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RESEARCH INTO TECHNOLOGICAL PROCESSES OF TREATMENT OF METALS, ALLOYS AND WELDED JOINTS USING ELECTROMAGNETIC FIELD (REVIEW)

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ABSTRACT

An analysis of promising technologies for improving the mechanical characteristics and the stress states of metal materials and welded joints based on the use of electromagnetic fields and their derivatives, such as electrodynamic pressure force, eddy currents, and shock waves, was carried out. The process of electrohydropulse treatment by high-energy discharge (EPT HED EHIPD) using a hydrocarbon liquid for the production of polydisperse mixtures used for alloying the weld metal of welded joints as part of flux-cored wires is considered. The positive effect of micro-additives of the Ti–TiC system modifier obtained by EPT HED on the operational properties of the deposited metal of the 25Kh5FMS tool steel type was determined. It is shown that treatment with a pulsed electromagnetic field (PEMF) improves the residual stress states of welded joints. New process diagrams for the application of electrodynamic treatment (EDT) of welded joints are considered. The advantages of PEMF and EDT of the weld metal in the welding process in comparison with treatment at room temperature are proved. The mechanism of surface hardening of 25KhGNMT steel as a result of its pulsed barrier discharge treatment (PBD) was investigated. It is proved that the PBD increases the dislocation density and disperses the microstructure, which has a positive effect on the mechanical characteristics of steel. The prospects for the use of PBD for non-destructive testing of residual stress states of welded joints are considered.

KEYWORDS: welded joint, electromagnetic field treatment, electrodynamic treatment, residual stresses, fusion welding, surface hardening, titanium carbide, polydisperse mixtures, residual deformations, aluminium alloys, structural steels, dislocation density

INTRODUCTION

The development of high-tech engineering industries stimulates the development of new technologies for extending the service life of welded structures based on the use of advanced electrophysical phenomena, including electromagnetic fields, electric currents of various configurations and electrodynamic forces. The research results give reason to believe that new technologies for treatment of welded structures can be based on the principles of controlling the mechanical properties of metal alloys and welded joints using electrophysical phenomena [1, 2].

THE AIM

of the study is to analyse promising technologies for improving the mechanical characteristics and stress state of metal alloys and welded joints based on the use of electromagnetic fields and their derivatives (electrodynamic pressure force, eddy currents, shock waves, etc.).

A high-voltage pulse discharge in a conductive liquid is used in the industrial technology of electrohydropulse treatment as a source of dynamic pressure, under the effect of which the materials being treated can change their size, structure and mechanical characteristics. Such treatment involves the impact of a dynamic load on the object initiated by a high-voltage electric discharge of a pulsed electric current in an aqueous medium. This is a cyclic process characterized by the release of energy in the discharge channel within microseconds and accompanied by the action of compression waves (which under certain conditions are transformed into shock waves), powerful hydroflows, cavitation, electromagnetic and thermal fields. Studies of the impact of the mentioned treatment on the stress-strain state of welded joints have shown that it reduces tensile stresses in welded structures by up to 90 % [3]. However, the technologies of such high-voltage electric discharge treatment have not been widely used in metal-working because of the low process performance and significant metal and energy consumption of the equipment.

The use of electrohydropulse treatment with a high-voltage electric discharge using a hydrocarbon liquid (instead of water) for the production of polydisperse mixtures containing nanoparticles with special properties used for alloying the weld metal of welded joints is promising. This treatment variant allows implementing an energy-efficient method of grinding metal alloys — discharge-pulse preparation of powders by using a high-voltage electric discharge in the liquid-powder dispersion system. Its cyclic action enables fine grinding by pressure waves due to the formation of a large number of defects in the powder, which helps to reduce the energy of crystal destruction, the formation of a large number of active centres and facilitates chemical interaction between the elements of the system under conditions of dynamic loading. The use of a hydrocarbon liquid as a working medium under such processing of powder mixtures not only provides elimination of their oxidation, but also creates thermodynamic conditions for the pyrolysis of kerosene with the formation of solid-phase carbon, which is capable of entering into carbidization reactions with powder particles, forming nanostructured strengthening phases [4, 5].

For electrohydropulse treatment with high-voltage electric discharge [4, 5], specialized equipment is used, which, in addition to the power source, includes a chamber — a container, where the powder grinding process takes place and which must withstand significant dynamic and thermal loads (Figure 1).

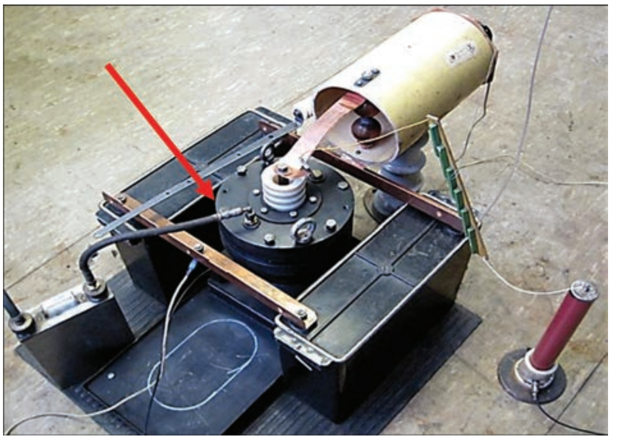

Figure 1. Appearance of equipment for electrohydropulse treatment using high-voltage electric discharge, where the arrow indicates the chamber in which powder grinding takes place [6]

To investigate the efficiency of using polydisperse mixtures produced by this treatment, the weld metal was alloyed with Al- and Ni-based alloys, into the melts of which powders were introduced.

The introduction of 0.01 wt.% of the Ti–TiC modifier, synthesized by this treatment of Ti-powder in kerosene and briquetted by spark plasma sintering, made it possible to reduce the grain size from 1–2 to 0.2–0.6 mm in all modified specimens of the Ni-based heat-resistant SM88U alloy [6]. Under these conditions, the ultimate tensile strength at 900 °C and long-term strength increased by 20 %. This indicates the prospects of using metal powders after treatment with a high-voltage electric discharge to modify the cast structure of welds of nickel alloy structures operating at elevated temperatures, as well as the effect of the Ti–Al–C system modifier after appropriate synthesis on the structure refinement and improvement of the properties of welded joints made of aluminium $AK7_{pch}$ (A357) alloy for the body parts of marine engines [7].

Polydispersed mixtures produced by applying a high-voltage electric discharge are used as part of the charge of flux-cored wires for arc surfacing. This simplifies the process of introducing the powder into the weld pool during the phase of the filler liquid metal transfer. The positive effect of micro-additives of the Ti–TiC system modifier on the operational properties of the deposited metal of the 25Kh5FMS tool steel type has been determined. The modifying powders of the Ti–TiC system were produced by the above treatment of Ti-powder in kerosene. The modification of the deposited metal with Ti-carbides in the amount of ≈ 0.01 % does not deteriorate the quality of the formation of deposited beads and slag crust detachment. The introduction of micro-additives of Ti carbides in the amount of 0.01 % to the deposited metal leads to an increase in its heat and wear resistance under conditions of elevated temperatures by 15–50 %, depending on the type of used modifying additive [8]. The effect of boron and titanium carbides modifying the boron additives introduced in the same amount into the charge of PP-Np-25Kh5FMS powder electrode wire on the structure and properties of the deposited metal was compared. It is shown that the introduction of additives of both types of modifiers in the amount of 0.01 % significantly affects the structure of the deposited metal, and their effect on the structure is different. It was found that modification with boron leads to a significant reduction in the size of crystallites, redistribution of non-metallic inclusions, and an increase in the microhardness of the metal. The introduction of titanium carbide micro-additives into the weld pool affects the kinetics of metal crystallisation, which provides elimination of the columnar structure of crystallites and its transformation into a cellular structure. It has been shown that due to these structural changes, the wear resistance and heat resistance of the metal deposited using both types of modifiers increase [9].

The obtained results help to improve the characteristics of materials for surfacing parts of special equipment operating under conditions of abrasive wear and cyclic thermomechanical loads. Thus, the use of polydisperse mixtures produced by a high-voltage electric discharge in a hydrocarbon liquid creates a new direction for optimizing the mechanical properties of deposited structural elements.

Based on the results of research in the field of materials science, the phenomenon of improving the ductility of a metal due to its active loading at the time of passing (through the metal) a high-density electric current pulse j (j ≥ 1.0 kA/mm^2) was established. The phenomenon is called the electroplastic effect, and the deformation initiated by it is called electroplastic [10]. The practical use of this effect has opened up new opportunities for metal-working and welding technologies [11]. The accompanying heating with a pulsed electric current treatment ($j \geq 1.0$ kA/mm^2) of structural steel specimens that were previously subjected to uniaxial elastic tension leads to tensile stress relaxation [12]. However, under heating conditions without the use of such a current, the tensile stresses in the specimen returned to their initial level after cooling to room temperature. The effect from the pulses action decreased with an increase in their number. From the point of view of electron-dislocation interaction, this is explained by the fact that a single current pulse acts on a material with a significant dislocation potential. Under the conditions of repeated impact of electric current pulses, the previous pulses remove some dislocations from the relaxation processes and the electroplastic strain decreases as a result of the electroplastic effect [13].

Changing the polarity of current pulses also affects the manifestation of this effect, and with the same amplitude (when studying a loaded specimen), bipolar pulses cause a smaller relaxation (jump) of stresses than monopolar ones [14], since electric current pulses of different polarity, initiating the movement of dislocations in opposite directions, counteract each other and their resulting effect is smaller than under conditions of monopolar electric current pulses. Their effect on the metal occurs in the plastic deformation area, accompanied by the release of the deforming force, while in the elastic deformation region, the electroplastic effect is not observed. Paper [15] discusses the mechanism by which stress relaxation is possible in the elastic region of loads and is caused by the action of current pulses. In [16], a procedure was developed for determining the part of the energy of ECP current pulses that is spent on the operation of electroplastic deformation.

Based on the results of studies of the electromagnetic effect of pulsed current on the mechanical characteristics of metals and alloys, technological processes of metal-working have been developed. Changes in the duration and energy of such a current and pulsed electromagnetic field lead to the activation of a spectrum of dislocation, phase and other physical processes, i.e., it becomes possible to control the mechanical characteristics of metals and alloys. Both electromagnetic effects implemented in various metal-working technologies cause structural changes in metals and alloys [17–19], which affect their mechanical characteristics. An increase in tool wear resistance [20], corrosion resistance [21–23], reduction in stress concentration [24], elimination of fatigue cracks, and extension of service life of parts made of light and special alloys [25] are noted. It has been found that at optimal values of the pulsed electric current parameters, the tensile strength of material, endurance limit, and durability increase without reducing the ductile properties of the material [26].

Analysing the abovementioned, it should be noted that the effects of pulsed electric current and pulsed electromagnetic field can be used to improve the mechanical characteristics and extend the service life of welded joints, which are also covered by the results [17–26] obtained for metals and alloys.

The study of stress relaxation features in metals and alloys caused by electric current pulses and pulsed electromagnetic field treatment is a promising area of engineering practice for control of residual stress states of welded structures. The effect of a pulsed field on reducing residual stresses in butt welded joints of the aluminium AMg6 alloy was investigated. A system of two plane inductors rigidly fixed on the same vertical axis on the outer and back surfaces of the weld was used. The welded joint to be treated, the inductor system, and the pulsed field generator (capacitive energy storage) are part of the discharge circuit [27]. The conducted studies have shown the possibility of reducing welding stresses by up to 30 % under the effect of a pulsed electromagnetic field. The low efficiency of this treatment diagram is associated with the irrational arrangement of the inductors, in which the vectors of electromagnetic pressure (which are initiated by the action of this field) on the weld metal on both sides of the plate act in the opposite direction to each other. This leads to mutual annihilation of the pressure on the weld metal, and stress relaxation occurs exclusively due to electroplastic deformation under the condition of $j \geq 1$ kA/mm^2, which was met in [27]. A more rational diagram with a single plane inductor and a shield of nonferromagnetic material (disc of AMg6 alloy) located on the same axis on both sides of the specimen with a butt weld, respectively, is described in [28]. The shielding of the weld metal during the pulsed electromagnetic field treatment provides (due to the growth of the skin layer in the specimen metal at a certain pulsed current frequency) an increase in the volume of the current-carrying medium. Since the pressure force directly depends on the volume of the medium, its increase (with the use of a shield) contributes to a threefold increase in force (compared to pulsed electromagnetic field treatment without a shield) at constant values of the treatment mode parameters. This ensures a reduction in residual tensile welding stresses by up to 90 % with an eightfold reduction in displacements of the specimen surface points after treatment.

The effect of a pulsed electromagnetic field on the level of residual stresses in welded and deposited specimens of low-carbon steels, based on the intensification of the dynamic effect of magnetostriction [29], provided the reduction in stresses by up to 40 %.

The results of studies of the effect of this field on the change in residual welding stresses are shown in [30]: residual tensile stresses in specimens of welded joints made of St2(semi-killed) steel are reduced by 3–25 %, and there is a more uniform distribution of α-phase over the volume of the treated metal.

Comparison of the efficiency of pulsed electromagnetic field treatment on residual stresses in welded joints made of ferromagnetic and nonferromagnetic materials showed that its effect on the former is less influential. The obtained results can be explained by the fact that under the conditions of pulsed electromagnetic field treatment of ferromagnetic materials, the electromagnetic pressure force is consumed not only for stress relaxation, but also for magnetoelastic interaction of interdomain boundaries (Bloch walls) with dislocations [13, 31]. During this treatment of welded joints made of nonferromagnetic materials, the domain structure is absent, and the electromagnetic pressure force is used exclusively for stress relaxation.

The combined use of electropulsed and mechanical effects for the treatment of welded structures in order to extend their service life serves as the basis for the development of such a method of treatment of welded joints as the electrodynamic method [32]. It is based on the initiation of electrodynamic forces arising from the passage of a pulsed electric current in the material, provided that $j \geq 1$ kA/mm^2. During electrodynamic treatment, welded joint is subjected to a volumetric electrodynamic effect, which is characterized by the joint occurrence of electrical pulse and dynamic processes, their synergy in the treatment zone initiating the relaxation of welding stresses (according to the mechanism of electroplastic deformation) and dispersion of the metal structure.

The method of electrodynamic treatment has been widely used in engineering practice to eliminate local welding deformations such as "bulging" [33]. The effect of the diagrams for treating the outer surface of the bulging, such as "spot", "concentric circles", and "spiral", was investigated. It was proved that the least effective is the "spot" diagram, and the most effective is the "concentric circles" or "spiral" diagram, which allows to completely eliminate this defect. A comparative analysis has shown that the energy costs for removing the bulgings by this method are significantly lower than for thermal straightening.

The development of the abovementioned method for correcting local deformations of the "bulging" type when using the "concentric circles" diagram is also considered in [34]. The equipment for its implementation has an electromechanical electrode device and a power source with a pulsed electric current. The device for electrodynamic treatment is made in the form of at least one pair of identical mechanisms, each of which contains an electromechanical electrode-indenter (Figure 2). The devices are rigidly connected to each other through a clamping mechanism for fixing the indenters, each of which is equipped with an ultrasonic vibrator connected to a common power source.

The improved method of electrodynamic treatment can be used, for example, for technological support of the ongoing production of cladding plates for welded ship hull structures. During the straightening process, the treatment is performed simultaneously on at least one pair of bulging surface areas, and in conjunction with ultrasonic radiation concentrated in both treatment zones. The diagram of elements is shown in Figure 2, which shows the design of the electromechanical part of the device with an orientation towards the elimination of local deformations of the "bulging" type of thin-walled elements of welded structures. The combination of electrodynamic and mechanical (ultrasonic) effects allows achieving maximum efficiency of the process of electrodynamic treatment of welded joints.

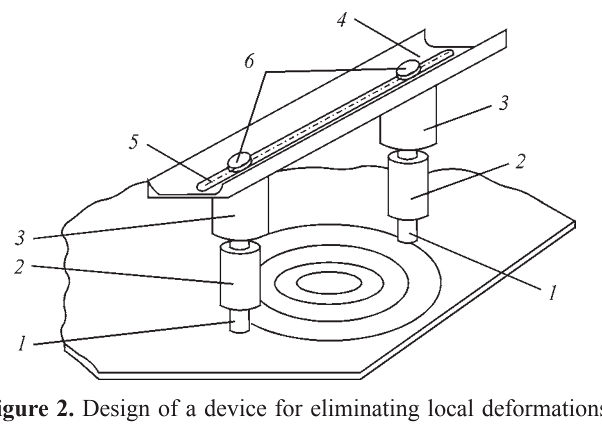

Figure 2. Design of a device for eliminating local deformations of the "bulging" type in plane elements of welded structures (discharge circuit branches are not indicated): *1* — movable electrode-indenter for electrodynamic treatment; *2* — ultrasonic exciter of mechanical oscillations (magnetostrictive or piezoelectric type); *3* — electromagnetic drive; *4* — traverse for mutual positioning of electrodes; *5* — linear groove; *6* — screw clamp [34]

Taking into account the results [14], which show that accompanying heating stimulates stress relaxation during electropulsed treatment of thin steel rods, research works on the efficiency of electrodynamic treatment of a cooling weld, performed during the thermodeformational welding cycle, are promising.

On the basis of [12–16], a hybrid technology "automatic welding + electrodynamic treatment" was developed, which allows lowering the energy intensity of the treatment process, reducing the working time for manufacturing a metal structure and simultaneously improving its quality [35]. The method of modernizing the process of electrodynamic treatment of welded joint metal differs in the fact that the weld on the root side is equipped with a sliding movable contact of the return terminal of the discharge circuit from the pulsed electric current power source. In the process of producing a welded joint, the movement of the movable contact is coaxial with the location of the contact zone of the electrode-indenter. The device for implementing the modernized method has an electrodynamic treatment unit with an electromechanical electrode-indenter and a pulsed electric current power source (Figure 3). The discharge circuit for the implementation of this treatment, in conjunction with the welding process by torch *8*, sequentially includes a movable indenter *2* and a part *14*, welded by weld *1* with a remote location of the reverse contact terminal *9*. The electromagnetic part of the indenter *4* and its movable impact mechanism are connected to the autonomous pulsed current power sources *5* and *6*, respectively, which is switched on at the electrode synchronously with the signals from the movable impact mechanism. The device contains a table *15* with a material sample in the weld location area *1* and a support traverse with a spring-loaded contact of a longitudinal slider *11* fixed below the table surface along the weld line, having an electrical connection to the return terminal of the pulsed power source of the corresponding electric current of the indenter impact mechanism (terminals I–II). This mechanism and the elastic contact of the slider have rigid mechanical connections with mechanisms for synchronizing the relative position of their axes. This modernization of the electrodynamic treatment method provides complete elimination of the effect of spark erosion of the treated material surface, as well as the possibility of a significant increase in the treatment efficiency based on the coordination of the phase characteristics of pulsed effects in the conditions of using a differentiator (synchronization device) in the pulsed electric current power source, i.e. in the pulsed power source (terminals III–IV).

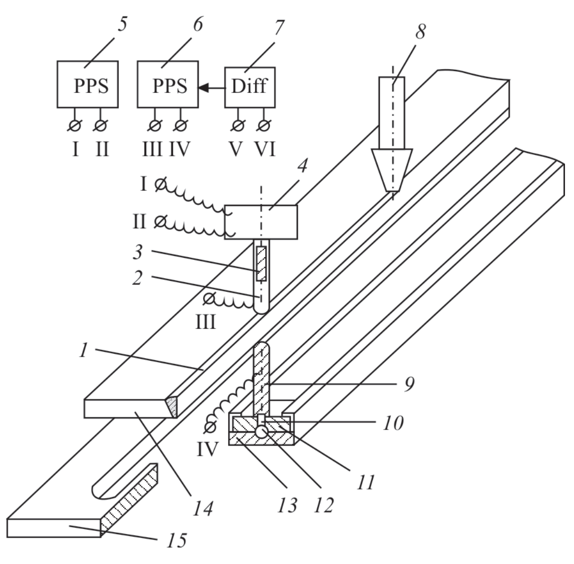

Figure 3. Diagram of the electrodynamic treatment method [35]: *1* — weld; *2* — movable part of the indenter; *3* — displacement sensor; *4* — electromagnetic part of the indenter; *5* — pulsed power source PPS (terminals I and II) of the electromagnetic part of the indenter; *6* — pulsed power source PPS (terminals III and IV) of the impact part of the indenter; *7* — differentiator Diff (terminals V and VI); *8* — welding torch; *9* — slider contact; *10* — rest spring; *11* — slider; *12* — roller slider rest; *13* — resting traverse; *14* — part to be welded; *15* — work table

A necessary condition for the implementation of this method is the synchronization of the pulsed electric current period with the time interval of dynamic pressure pulses based on a rational configuration of the discharge circuit, where the current pulse of the movable part of the electrode-indenter is controlled and transferred only when the signal is ready to propagate in the weld metal. The signals are synchronized by the element base using a differentiator *7*. The preceding action of the dynamic pressure pulse provides the necessary contact pressure for the passage of the pulsed electric current and eliminates the manifestation of spark-arc effects. Thus, the implementation of the electrodynamic treatment method is ensured by the design and composition of the equipment of the corresponding device. The mechanical equipment corresponds to one of the possible variants of the power layout of the equipment for this treatment with support for the function of stabilizing the relative positioning of the contact elements of the discharge circuit.

The method of "electrodynamic treatment + TIG welding" is implemented in an automated welding complex (Figure 4, *a*), whose design principles are based on the results of [35]. Testing of the method confirmed its efficiency in eliminating residual tensile stresses in butt joints of AMg6 alloy. The initial values of σ_x (along the weld) of membrane stresses (without electrodynamic treatment) reached up to 100 MPa in the centre of the weld. It was proved that while the above treatment after welding (at T = 20 °C) ensured the formation of membrane compressive stresses σ_x (along the weld) up to –50 MPa in the centre

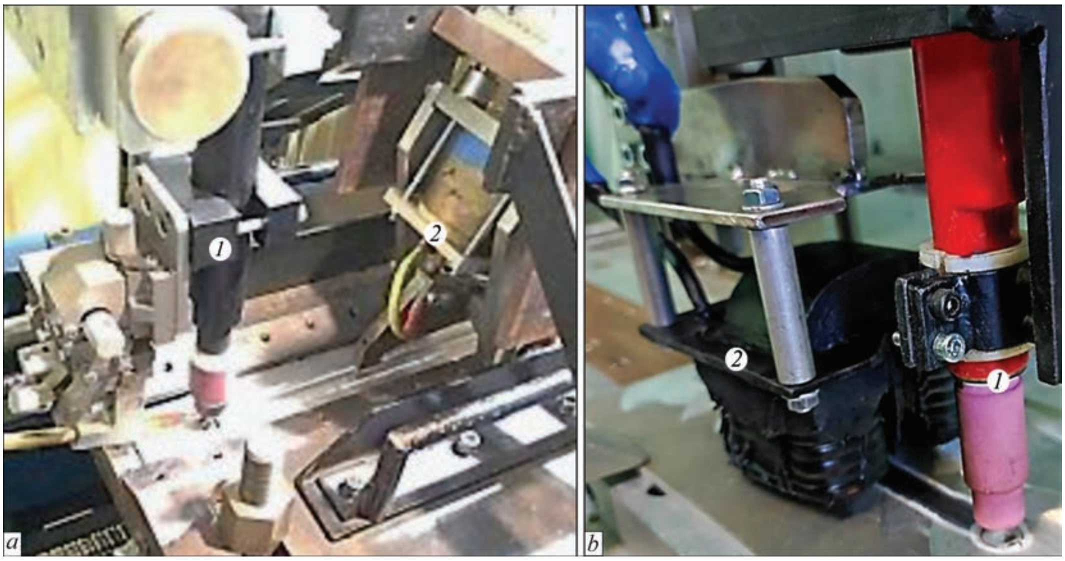

Figure 4. Appearance of equipment for hybrid welding technologies: *a* — "TIG welding + electrodynamic treatment" [36]: *1* — TIG torch; *2* — electrode system for this treatment [36]; *b* — "TIG welding + pulsed electromagnetic field treatment" [41]: *1* — TIG torch; *2* — inductor for this treatment [41]

of the weld, after it during welding (at T = 150 °C) $\sigma_x = -100$ MPa [36].

Among the recent methods of external effect on the quality of metal products is the study of the effect of pulsed electromagnetic fields and constant magnetic fields) applied to the melt during its solidification to produce cast billets and parts from nonferromagnetic materials, such as aluminium alloys. It has been determined that the effect of constant magnetic fields contributes to the evolution of their structure and increases resistance to corrosion damage. The mechanism of structure formation is based on the manifestations of the action of these fields — structural components decrease, a morphology of intermetallic phases changes, their microhardness increases, their sizes and configuration change, which are similar to the solidification processes at high cooling rates [37].

The liquid metal, which is the content of the weld pool, in fusion welding, under certain assumptions, is similar in properties (with a much smaller volume) to the metal during casting, i.e., suitable for treatment with a pulsed electromagnetic field and a constant magnetic field. Taking into account the results of [37], it should be noted that the abovementioned treatment of the cooling metal at the rear front of the weld pool is appropriate to improve the residual stress-strain state and structure of the welded joint metal. This led to the creation of a suitable method for treating welded joints during a thermodeformational welding cycle and a hybrid technology "automatic welding + constant magnetic field treatment" [38]. This method is advisable for welded joints made of nonferromagnetic metal alloys based on Al, Mg, Ti, which do not have domain structures. This results in a higher electromagnetic pressure force (compared to carbon steels) generated by a constant magnetic field.

As a tool to control the structure of the weld metal and the stress state of the welded joint, it is promising for energy reasons to use a pulsed electromagnetic field instead of a constant field with a set frequency to influence the rear front of the weld pool. The use of a pulsed field can significantly increase the energy and, as a result, the force of electromagnetic pressure on the weld metal compared to the use of a constant field. ECP generators based on components of modern power electronics provide a pulsed electromagnetic field frequency of $\leq$ 1/s [39, 40]. The frequency of its actions at standard TIG welding speeds V_w = 4 mm/s is comparable in efficiency to the effect of a constant magnetic field. A mathematical model of electrophysical processes under the action of a pulsed field on nonferromagnetic materials based on Al was developed and its positive effect on the structure and residual stresses of welded joints made of AMg6 alloy was proved [41, 46]. Based on the results of [39–41, 46], an automated welding complex was created (Figure 4,*b*), which implements the hybrid technology "pulsed electromagnetic field treatment + TIG welding".

A promising direction for the treatment of metal alloys and welded joints is the use of electro-pulse AOTs technologies, originally developed for the technical purification of aqueous solutions [42]. The generation of electric current pulses in AOTs occurs near the surface of the medium being treated and uses a pulsed barrier discharge that acts on the surface through a dielectric barrier.

The generation of electric current pulses on the surface of metal alloys has led to the creation of a new technological process — metal pulsed barrier discharge treatment (Figure 5) [43]. It generates low-temperature plasma on the surface of the metal being treated, and its application is a new approach to optimizing the mechanical properties of high-strength steels for welded

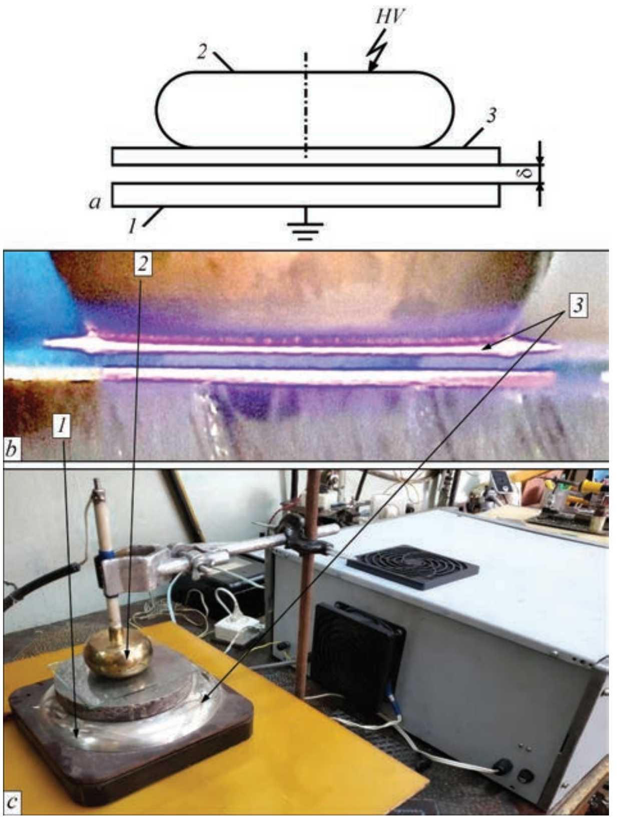

Figure 5. Treatment of metal alloys by pulsed barrier discharge (PBD) [44]: *a* — treatment diagram; *HV* — high voltage from the pulsed current generator; *1* — metal being treated; *2* — electrode; *3* — dielectric barrier (quartz glass); δ — air gap; *b* — structural steel treatment process; *1–3* correspond to Figure 5, *a*; *c* — hardware complex for treatment of metals and welded joints

structures, based on electrophysical processes. In [44], the strengthening of 25KhGNMT steel as a result of the action of such a discharge on its surface was investigated. Based on the transmission electron microscopy method, it was found that the HV hardness values after pulsed barrier discharge treatment increase from 420 to 505 kg/mm^2 and are accompanied by a general increase in dislocation density and microstructure dispersion. This has a positive effect on the mechanical properties of 25KhGNMT steel for welded structures operating under dynamic loads. The obtained results open up new possibilities for the application of pulsed barrier discharge treatment for the evolution of the structure of metal alloys and welded joints.

Figure 6 shows a structural diagram of electrophysical technologies based on processes using a pulsed electromagnetic field. One specific area of research is the study of the effect of pulsed barrier discharge treatment on the service life of metal alloys and welded joints, including light and non-ferrous alloys and structural steels, with the aim of evolving their structure to increase hardness and regulate stress states.

Studying the possibility of using pulsed barrier discharge treatment for local non-destructive evaluation of residual stress states in metals, alloys and welded joints is promising. Treatment of local areas (with a diameter of ≤ 1.0 mm) can be an alternative to drilling local holes on the metal surface, which is a necessary condition for the use of the electronic speckle interferometry method to determine stresses [45]. The disadvantage of this procedure is that it is conditionally destructive. This limits its use on full-scale critical metal structures that are intended for operation and on which even minimal surface point damages are excluded.

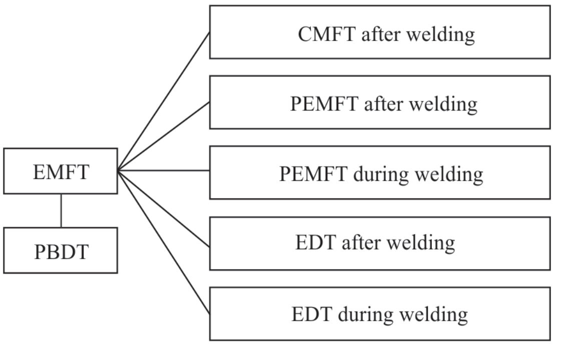

Figure 6. Structure of promising research on the effect of magnetic field treatment (EMFT) on the life of metal alloys and welded joints: CMFT — constant magnetic field treatment with a; PEMFT — pulsed electromagnetic field treatment; EDT — electrodynamic treatment; PBDT — pulsed barrier discharge treatment

Thus, the use of the speckle interferometry method is only possible on witness specimens or simulation structures. In the proposed procedure, pulsed barrier discharge treatment of a local surface area can be used for stress relaxation (instead of drilling a hole). Determining correlation dependence between the speckle-patterns of the surface around the treated area and around the drilled hole will allow using electronic speckle-interferometry as a non-destructive method for evaluating stress states on the surface of metal welded structures.

The experience in studying the impact of electromagnetic fields on metals and alloys proves the possibility of using electrophysical technologies to control stress states, improve the structure, tribological and mechanical characteristics of welded joints in structures of mechanical engineering, shipbuilding and aerospace industry.

CONCLUSIONS

1. Promising technologies for improving the mechanical properties and stress state of metal alloys and welded joints based on the use of electromagnetic fields and their derivatives, such as electrodynamic pressure force, eddy currents, and shock waves were analyzed.

2. The positive effect of microadditives of the Ti–TiC system modifier, obtained by electrohydropulsed treatment with high-energy discharge, on the operational properties of the deposited metal of the 25Kh5FMS tool steel type were proven.

3. It was shown that various methods of treatment with a pulsed electromagnetic field contribute to the reduction of residual stresses in welded joints. The advan-

tages of such treatment of weld metal during welding compared to treatment at room temperature were proven.

4. The mechanism of surface strengthening of 25KhGNMT steel as a result of its pulsed barrier discharge treatment was investigated. It was proven that it contributes to an increase in dislocation density and microstructure dispersion, i.e. it has a positive effect on the mechanical properties of steel. The prospects for using pulsed barrier discharge for non-destructive testing of residual stresses in welded joints was considered.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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