USE OF ELECTRIC PULSE TREATMENT FOR RELAXATION INTERNAL STRESESS

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Abstract. The article deals with explanation of the effect redistribution of residual stresses after processing electrical pulses based on aluminum alloy after welding. The results indicate quite significant influence of electrical pulse treatment on both the morphology of alloy structural components and the relation of chemical elements involved in the formation of certain phases alloy. Studying the chemical composition of the phase components was found out that the observed structural changes of alloy as a result of processing electrical pulses first of all may be caused by the redistribution of chemical elements, which form the compounds themselves. After the processing electrical pulses of the welded joint, the alloy hardness increase is accompanied by the decrease in the number of crystal structure defects and coarsening of the coherent scattering regions.

Key words: electrical pulses, aluminum alloy, welded joint, hardness.

1. INTRODUCTION

Proportional to the temperature of heating the processes of structural transformations develop in the metal of pool and heat affected zone have an unchanging impact on the property package of the welded joint. The observed structural changes are in fact resulted from the simultaneous impacts of several factors, notably the processes of diffusion mass transfer and redistribution of internal stresses of different origin [1]. The residual stress diagram after the welded joint forming might be of such form that the summing of one sign of residual stresses and the strains during the structure operation will take place in some nodal points [2]. In this case, the unaviodable excess of computed values from actual stresses will lead to the breach of the guaranteed conditions of trouble-free service for the welded joint. On this basis, the development of measures to reduce the intensity and gradient of residual stresses in the welded joint is quite an urgent problem of modernity [1]. Except the thermal and mechanical ways to decrease the residual stresses, such as a reversible deformation [3], the technologies based on the use of strong magnetic and electric fields [4–6] should be included to these treatments [8]. The purpose of this work is the explanaion of redistribution effect of residual stresses after electric pulse treatment of the silumin arc welded seam.

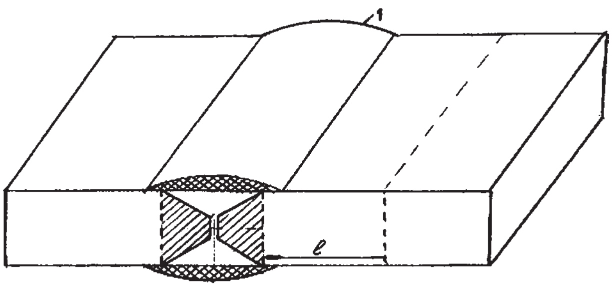

Fig. 1. Schematic representation of the welded plates after welding (1 — weld reinforcement, l – thermal zone –size)

2. METHODOLOGY

An alloy on the basis of aluminum (8,1%Si, 2,9%Cu, 0,7%Zn, 0,35%Mg, 0,18%Ti, the rest Al), 9 mm thick plates after are being connected were butt welded using the technology of semi-automatic argon arc welding by the electrode with 3 mm diameter of (5%Si, 1,2%Cu, 0,5%Mg, the rest Al) alloy. The Rockwell hardness (*HR*), with the loading of 60 kg was used as a strength characteristic of alloy. Microhardness measuring of the phase constituents using the device PMT-3, with the indenter loadings 5 and 10 g. Metal structure of the welded joint was examined under the light and scanning electronic microscope JSM-6360 LA. The crystalline structure parameters of alloy (dislocation density and the size of coherent scattering regions) were determined using the methods of X-ray structural analysis [9]. The electric pulse treatment (*EP*) was carried out on the special equipment in conditions of the DS enterprise. The electric current density was 16 A/mm^2.

3. FINDINGS

Taking into account the existence of qualitatively different structural condition of the metal after the arc welded joint formation the studies were carried out for two superheated areas from the welding pool: marked I and III, respectively. The welding pool region marked II (Fig. 1). Values the alloy hardness after welding was 62 and 61 units *HR* for I and III regions respectively, when for the II region — 46 *HR*. The microstructural studies showed (Fig. 2) that the alloy represents a multiphase composition consisting of a matrix in the form of a solid solution (A), and the second-phase particles (B). The metal of welded joint has a structure of as cast condition, with almost the same dispersion. Second-phase particles, which are similar in form to the plates, have an uneven distribution in the metal matrix. Micro-hardness measurements of the alloy structural components showed quite significant difference in the absolute values. For the second phase particles, depending on the distance of tested alloy volume from the welding pool, the microhardness excess as compared to the matrix has reached from ten to a few times. For the alloy without electrical pulse treatment, the parameters change of alloy crystalline structure showed qualitative correspondence with the nature of strength characteristics change, which is typical for the majority of metallic materials [3]. The increase of dislocation density (ρ), and dispersion coherent scattering regions (L) is accompanied by quite natural hardness increase about 25–27%.

After electric pulse treatment a progressive softening of alloy in the heat affected zone was observed. The electrical pulse treatment was accompanied by the decrease of hardness characteristics as compared to the original (without *EP*), for the regions I and III by 15% decrease after *EP*. For metal volume of the welding pool the situation is somewhat different. Initially the hardness measurements showed increase in hardness from 46 *HR* (without *EP*) up to 50 *HR* (after *EP*). The observed effect of changing the hardness of the metal weld pool can be seen as evidence of structural changes in the electric pulse treatment in cast metal, and for heat-affected zone [7, 8]. Moreover, the welding pool metal having a different phase composition [2] with a simultaneous change of aggregative state (during the welding) as a whole leads to the qualitative change in the nature of hardness change. The metal of heat-affected zone having a multi phase structure may be subjected to the phase hardening to a greater extent as a result of the thermal stresses during the welding joint formation. The experimental data analysis confirmed the existence of qualitatively identical nature of relationship between ρ and L for the alloy without and after *EP* (Fig. 3*a*) and different for relationship between ρ and *HR* (Fig. 3*b*). So, regardless of the research areas I, II or III, the hardness increase is accompanied by the decrease in defect number of crystal structure and coarsening of coherent scattering regions. In other words, for the vast majority of steels and alloys the nature of these relationships ($HR=f(\rho, L)$) should corre-

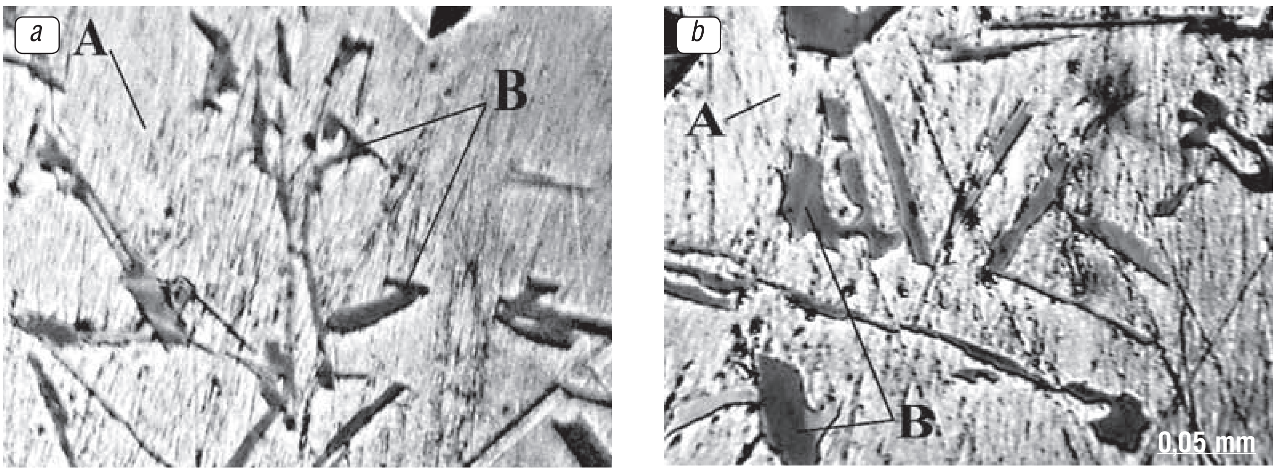

Fig. 2. The structure of the alloy (A — matrix; B — chemical compounds) after welded at a distance 3,5 mm (*a*), and 7 mm (*b*) from the melting boundary

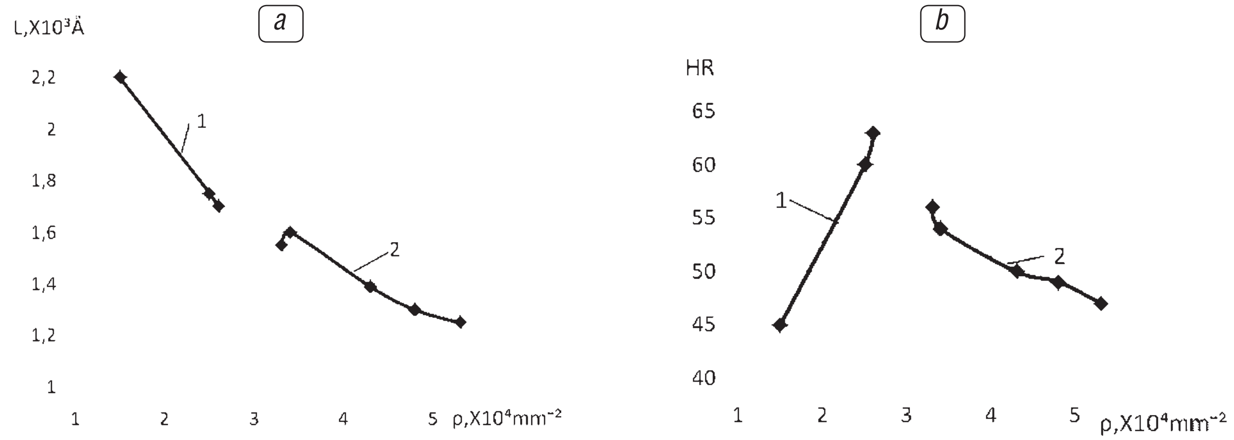

Fig. 3. The relationships between ρ and *L* (*a*), *r* and *HR* (*b*) for the alloy without *EP* — (*1*), after *EP* — (*2*)

spond to the development of softening process, not strengthening. At the same time, it is unclear due to what effects the nature of $HR=f(\mu)$ relation was corresponding to the hardening.

On the basis of studies the previously obtained softening effect of aluminum alloy welding joint as a result of electrical pulse treatment was confirmed [8]. Explanation of the observed phenomena on the basis of study of the crystalline structure characteristics only did not uniquely determined the main influence factors. It is hoped that the use of scanning electron microscopy will give the opportunity to get more information on the observed softening effect. Moreover, the qualitative changes of the relation nature between the hardness and dislocations density after the electric pulse treatment shown on the Figure 2*b* may be associated with the changes of alloy phase composition. In case the observed relations of crystalline structure and hardness of alloy will

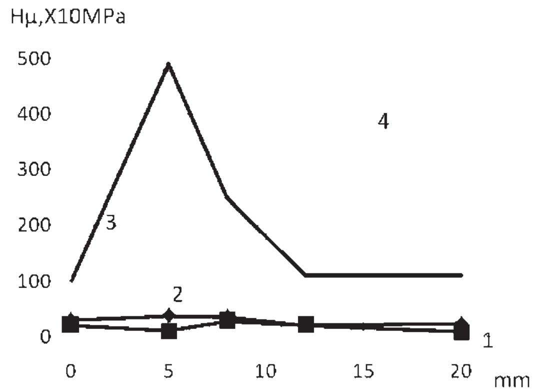

Fig. 4. The microhardness change of alloy matrix (*1*, *2*) and chemical compounds (*3*, *4*) depending on the distance from the welding pool (*1*, *3* — without; *2*, *4* — after *EP*)

be associated with the redistribution of chemical elements forming the phase components of the alloy, the processes of diffusion mass transfer should explain the effects nature in the electric pulse treatment.

The microhardness distribution in the aluminum matrix ($H\mu$) depending on the distance from the welding pool is shown on the Figure 4. The extreme nature of dependency indicates a rather complex distribution of residual internal stresses. Subjecting the heat-affected zone of alloy after the welding joint formation to the electric pulse treatment, the nature change of microhardness distribution is detected. The analysis of the dependencies indicates the existence of qualitative differences, especially for the superheated area of alloy. Moreover, based on the comparative analysis of absolute values of the alloy matrix hardness (α- solid solution Si in Al), as a result of electric pulse treatment a decrease in hardness difference (approximately 10% from the minimum to maximal values) is achieved. Something like that by the nature of its manifestation is noted for the areas of the second phases (Fig. 4, curves 3 and 4).

Comparative analysis of the absolute values of chemical compounds hardness shows that as a result of *EP* the reduction of hardness difference is also achieved. Although this reduction is more significant: before electric pulse treatment the hardness difference was 75%, and after that — approximately half as large (Fig. 4, curves 3 and 4). The experimental data analysis of microhardness distribution indicates that as a result of *EP* use of arc welding joint it is detected not only the gradient microhardness decrease, but the simultaneous reinforcing effect. Indeed, on the basis of the dependencies shown on Figure 4, for both the matrix and the chemical compounds for the full range of distances (from the welding pool) a quite unambiguous hardness increase is observed. The results of studies of the alloy structure using the scanning electron microscopy are presented on Figure 5. As compared to the microstructure observed under a microscope (Fig. 2) when it can only be classified as a two-phase, the electron microscopy indicates the existence of at least two chemical compounds and two solid solutions (Fig. 5). The obtained results of the study are in good agreement with well known published data [2]. Despite this, the shown dependencies of change *H*μ for the solid solution areas and sections of chemical compounds before and after electric pulse treatment (Fig. 4) still represent a particular scientific interest. This is caused by the fact that actually the represented dependencies are the result of the hardness values averaging according to the two solid solutions and some chemical compounds. The microstructure studies revealed that according to the characteristic features of the alloy structure before and after the welded joint formation are practically the same that corresponds to the metal condition after casting. The observed minor differences have more to do with segregation phenomena of chemical elements during the alloy manufacturing and its crystallization. After *EP* of the alloy welded joint the developed processes of structural transformations have led not only to the changes of the structural component dispersion, but also to the changes of their distribution in the matrix (Fig. 1, 5).

Thus, the comparative analysis points to a qualitatively different structural condition of the alloy after electric pulse treatment. Indeed, in case the as-welded alloy has obvious signs of cast condition, then after *EP* these signs are almost absent. In the majority of cases the phase components are presented in the form of globular particles or areas with specific length (Fig. 5). When studying the chemical composition of the phase components, it was found out that the observed structural changes of alloy as a result of electric pulse treatment first of all may be caused by the chemical elements redistribution, which form the compounds themselves. Something similar was observed during the variation of silumin chemical composition, the use of special modifiers [2] or by changing the crystallization conditions [1]. Indeed, studies have shown that the relation of chemical elements that are involved in the formation of certain compounds changes after electric pulse treatment.

The microhardness nature of the phase components confirms the above mentioned. If we consider the microhardness change of the alloy matrix (Fig. 4), then it is safe to assume that as a result of electric pulse treatment the slight hardness increase as a whole should not be accompanied by changes of solid solutions concentration. The micro spectral analysis data of solid solutions of the alloy matrix confirmed their practical constancy (Fig. 5). Indeed, α — a solid solution (Si in Al), which consisted of 97% Al, 1,5% Si and 2,7% Cu after *EP* remained almost the same: 96% Al, approximately 1% Si and 2,9% Cu. The same can be said of β in the solid solution (Al in Si). Before *EP* its composition was: 2,8% Al and 97% Si, elsewhere 10% Al and 90% Si, which indicates the substantial segregation of the chemical elements in solid solutions. After *EP* the following relation of chemical elements was found out: 6,4% Al and 94% Si. Concentration averaging of elements in the solid solutions alloy matrix shows almost unchanged relation before and after *EP*. Consequently, as a result of *EP* the relation of chemical elements in the alloy matrix (α-solid solution), and in the sections of β solution after termination of electrical pulses remains almost unchanged. In this case the observed changes during electric pulse treatment, should be more fully

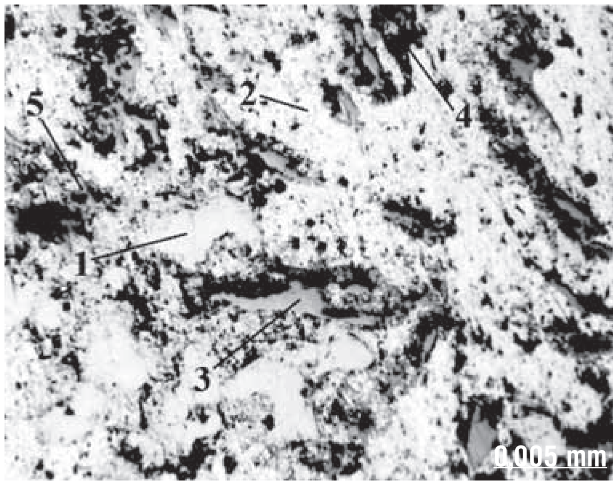

Fig. 5. Alloy microstructure after *EP* of the welded joint formation (chemical compound: $Al_{15}(Fe, Mn)$ — (*3*); Al_5FeSi — (*4*); Al_2Cu — (*5*), solid solution: Al in Si — (*1*); Si in Al — (*2*))

explained by structural changes, such as changes in grain size and shape, concentration and distribution of dislocations, coherent scattering regions that in fact is confirmed by the results of X-ray analysis (Fig. 3). During the behavior analysis of the chemical compounds the nature of changes is much more difficult. The analysis of such chemical compound as Al_5FeSi and $Al_{15}(Fe, Mn)_3Si_2$ has shown the constancy of elements relation, both before and after *EP* with a sufficiently high accuracy. Unexpected results should also after *EP* include the appearance of the new chemical compound Al_2Cu (50% Al, 1,3% Si and up to 48% Cu). Taking into account the relatively high sensitivity of aluminum alloys to the presence of iron in their composition that reduces the plastic characteristics supply the reduction of the negative impact of Fe is an important technological problem. In practice, one reduces the embrittlement effect by the change of casting technology, using the injection casting and chill casting, or changing the chemical composition of the alloy. Indeed, the harmful iron impact can be reduced by the manganese or chromium introduction [2]. On the basis of data of the work [2, 6, 8], the complexity of these phases results in the change of their morphology: the form of plate is replaced by the skeletal form. In this case, the eutectic components location at the grain boundaries of the alloy matrix results in the deviation from the strict plate form. As a result, a decrease of the embrittlement effect is observed. And even higher level of plastic characteristics is observed for globular structures. In this case, the plasticity increase can reach the level of 3%. The results indicate quite significant influence of electrical pulse treatment on both the morphology of alloy structural components and the relation of chemical elements involved in the formation of certain phases. Indeed, if after the welding (zone I, III) the alloy had the majority of the signs of the cast condition with characteristic plate forms of the eutectic components (Fig. 2), the use of electric pulse treatment has led to the quite significant qualitative changes in the internal structure. The globular structures formation (Fig. 5) indicates a high degree of ET influence on the development of structural change processes. In some cases the above mentioned treatment can even compete with the thermal technologies. On this basis, the effect of gradient microhardness reduction (gradient of internal stresses) in the heat-affected zone during the welded joint formation is actually quite clearly explained by structural changes.

4. CONCLUSIONS

1. After the electric pulse treatment treatment of the welded joint, the silumin hardness increase is accompanied by the decrease in the number of crystal structure defects and coarsening of coherent scattering regions.

2. The development of the redistribution processes of chemical elements during the electric pulse treatment is accompanied by the morphology changes and the structural components distribution, the appearance of additional chemical compounds.

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