varied from 55 to 294 MPa, which approximately corresponds to previous experiments. The dependencies $\Delta\sigma/\sigma_0$ on σ_0 at different U

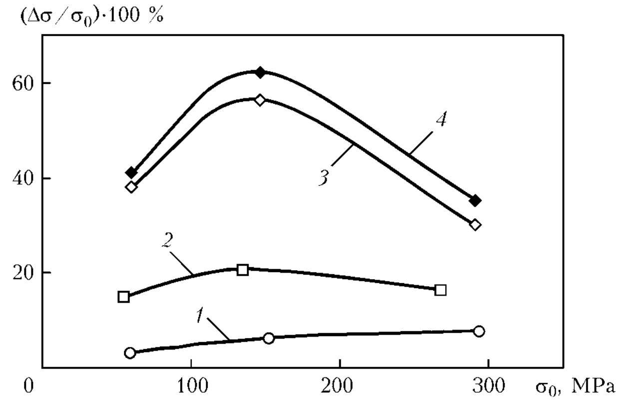

Figure 3. Effect of initial stress σ_0 on relative efficiency $\Delta\sigma/\sigma_0$ at EDT of alloy AMg6 and its welded joints at different values of charge voltage: *1* — U = 200; *2* — 300; *3*, *4* — 500 V; *1–3* — base metal; *4* — welded joint

determined for AMg6 alloy and its welded joints are presented in Figure 3, which shows that maximal efficiency of EDT corresponds to the level of initial stresses close to conditional yield strength of AMg6 alloy, that is confirmed by the data of works [2, 9]. The decrease of $\Delta\sigma/\sigma_0$ values at increase of tensile load higher than relative yield strength can be explained by negative influence of plastic deformation on efficiency of electrodynamic effects, that was earlier noted in the work [9].

The influence of charge voltage U of capacitor battery on parameters of electrodynamic effect of EDT, such as amplitude values of pulsed current I and dynamic load P in the time period t of capacitor discharge, was investigated. The measurements I and P were performed in hardware complex, the appearance and design elements of which are presented in Figure 4. The values of pulsed current I were registered using contactless method (Rogowski loop), which represents a solenoid of toroidal shape, embracing the conductor with current, whose principle of work is based on recording the magnetic field generated by measured current during its passing through the solenoid.

The parameters of dynamic loading P were determined using piezoelectric pressure sensor LKh-604.

The parameters I and P were measured using the following procedure. At the moment of discharge of capacitor battery C (see Figure 4, *b*) as a result of response of thyristor commutator *Com*, the pulsed current, passing through the inductance coil *1*, flat disc *3*, electrode *4*, cylindrical specimen *5* subjected to load P, pressure sensor *6*, was measured using Rogowski loop *7* and controlled using fast-response digital oscillograph *8*.

In this case the mechanical pressure generated by a pulsed magnetic field of inductance coil was transferred through the insulator *2* to the flat disc and electrode, spherical edge of which during indenting into cylindrical specimen transferred impact load to a piezoelectric sensor, whose indications were recorded similarly to current values. Thus, material being treated, whose functions were fulfilled by the cylindrical specimen of low-carbon steel of 9 mm diameter and 6 mm height, was simultaneously affected by dynamic load P of working tool (electrode) and pulsed electric current I, caused by the discharge of capacitor battery.

The amplitude values of parameters I and P were recorded at different levels of charge voltage (Figure 5). During study of distribution of I and P in the time period the assumption was taken, based on the data of works [10, 11], that maximal influence on efficiency of electric pulsed and dynamic effects (to which EDT relates) is exerted by the processes of increment of pulsed current and pressure up to maximum values.

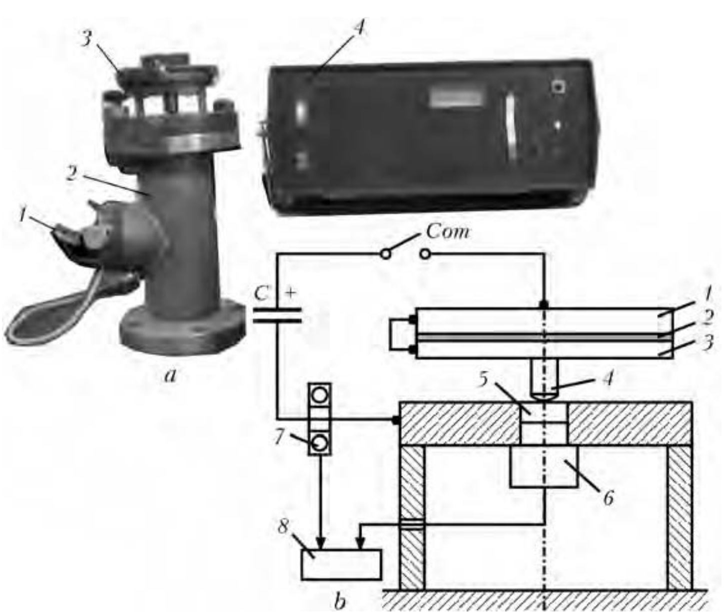

Figure 4. Appearance of hardware complex for measuring amplitude values of pulsed current I and dynamic loading P at EDT (*a*: *1* — Rogowski loop; *2* — casing of system for measuring load P; *3* — inductance coil with electrode; *4* — unit of charge and discharge of capacitors) and its design diagram (*b*) (for *1–8* see the text)

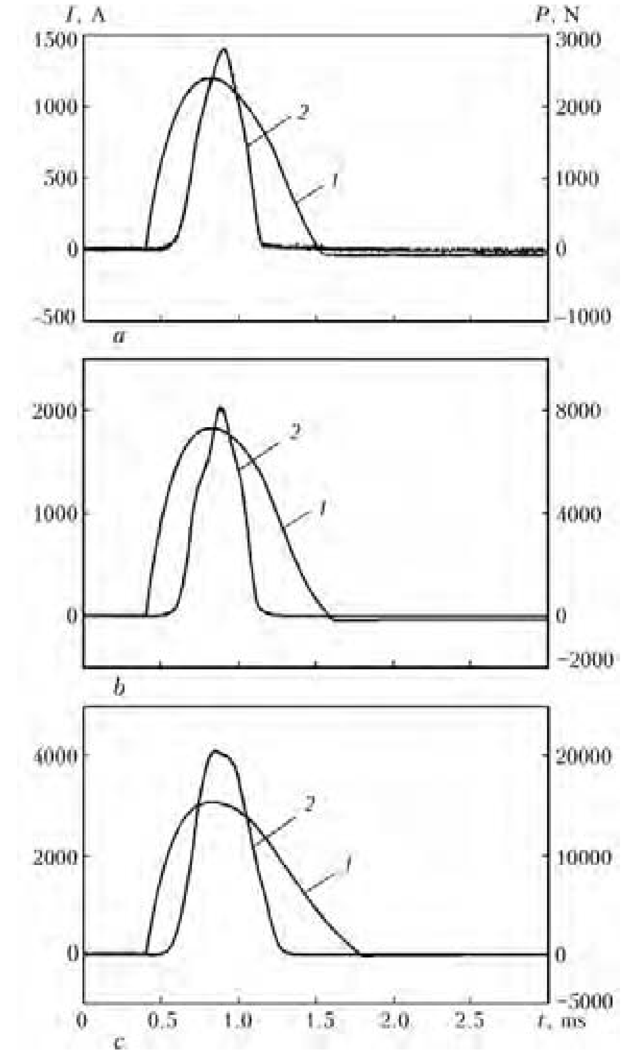

Figure 5. Amplitude values of pulsed current I (*1*) and dynamic load P (*2*) at different values of charge voltage: *a* — U = 200 V, I_{max} = 1195 A, P_{max} = 2792 N; *b* — U = 300 V, I_{max} = 1838 A, P_{max} = 8162 N; *c* — U = 500 V, I_{max} = 3080 A, P_{max} = 20461 N

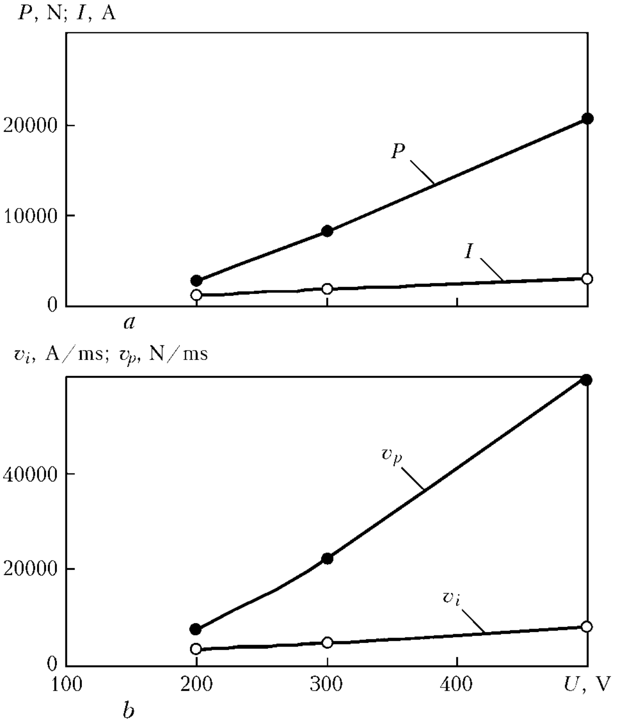

Figure 6. Effect of charge voltage U on pulsed current I, dynamic loading P (*a*) and rate of their growth v_i and v_p (*b*)

As is seen from Figure 5, maximal values of pulsed current I_{max} cover the range from 1195 to 3080 A and are in direct dependence on the charge voltage U. This relates also to the rates of current increment up to I_{max} − v_i, which at U = 200, 300 and 500 V were, respectively, 3400, 4600 and 8000 A/ms.

The process of growth of dynamic pressure of electrode to the material being treated is running intensively. Thus, the maximal values of amplitude of pressure P_{max} are in the range from 2792 to 20461 N. Here, the time period t of growth of pressure from 0 to P_{max} at increase of values of charge voltage U from 200 to 500 V decreased from 0.375 to 0.340 ms, which determined the increase of rate of v_p of contact interaction of electrode with metal with increase of U. If v_p at U = 200 V did not exceed 7500 N/ms, then at increase of voltage up to 300 and 500 V its values were respectively 22000 and 60200 N/ms. Thus, the value of charge voltage U determines such parameters of dynamic pressure as P_{max} and gradient of function of increment P.

It can be seen in comparison of curves of increment of pulsed current and loading (see Figure 5) that the pulse of pressure is shorter and has steeper fronts of increment and drop. In the whole range of U values being investigated the delay of beginning of the process of increment P from increase of I by 0.1 ms occurs, which can be explained by deformation of contact surfaces of electrode and metal being treated. The increment of P begins at pulsed current 600, 800 and 1500 A for voltages, respectively, 200, 300 and 500 V. Thus, the process of contact interaction of electrode with metal begins at values of current approximately corresponding to $0.5I_{max}$.

The dependencies of amplitude values of current I and loading P, and also rates of their increment v_i and v_p on charge voltage U are presented in Figure 6, which shows that with increase of U the increment of I and P (Figure 6, a) as well as v_i and v_p (Figure 6, *b*) has a linear nature.

CONCLUSIONS

1. The experimental procedure of investigation of effect of electric parameters of EDT, such as charge voltage U and capacitance of capacitors C, on relative efficiency of treatment of AMg6 alloy and its welded joints as a result of electrodynamic effects has been developed.

2. It was established that efficiency of EDT is directly proportional to capacitance C at U = const and square of voltages U^2 at C = const, that corresponds to the expression for accumulated energy of the capacitor.

3. The experimental procedure was developed, on the basis of which the hardware-measuring complex was assembled to investigate the effect of charge voltage at EDT on such parameters as amplitude values of pulsed current I and dynamic loading P.

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RISK OF FAILURE IN THINNING OF MAIN PIPELINE WALL AT THE AREA OF CIRCUMFERENTIAL WELDS IN THE PRESENCE OF BENDING MOMENTS ALONG THE PIPELINE AXIS

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The effect of longitudinal bending moment in pipeline with a wall thinning defect of large overall size in circumferential direction on the risk of failure is considered. It is shown that the critical sizes of thinning in circumferential direction can be determined with a certain conservatism on the basis of total nominal stresses induced by bending and internal pressure in pipeline.

Keywords: *main pipelines, critical sizes of defects of wall thinning, effect of bending moment, risk of failure, Weibull distribution*

Allowable overall size c of defects of thinning along the pipe circumference is much larger than that of s along the generatrix in pipeline loading with internal pressure P that is due to a large extent to higher circumferential normal stresses $\sigma_{\beta\beta}$, as compared with axial ones σ_{zz}, at other things being equal, that is demonstrated visually by the typical diagrams of limiting overall sizes c and s, given in work [1].

However, the thinning with high c values can be rather often observed under loading conditions when alongside with internal pressure P in the zone of thinning the bending moment M_{bend} is acting, caused by soil settling down (for underground pipeline) or wind load at certain air transitions, etc. The nominal stresses at such loading can noticeably change in the zone of a defective area of the pipeline wall.

There is a relationship for points in section $\beta \le 0$ for nominal longitudinal stresses σ_{zz} in pipeline with internal pressure P and bending moment M_{bend}, acting in longitudinal plane $\beta = 0$, assuming the presence of pure elastic deforming and preserving the shape of pipe transverse sections:

$$\sigma_{zz} = \frac{PR}{2\delta} + \frac{M_{\text{bend}} \cos \beta}{\pi R^2 \delta}\left(1 + \frac{\xi}{R}\right), \qquad (1)$$

where R is the internal radius of pipeline; δ is the wall thickness ($-\delta/2 < \xi < \delta/2$).

Relationship (1) can be presented in the form of

$$\sigma_{zz} = \frac{PR}{2\delta}\,[1 + \kappa(\beta)],$$

where $\kappa(\beta) = \dfrac{2M_{\text{bend}} \cos \beta}{\pi R^3 P}\,(1 + \xi/R)$ determines the addition, due to M_{bend}, to nominal stresses σ_{zz}, caused only by pressure in pipeline. If the defect of thinning is located so that $\beta = 0$ is in the middle of the defect length c and $c/2R < 0.1\pi$, then the membrane stresses in this zone prevail for all the β inside the interval