INFLUENCE OF REPEATED LOADING ON THE EFFICIENCY OF ELECTRODYNAMIC TREATMENT OF ALUMINIUM ALLOY AMg6 AND ITS WELDED JOINTS

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The mechanism of reduction of preliminary stresses in repeated loading and electrodynamic treatment of AMg6 alloy and its welded joints were investigated on the basis of the developed procedure. It was established that the history of loading of AMg6 alloy has no substantial effect on relaxation characteristics of metal subjected to repeated impact by current pulses.

Keywords: *aluminium alloy, welded joint, residual stress, electric current pulse, electrodynamic treatment, efficiency of treatment, relative yield strength, tensile strength*

During service of welded structures of aluminium-magnesium alloys operating under conditions of influence of pulse electric and magnetic fields, the residual stresses causing fracture of single elements can arise at certain conditions. The beginning of plastic flow of metal begins at values of working stresses below the relative yield strength [1–3].

Since the end of the last century a number of domestic and foreign scientific organizations conduct research works on optimization of structure and properties of structural materials and welded joints using their treatment by pulse electromagnetic fields. It was established that pulse influence of current on metals and alloys affects the fatigue resistance, static strength and other mechanical characteristics [4]. At the same time the data of work [3] evidence negative role of electromagnetic effect on the strength of metals and alloys.

One of the methods of electric current impact on the metals is electrodynamic treatment (EDT) based on initiating of electrodynamic forces in the material, which are formed during passing of electric charge through the current conducting material [5]. While summing them with outer loadings, applied to the structure being treated, the local fields of plastic yielding of metal arise in the zone of current impact [6].

During investigation of EDT influence on aluminium alloys and low-carbon steels the main attention was paid on studying mechanism of stress state relaxation [7–9] and evolution of structure of base metal and welded joint [10]. It should be noted that questions about changing strength characteristics of welded joints under the impact of energy of current charges initiated by EDT practically were not studied. At the same time in the works [3, 4] different opinions about influence of pulse electromagnetic fields on the strength of structural materials are given. Besides there are no data in modern literature about the effect of repeated loading on relaxation of stresses in metal at electromagnetic effects.

The purpose of this work is investigation of influence of EDT on mechanical properties of aluminium alloy AMg6 and its welded joints at uniaxial tension as well as on relaxation of stresses at repeated loading of metal.

The EDT of specimens of base metal and welded joints of annealed aluminium alloy AMg6 of 4 mm thickness with a size of 110 × 30 mm working area loaded by uniaxial tension at the speed of 0.1 mm/s were carried out. Three levels of tensile loadings were preset: at the low elastic stresses of 52–60 MPa; at the stresses of 116–147 MPa close to elasticity limit of AMg6 alloy (which approximately correlates with the level of residual welding stresses in the alloy being investigated); at the stresses beyond elasticity limit. The tension in elastic-plastic zone was brought to 260–280 MPa, i.e. till generating Portevin–Le Chatelier effect which is manifested in the discontinuous yielding of metal in the zone of prefracture [11].

EDT was performed using laboratory machine, the description of which is given in the work [9]. EDT of specimens after tension was performed using contact of working electrode with a surface of a metal according to the scheme presented in [7]. The specimens were subjected to tension till generating stresses of preset value in them and treated with a series of current discharges, after each pulse the drop of tensile force in the material was controlled. The EDT was conducted at the energy of current discharge E = 140, 300 and 800 J.

After termination of EDT, the 50 % of investigated specimens were subjected to fracture and remained part was again subjected to tension and treatment under similar conditions to determine influence of repeated cycle of EDT on stress relaxation.

The changes of mechanical properties of AMg6 alloy and its welded joints at different levels of loading and energy of current discharge are given in the Table. Analyzing its data it can be concluded that EDT at E = 140–300 J of specimens loaded up to 140 MPa (series Nos. 2, 3, 5, 6) practically does not influence the characteristics of static strength as compared with initial values (series No.1). The same concerns the variant of treatment at E = 800 J and σ_{in} = 60 MPa (series No.8). The EDT at E = 800 J at increasing σ_{in} to the values close to elasticity limit of AMg6 alloy, 15–20 % increases $\sigma_{0.2}$ of base metal and welded joint (series No.9). The values of σ_t of a welded joint are increased approximately by 15 %. The combined impact of electric current pulses and elastic-plastic loading enhances yielding processes in the specimens being studied which are determined according to increase of values $\sigma_{0.2}$ by 45–50 % (series Nos. 4, 7, 10). The tensile strength of base metal increases approximately by 8, and that of welded joint — by 20 %.

Figure 1 shows dependence of the level of initial tensile stresses of specimens of welded joints on the number of discharges at the first and repeated tensions. Figure 1, *a* shows that at E = 140 J negligible decrease of values σ_{in} after the first EDT (curves *1* and *3*) and repeated (curves *2* and *4*) occurs in elastic loading area. At σ_{in} < 60 MPa the relative decrease of values of stresses at the first and repeated EDT was respectively 16 and 21 %. For specimens at tensile stresses up to 120 MPa the similar values after two series of EDT did not exceed 20 %. In elastic-plastic area at σ_{in} = 260 MPa after the first (Figure 1, curve *5*) and repeated (Figure 1, curve *6*) EDT the decrease of stresses amounted, respectively, to 11 and 14 %, i.e. lower than at small loads (Figure 1, curves *1* and *2*).

More efficient is EDT of welded joints at E = = 800 J. After the first and repeated series of EDT of specimens after tension at tensile stresses of up to 60 MPa (Figure 1, *b*, curves *1*, *2*) the relative decrease of applied loading in both cases was 55 %. The increase of tensile forces to the values close to elasticity limit of 140 MPa (Figure 1, curves *3*, *4*) practically does

Mechanical properties of AMg6 alloy and its welded joints after EDT

No. of series of specimen	Energy of current discharge E, J	Initial tensile stresses σ_{in}, MPa	Relative yield strength $\sigma_{0.2}$, MPa	Tensile strength σ_t, MPa
1	–	–	140/130	305/246
2	140	60	140/130	305/245
3	140	140	145/131	304/248
4	140	260	253/232	330/303
5	300	55	145/130	305/246
6	300	135	144/132	310/245
7	300	265	258/237	330/303
8	800	60	145/133	305/245
9	800	146	170/152	310/285
10	800	260	261/256	332/305

Note. 1. Numerator denotes the data for base metal, while denominator gives data for welded joint. 2. Series of specimens Nos. 7, 9 and 10 obtained increment of values $\sigma_{0.2}$ and σ_t under the effect of EDT.

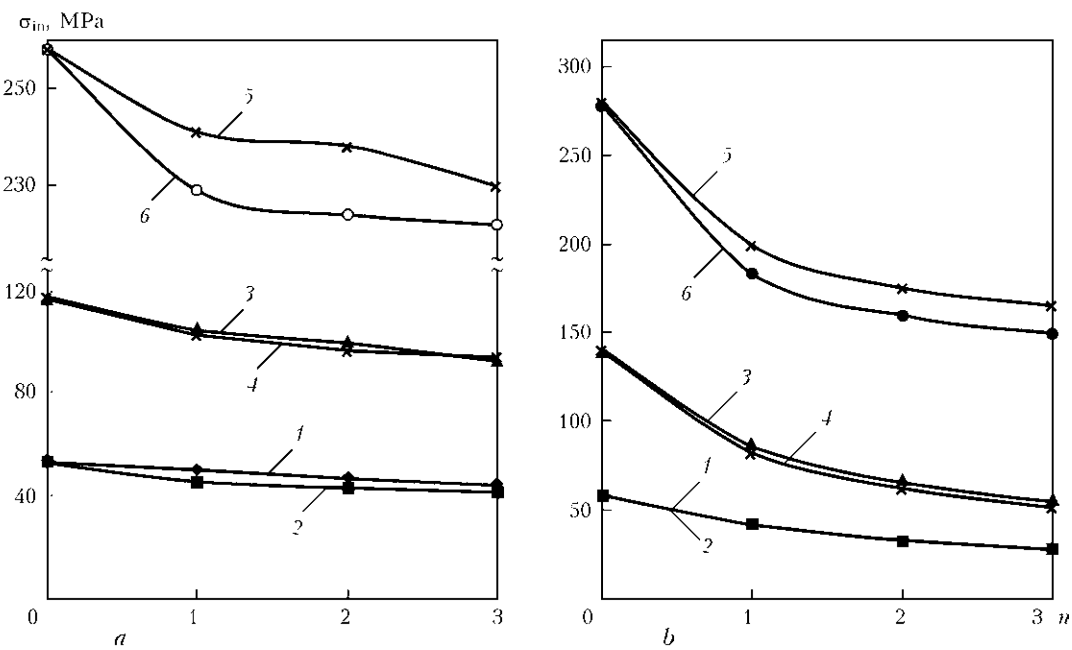

Figure 1. Dependence of level of tensile stresses σ_{in} on number of discharges n in specimens of welded joints of AMg6 alloy at E = 140 (*a*) and 800 (*b*) J after the first (*1*, *3*, *5*) and repeated (*2*, *4*, *6*) EDT

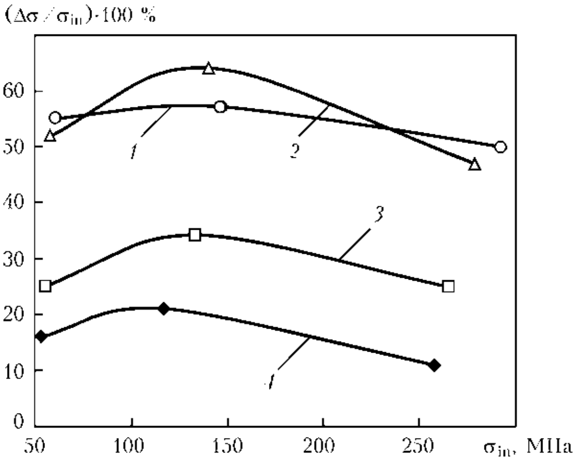

Figure 2. Dependence of relative efficiency $\Delta\sigma/\sigma_{in}$ of EDT in specimens of AMg6 alloy (*1*, *3*) and its welded joints (*2*, *4*) on the level of tensile stresses σ_{in} at E = 800 (*1*, *2*), 300 (*3*) and 140 (*4*) J

not influence the efficiency of current impact. Therefore after two series of EDT the relative decrease of loading was respectively 60 and 65 %. In elastic-plastic area the level of tensile stresses reaches 280 MPa as well as at EDT with E = 140 J (Figure 1, *a*), the efficiency of treatment is somewhat decreased. Here,

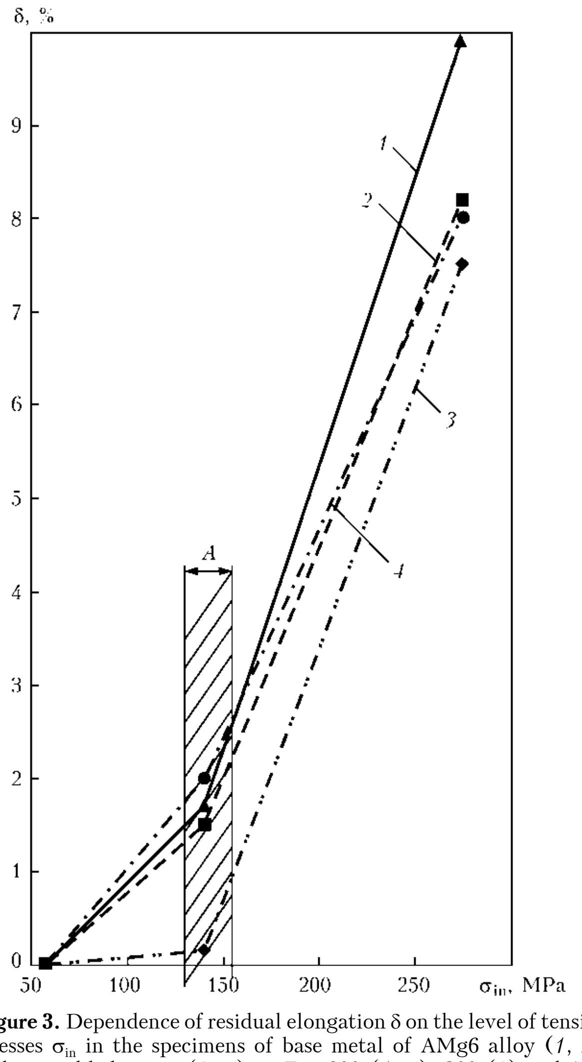

Figure 3. Dependence of residual elongation δ on the level of tensile stresses σ_{in} in the specimens of base metal of AMg6 alloy (*1*, *2*) and its welded joints (*3*, *4*) at E = 800 (*1*, *4*), 300 (*2*) and 140 (*3*) J: *A* — region of maximal $\Delta\sigma/\sigma_{in}$ values

the difference is observed in values of drops of loading after first and second EDT (Figure 1, curves *5*, *6*), relative efficiency of these processes is respectively 40 and 50 %.

After EDT the values of δ_{in} in the specimens of base metal (AMg6 alloy) were practically the same as in Figure 1 which evidences the similarity of relaxation mechanisms in welded joints.

Figure 2 shows that resulting efficiency of the process of treatment is directly proportional to the energy of current discharge in the range being investigated. EDT with E = 800 J provides maximal decrease of applied tensile stresses in the whole range of loadings being investigated. The highest effect at all the values of energy of current discharge used in this work is achieved at the level of initial tensile stresses close to limit of elasticity for AMg6 alloy (150 MPa) which is approximately in compliance with the peaks of tensile stresses for AMg6 alloy. The comparison of efficiency of current impact on the specimens of base metal and welded joints (Figure 2) showed that cast structure of a weld is more subjected to EDT impact with E = 800 J at σ_{in} = 130–150 MPa. This is expressed in the higher level of efficiency of reducing stresses after EDT in the specimens of welded joints as compared to the base metal (accordingly 60 and 55 %) which makes the premises for the development of EDT technology to control the stressed state of welded structures of aluminium-magnesium alloys. At the same time the decrease of values of relative efficiency of EDT at σ_{in} = 260–280 MPa (Figure 2) can be connected with deformational strengthening initiated by current discharges in AMg6 alloy [10].

The evaluation of residual elongation δ of base metal and welded joints initiated by current discharges in the specimens at EDT was carried out. In accordance with the data of the works [4, 6] the passing of current pulse through the loaded material results in formation of plastic deformation in it which can influence the characteristics of static strength. Figure 3 shows that at E = 140 J the residual elongation of specimens is stimulated by EDT process at tensile stresses of more than 120 MPa, and at σ_{in} = 150 MPa δ = 1.5 % and can reach 7.5 % in elastic-plastic area of loading at σ_{in} = 275 MPa. At σ_{in} = 60 MPa the use of the whole range of energies of current discharge did not result in increase of elongation that proves a low efficiency of EDT process of AMg6 alloy with a low level of initial stresses. At the same time at $\sigma_{in} > 125$ MPa the current discharges with energy of 300 and 800 J lead to the increase in elongation up to 1.5 % and with increase in tensile stresses up to 150 MPa the residual plastic deformation increases up to 2.0. The further increase in $\sigma_{in} \geq 290$ MPa results in elongation of specimens up to 8–10 %, it is difficult to share EDT contribution and plastic yielding of material under load. According to Figure 2 maximal efficiency of EDT in the whole range of values of energy of current discharge occurred at tensile stresses up to 150 MPa, to which the elongation of up to 2 % of a specimen of AMg6 corresponds. Its further elongation deteriorates efficiency of treatment which is, as described above, connected with development of deformational strengthening processes, initiated by current discharges [9], which negatively influence the efficiency of EDT process.

CONCLUSIONS

1. EDT has no influence on decrease of values of relative yield strength $\sigma_{0.2}$ and tensile strength σ_t of AMg6 alloy and its welded joints. At EDT of specimens after tension until elasticity limit, the parameters $\sigma_{0.2}$ and σ_t are increased by 15–20 %, and elastic-plastic state is increased, respectively, by 50 and 20 %.

2. The repeated loading of specimens of AMg6 alloy has no substantial influence on efficiency of current impact. At EDT with E = 140 J the relative decrease of level of applied stresses in AMg6 alloy is 20 %, and at E = 800 J it is 65 %.

3. The maximal efficiency of EDT of specimens of AMg6 alloy and its welded joints is observed at σ_{in} = = 150 MPa.

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EFFECT OF ALLOYING OF THE WELDS ON STRUCTURE AND PROPERTIES OF WELDED JOINTS ON STEEL 17Kh2M

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Structural-phase state of metal of the welded joints on high-strength low-carbon steel 17Kh2M ($w_{6/5}$ = 20–23 °C/s) produced by using welding wires of different chemical compositions and structural types (Sv-08G2S, Sv-08Kh20N9G7T, Sv-10KhN2GSMFTYu) was investigated. Analytical estimation of differential contribution of each structural parameter to a change in the set of mechanical properties (strength, ductility) of the HAZ and weld metal, as well as of a character of distribution and localisation of strain, level of local internal stresses, intensity and size of the stress raisers, which are potential sources of cracks forming during the welding process, was carried out on the basis of experimental data.

Keywords: *arc welding, high-strength steel, welded joints, weld and HAZ metal, type of weld alloying, structural-phase parameters, mechanical properties, localised strain, local internal stresses, crack resistance*

High-strength steels with yield stress σ_y = 590 MPa or more are used in the national and foreign practice to fabricate critical welded structures. With the rational utilisation of these steels it is possible to substantially improve technical and economic indices of machines, mechanisms and engineering structures. However, the main problems in welding of high-strength steels are related not only to the requirement to ensure the sufficient strength level, but also to the need to prevent cold cracking of the welded joints. This is determined to a considerable degree by formation of optimal structures in the weld and HAZ metal, which can improve not only strength but also brittle fracture resistance of the welded joints [1–3].

The effect of the structure of metal of the welded joints on their properties is evidenced by the fact that welding of high-strength steels is performed, as a rule, by using consumables that provide welds with the bainitic (B) or bainitic-martensitic (B-M) structures. However, the low- or high-alloyed consumables are used in certain cases to increase cold crack resistance of the welded joints, the resulting welds having the