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EFFECT OF PHYSICAL-MECHANICAL PROPERTIES OF THE MATERIALS JOINED AND GEOMETRY OF THE PARTS ON DISTRIBUTION OF STRESSES DURING DIFFUSION BONDING IN VACUUM

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The method of computer modelling based on FEM was used to study the stress-strain state of cylindrical parts in diffusion bonding. It is shown that the complex stressed state with a non-uniform distribution of stresses is formed over the surface of a bond in joining even simple parts from dissimilar materials. It is established that thermal cycling is indicated to localise plastic strains within the bond zone in joints with different values of linear temperature expansion coefficient.

Keywords: diffusion bonding, similar and dissimilar materials, stress-strain state, computer modelling

Diffusion bonding in vacuum, which is one of the pressure joining methods, opened up wide prospects for making unique assemblies and parts applied in most diverse industries [1]. One of the factors providing a physical contact and activation of the mating surfaces and, therefore, quality joining of the parts is plastic deformation of metal, which depends upon the compression pressure, bonding temperature and loading speed [2–4].

According to the classical scheme of diffusion bonding, a punch presses together the parts being joined at a certain force, the distribution of which over the mating surfaces is assumed to be uniform, and the stress-strain state is assumed to be linear. It is not favourable for interaction of the mating surfaces, nor does it correspond to reality. As follows from literature data [1, 3, 5, 6], different bonding conditions may be recommended for the identical materials, and they may not coincide for real parts and experimental samples. No results of investigations into the stress-strain state during the process of diffusion bonding have been reported in literature. It has been noted, however, that the quality of bonding is determined by the processes occurring within the bonding zone, wherein the plastic deformation is localised [2, 4]. In this connection, investigation of the stress-strain state in diffusion bonding is a pressing problem in current research.

The purpose of this study was to investigate the capabilities of regulation of the stressed state in diffusion bonding of parts made from dissimilar materials in order to provide a quality bond with no significant general deformations of an assembly being made.

The character of distribution of normal (axial and radial), tangential and equivalent stresses over the entire bond plane, localisation of maximal equivalent stresses within the bonding zone, and size of the zone where the equivalent stresses exceed the value of yield strength were taken as criteria for evaluation of the stressed state. The first criterion determines homogeneity of the bond over the entire bonding surface, while the second and third criteria determine general deformations of the parts during bonding. It was assumed that normal axial stresses provide drawing of the mating surface together, and tangential and equivalent stresses act as decisive ones for activation of the processes of interaction of these surfaces and ensuring of the physical contact due to plastic deformation [3, 7, 8].

Joining of dissimilar materials with a different elasticity modulus and different linear thermal expansion coefficient (LTEC) is a quite common problem, which has to be solved in manufacture of assemblies of engineering parts. The above differences cause changes in the stress-strain state within the bonding zone. So, they may have a substantial effect on quality of the bond, as it is difficult to provide identical deformation conditions over the entire bond surface area.

Investigations of the cylindrical, *C–C* (Figure 1, *a, b*), and sleeve–sleeve, *S–S* (Figure 1, *c, d*), samples were conducted by computer modelling using the finite element method. As assemblies in the samples were located symmetrically about the axial line, the problem to be solved was of the axisymmetric type with annular finite elements (Figure 1).

Investigations were carried out to study the stress-strain state of models with different variants of combinations of physical-mechanical properties and loading types. Rigidity (elasticity modulus E) and values of LTEC of the materials joined were varied. The values of rigidity of the parts joined (1 and 2, Figure 1) were assumed to be identical ($E_1 = E_2$) and two times different ($E_2 = 2E_1$), respectively, at the identical ($\alpha_1 = \alpha_2$) and two times different ($\alpha_2 = 2\alpha_1$) values of LTEC.

It was assumed in the calculations that mechanical interaction of the mating surfaces is determined by the mechanics of deformation of an elasto-plastic continuum, i.e. at the absence of slip between the mating surfaces. Considered was the stage of force and temperature loading on the bond after initial compression of heated parts and formation of a physical contact. The stress fields were studied in compression under pressure P = 40 MPa, heating and cooling by 100 °C without loading, and in combined effect by the compression force and temperature variations (Table). The calculations resulted in deriving the fields and diagrams of distribution of axial, radial, circumferential, tangential, principal and equivalent stresses (Figures 2–6, Table).

As shown by the investigation results, there occurs violation of the uniformity of stress distribution across the section of samples (Figures 2–5, variants 1) in compression without temperature variations of even the simplest samples (cylinders or sleeves) made from materials of a different rigidity (variants 1, Table). In the vicinity of the bond, radial, circumferential and tangential stresses are added to the axial ones. The stressed state in this zone acquires a volumetric character. These stresses are low, and their values in a major portion of the bond do not exceed 10–15 % of the calculated axial ones (Figures 4, 5). The character and values of circumferential stresses almost completely coincide with those of the radial ones. Therefore, they are not shown in the Figures. The character and values of tangential stresses within the bond zone in both materials (sections of models 1–1 and 2–2) are almost identical. In samples of the *C–C* type, they grow from zero at the centre of the bond to maximal on its periphery. And in samples of the *S–S* type, the point with zero tangential stresses is located closer to the internal surface at a distance of about 1 / 4 of the sleeve thickness (Figure 5, *a*).

Axial and equivalent stresses along a major portion of the bond are distributed uniformly (Figures 3, *a*, *b*, and 6, *a*, *b*). Radial and circumferential stresses on the side of a more rigid material are tensile (Figure 4, *b*, *c*), this, in combination with compressive axial stresses, increasing equivalent stresses to some extent (Figure 6, *b*, *c*). Radial and circumferential stresses forming on the side of a less rigid material are compressive (Figure 4, *a*, *c*), this leading to a slight decrease in equivalent stresses (Figure 6, *a*, *c*).

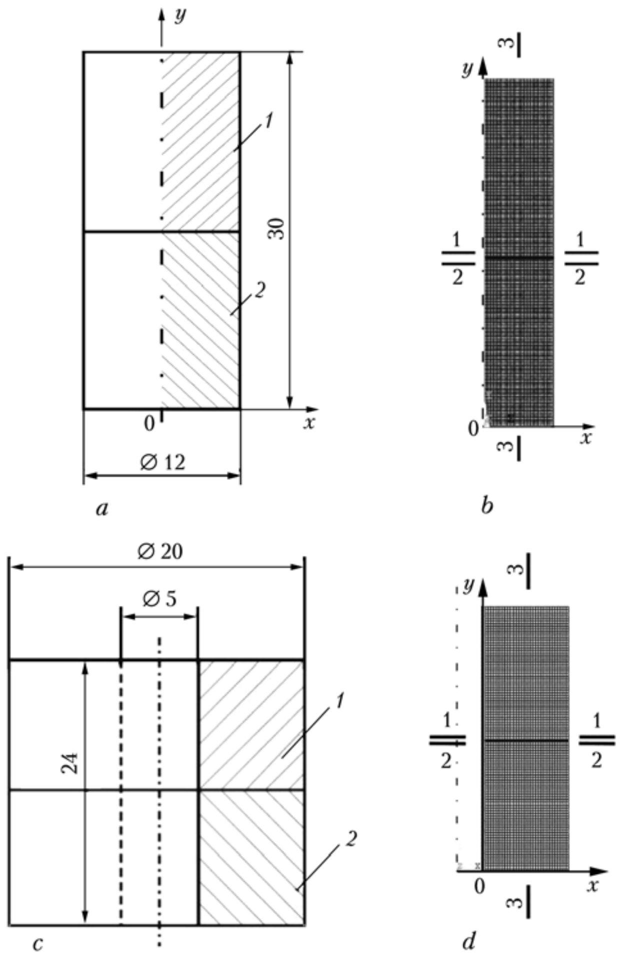

Figure 1. Schematics of samples of the bonds of the *C–C* (*a*) and *S–S* (*c*) types, and their models (*b*, *d*)

Principal minimal stresses σ_3 along the bond are distributed almost uniformly. They increase to some extent on the periphery and are normal to the bond.

Therefore, certain increase in equivalent stresses in compression of the samples of a more rigid material creates more favourable conditions for plastic deformations to occur. However, equivalent stresses decrease within the bond zone in a material having a lower rigidity. Thus, formation of plastic deformations will take place far from the bond, which is undesirable, as general deformations grow in welding. Tangential

Variants of models investigated

Type of bond	Variant No.	Å$_1$ = Å$_2$	Å$_2$ = 2Å$_1$	$\alpha_1 = \alpha_2$	$\alpha_2 = 2\alpha_1$	Ð = 40 MPa	Ò = ±100 îÑ
C–C	1	–	+	+	–	+	–
	2	+	–	–	+	–	+
	3	+	–	–	+	+	+
	4	–	+	–	+	+	+
S–S	1	–	+	+	–	+	–
	2	+	–	–	+	–	+
	3	+	–	–	+	+	+
	4	–	+	–	+	+	+

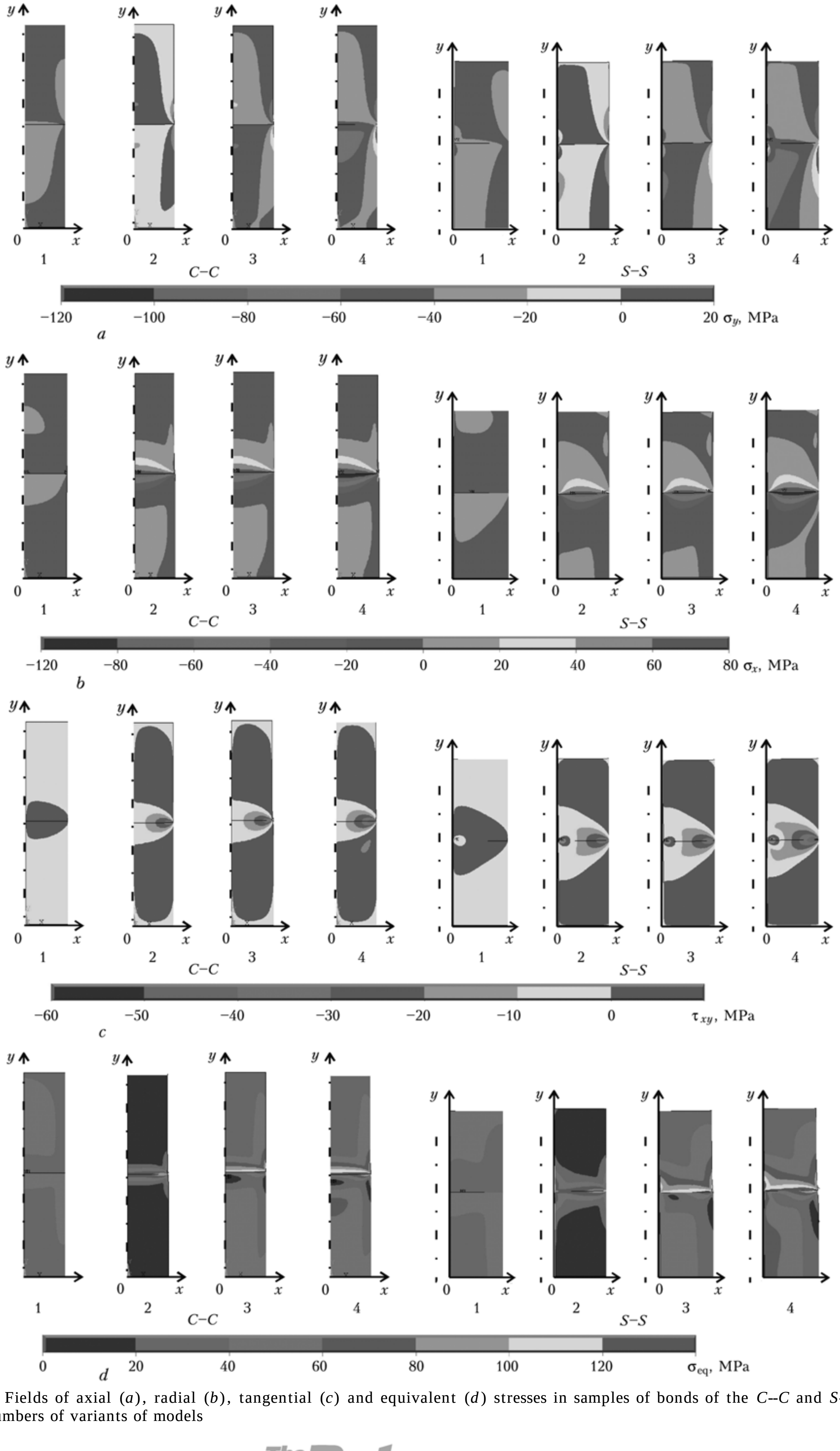

Figure 2. Fields of axial (*a*), radial (*b*), tangential (*c*) and equivalent (*d*) stresses in samples of bonds of the *C*–*C* and *S*–*S* types: 1–4 — numbers of variants of models

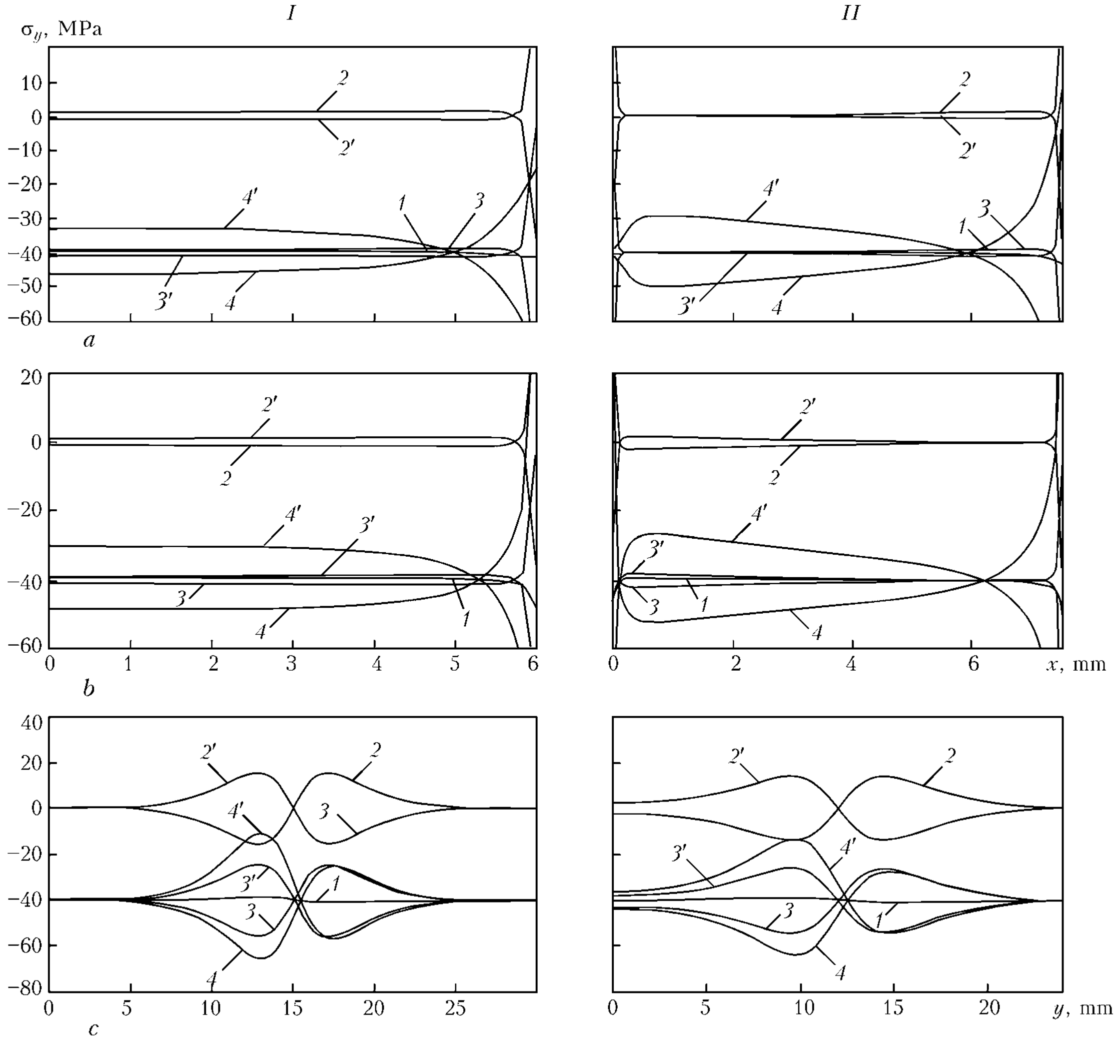

Figure 3. Diagrams of axial stresses σ_y in sections 1–1 (*a*), 2–2 (*b*) and 3–3 (*c*) of samples of bonds of the *C–C* (*I*) and *S–S* (*II*) types (here and in Figures 4–6): *1* — compression at constant temperature; *2–4* — compression in heating; *2′* — cooling without compression; *3′*, *4′* — compression in cooling

stresses are low, which hardly favours activation of the surface within the bond zone.

Variations in temperature by 100 °C without compression in the bond of the samples of materials with different LTEC (variants 2, Table) lead to formation of a more complex volumetric stressed state within the bond zone (Figure 2, variants 2). Radial and circumferential stresses in this case amount to 60–70 MPa, which constitutes 150–175 % of the nominal ones (Figure 4). They are tensile in a material with lower LTEC with increase in temperature, and compressive with decrease in temperature. The value of axial stresses in a major portion of the bond is close to zero, and only on the internal surface of a sample outside the bond it increases to 70 MPa. Axial stresses grow with distance from the bond, and at a distance of about 2–3 mm their values amount to 15–20 MPa (Figure 3, *c*). Their signs in the bulk of a sample coincide, and on the surface they are opposite to radial and circumferential stresses. The values of tangential stresses vary almost linearly — from zero on the axis of a cylindrical sample to 40 MPa near its peripheral edge (Figure 5, *a*).

In a bond of the *S–S* type, tangential stresses decrease from +40 (near the external surface) to –30 MPa (near the internal surface). The point with zero tangential stresses is located at a distance equal to about 1 / 4 of the sleeve thickness from the internal surface. This complex stressed state forming due to sufficiently high equivalent stresses and reaching the yield strength value creates favourable conditions for formation of plastic deformations particularly within the bond zone. The values of the latter grow from 70 (in the bulk of the bond) to 90–95 MPa (near its peripheral edge) (Figure 6, *a*, *b*, curves *2*). The level of equivalent stresses in cylindrical parts is slightly lower than in sleeves. With a 100 °C decrease in temperature, the signs of all the stresses change into the opposite ones, the diagrams of equivalent stresses remaining unchanged.

Principal compressive stresses σ_3 are distributed almost uniformly across the bond (in heating of a material with high LTEC, their values are 70–80 MPa and increase to 95 MPa on the periphery). The angle of inclination of these stresses varies from zero (parallel to the bond) in the middle part of the bond to 45° (near its periphery). In a material with lower

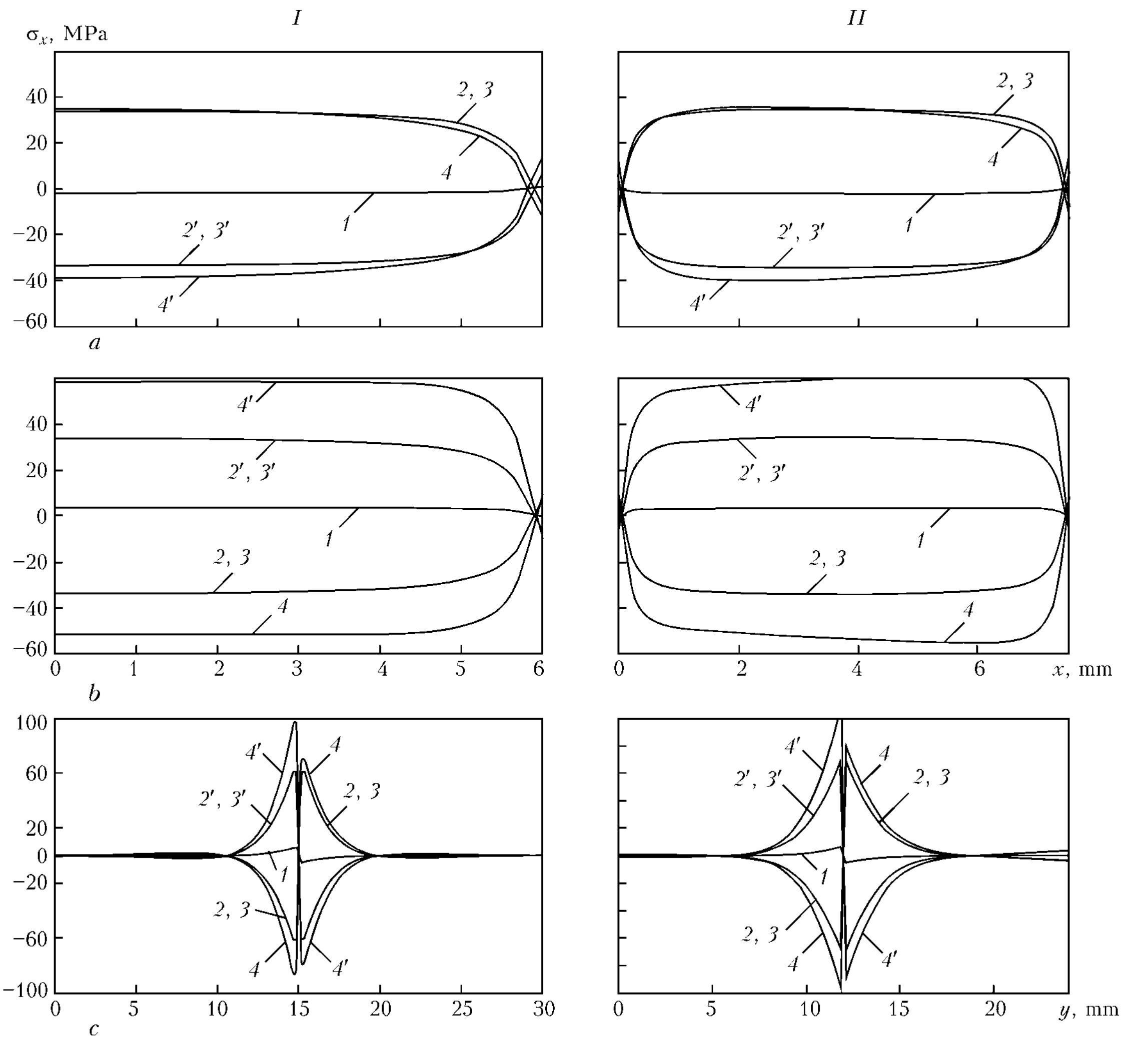

Figure 4. Diagrams of radial stresses σ_x in sections 1–1 (*a*), *2–2* (*b*) and *3–3* (*c*) of samples of bonds of the *C–C* (*I*) and *S–S* (*II*) types

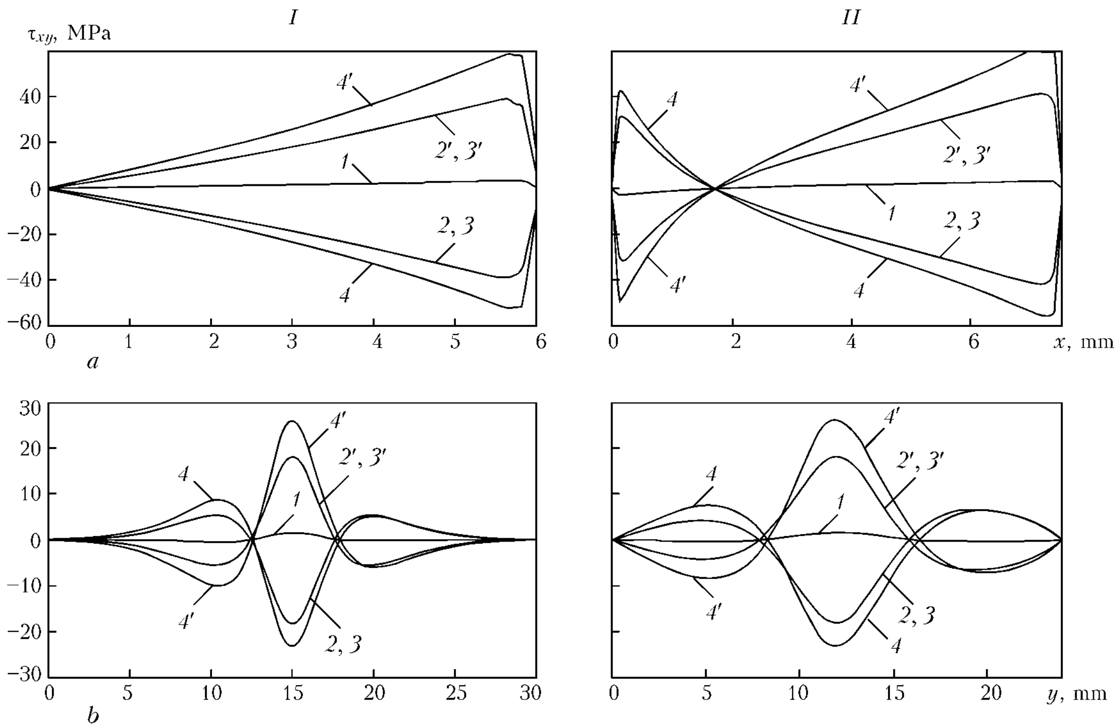

Figure 5. Diagrams of tangential stresses τ_{xy} in sections 1–1, 2–2 (*a*) and 3–3 (*b*) of samples of bonds of the *C–C* (*I*) and *S–S* (*II*)

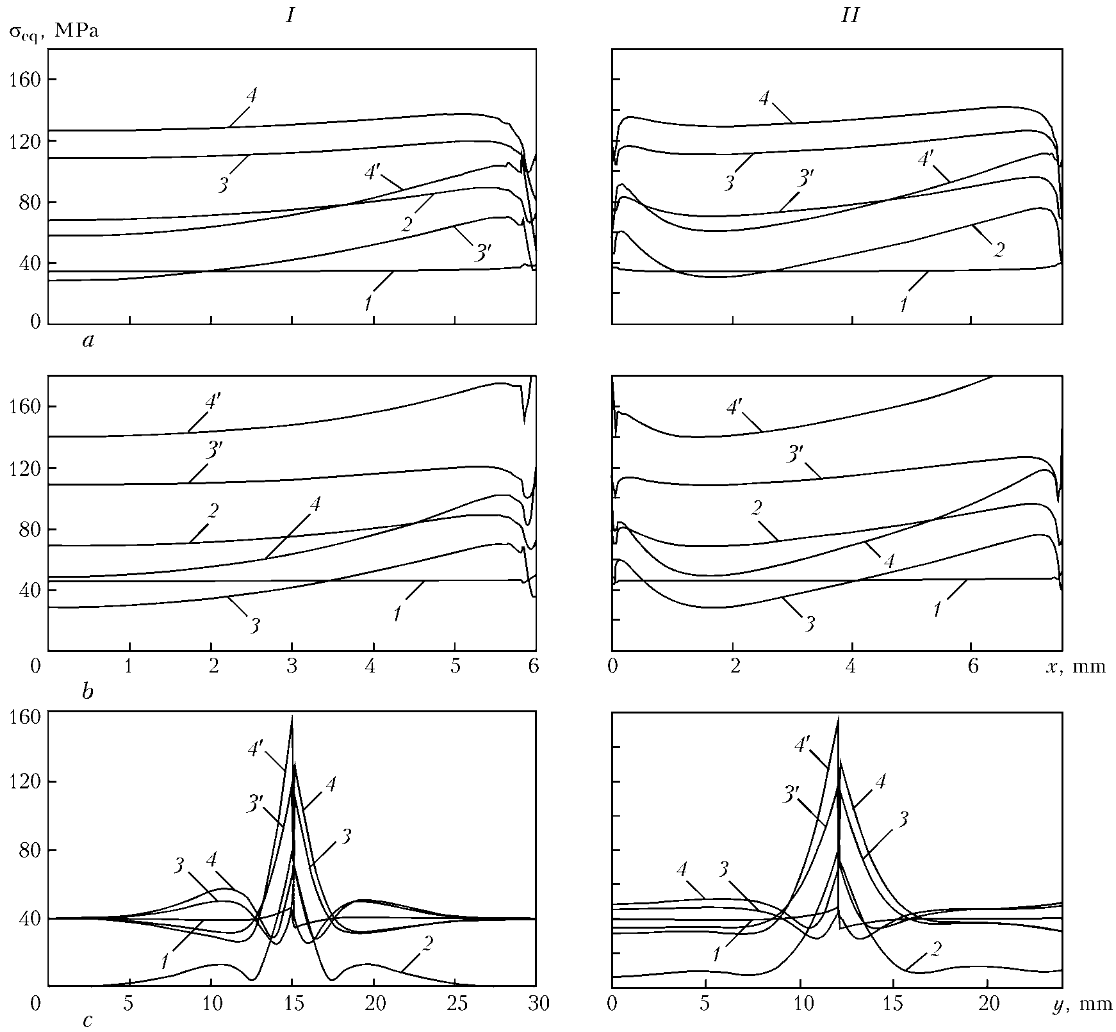

Figure 6. Diagrams of equivalent stresses σ_{eq} in sections 1–1 (*a*), 2–2 (*b*) and 3–3 (*c*) of samples of bonds of the *C–C* (*I*) and *S–S* (*II*) types

LTEC, a change in these stresses is much smaller — from zero (in the central part of the bond) to 30 MPa (at its edge), the inclination angle changing from 90° (in the central part of the bond) to 45° (on its periphery). In cooling, the field distribution patterns change places.

Under the combined impact by the axial compression force and 100 °C increase of temperature, the stressed state in the bond materials with the same rigidity but different LTEC (variants 3, Table) becomes even more complex. The values of the character of distribution of radial, circumferential and tangential stresses remain at the same level (Figures 3–5). The values of axial stresses change towards increase in compressive stresses. As a result, the character of the equivalent stress field markedly changes (Figure 2, *d*, variants 3), and its symmetry along and across the bond is violated (Figure 6, curves *3*). Equivalent stresses within the bond region substantially grow in a material with lower LTEC, and at higher LTEC they decrease and become lower than the nominal ones over a large part of the bond. As the temperature is increased, the stress distribution pattern changes into opposite (Figure 6, curves *3*′).

The character of the curves of stresses σ_3 changes but slightly, but the level of their values and inclination angle relative to the bond grow to some extent.

Therefore, the most favourable conditions for plastic deformations in both materials are created in thermal cycling in the compressed state. Considering a non-uniform distribution of tangential and equivalent stresses along the bond (see Figures 5, *a*, *b*, and 6, *a*, *b*), it can be concluded that the most favourable conditions for activation of the mating surfaces are created in peripheral regions of the bond, and that plastic deformations should be formed to the maximal degree closer to the edges, and to the lowest degree — in the bulk of the bond.

The pattern of the stressed state and its main mechanisms persist in bonding of materials with a differing rigidity (variants 4, Table). However, the level of stresses grows to some extent (see Figure 2, *a*, variants 4).

Thus, as shown by the calculations, diffusion bonding of even simple samples of dissimilar materials results in formation of a complex stressed state, rather than the uniaxed one, as was initially assumed in the development of process parameters.

CONCLUSIONS

1. Application of the finite element method makes it possible to determine the stress-strain state of parts in diffusion bonding, which should be taken into account when specifying parameters for bonding complex assemblies of dissimilar materials.

2. Formation of the complex stress-strain state in diffusion bonding of parts allows localisation of plastic deformation within the bond zone.

3. Combination of compression and thermal cycling is the most efficient (optimal) method for localisation of plastic deformations within the bond zone in bonding of materials with different LTEC values.

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ELECTROSLAG CLADDING OF END SURFACES OF PARTS BY USING SLAG POOL DOUBLE-LOOP POWER CIRCUIT

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Relationship was established between electrical and technological parameters of electroslag cladding conducted in a current-conducting mould by using a non-consumable hollow electrode, which allows control of the process of deposition of a multi-component metal with the γ-Ni_3Al aluminide based matrix on the end surfaces of 25–90 mm diameter parts. It is shown that with a double-loop DC circuit powering the slag pool the processes running in the hollow electrode–workpiece cladding circuit have a dominant influence on heat released in the pool.

Keywords: *electroslag cladding, current-conducting mould, modelling, double-loop power circuit, hollow electrode, current and voltage topology, process power, formation of deposited metal*

Application of a current-conducting mould (CCM) [1, 2] allows an efficient utilisation of thermal power of the slag pool for cladding large-size parts with discrete non-compact steel and cast iron materials. For cladding new types of heat-resistant alloys, e.g. multi-component nickel-base superalloys, nickel aluminide γ-Ni_3Al, etc., it is necessary to use composite cladding consumables with a high content of refractory components [3].

With conventional methods of electroslag cladding (ESC), melting of such materials in a low-temperature (no more than 2200 °C) slag cannot provide the chemically and physically homogeneous deposited metal.

The proposed ESC method using the slag pool double-loop power circuit [4, 5] allows raising the slag temperature to 3500 °C and provides stable melting of composite wires in the slag. Unlike the known cladding scheme developed by the E.O. Paton Electric Welding Institute [6], the present cladding method involves the use of the DC power supplies. This makes it possible to improve stability of the ESC process at a small volume of the slag pool and increase the current density in the near-electrode slag region due to unipolarity of the current-conducting section and hollow electrode.

The purpose of this study was to investigate the effect of electrical and technological parameters of the ESC process using the non-consumable hollow electrode and double-loop DC power circuit on formation of a multi-component metal with the γ-Ni_3Al-based matrix deposited on the cylindrical ends of parts 25–90 mm in diameter.

Cladding of the samples of steel 40KhNM with diameters of their end surfaces equal to 30, 55 and 90 mm was performed by using flux ANF-6. Cladding circuits comprising a hollow graphite electrode, as well as a current-conducting mould with a removable forming section and device for flux melting were connected to the DC power supplies with a rated current of 500 and 1000 A. Cladding of the samples with a diameter less than 60 mm was started by melting the flux due to the electric arc heat (solid start). With a workpiece diameter exceeding 60 mm, the slag was pored into CCM at a voltage between the section and workpiece increased by 25–30 % above the rated value (liquid start).

The use was made of a 5 mm diameter composite wire with a two-layer sheath (nickel NP-2 — external layer, and aluminium A97 — internal layer) and a core comprising wires NP-Kh20N80T of commercially pure molybdenum, tungsten, tantalum, nichrome and a mixture of metallic powders of aluminium, zirconium, molybdenum boride and graphite. The wire was fed through the electrode cavity at a speed of 4.5 mm / s.

To decrease the intensity of electric erosion of the tip of a hollow electrode with diameter d_e = 12 mm, the values of the current flowing though it were limited to 150–300 A. This allowed the region with a temperature above 3300 °C, wherein thermophysical conditions were created for melting of a filler material containing refractory components, to be formed in the bulk of the slag located in a hemisphere at the electrode tip [7].

Electrophysical processes occurring in the slag pool were investigated by using a unit consisting of a model mould and hollow graphite electrode with diameter d_e = 12 mm, the tip of which had a hemispherical shape. Copper rings 50 mm in diameter and 3 mm thick, which were placed in a cylindrical glass cavity, were used as a material of the model mould. A copper cylinder was used as a workpiece, and the 26 % NaCl solution simulated the slag pool. The ratio of electrical conductivity of the model solution to that of the overheated slag ANF-6 was 16:1. When measuring the potential field in electrolyte, position of the coordinate investigated was set by vertical movement of the probes and horizontal movement of the mould. Field intensity E was determined, and the current density was calculated as a product of $E\kappa$ on the basis of the difference of potentials at two neighbouring coordi-

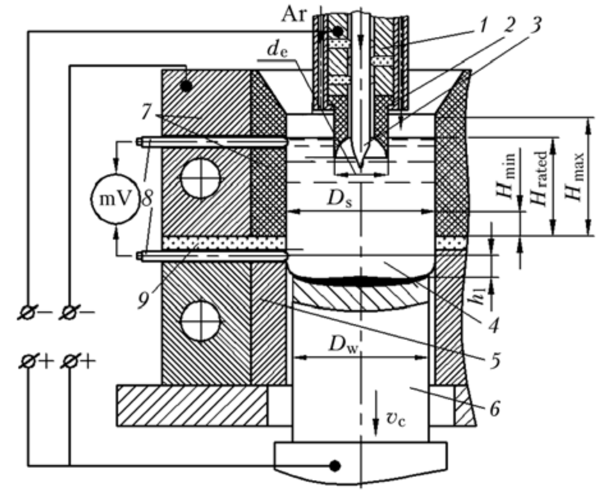


Figure 1. Flow diagram of electroslag cladding in CCM: *1* — current conductor to hollow electrode; *2* — hollow graphite electrode; *3* — composite wire; *4* — slag pool; *5* — removable forming section; *6* — end of workpiece; *7* — insulator; *8* — sensors to monitor levels of the slag and metal pools; *9* — split graphite and copper current-conducting sections; v_c — cladding speed; the rest of the designations are given in the text

nates. In the experiments, a voltage of 1 V was fed from each power unit to the salt solution. Power q of the heat released in the bulk of the slag pool was determined from density of the heat sources, $q = \kappa E^2$.

In ESC, it is necessary to provide a certain volume of the slag pool, which is controlled by the level of its surface in a cavity of the mould, for each diameter of the end surface being clad (Figure 1). It was experimentally found that the level of the slag pool surface should be increased to a value of its height H_{rated} with increase in diameter of the end surface of a workpiece. When the slag pool level is above its maximal value H_{max}, thermal power released in the slag is insufficient, and deposited metal has a poor formation. If the slag pool level is below some minimal value H_{min}, the slag becomes overheated, this leading to violation of stability of the ESC process and unsatisfactory formation of the deposited metal. This effect is observed at a minimal value of distance h_l from the lower level of the slag pool to the lower end of the current-conducting section. Hence, the h_l value is maintained in a range of $(0.20–0.25)D_s$. Maintaining the constant level of the metal pool surface provides the high quality of the deposited metal.

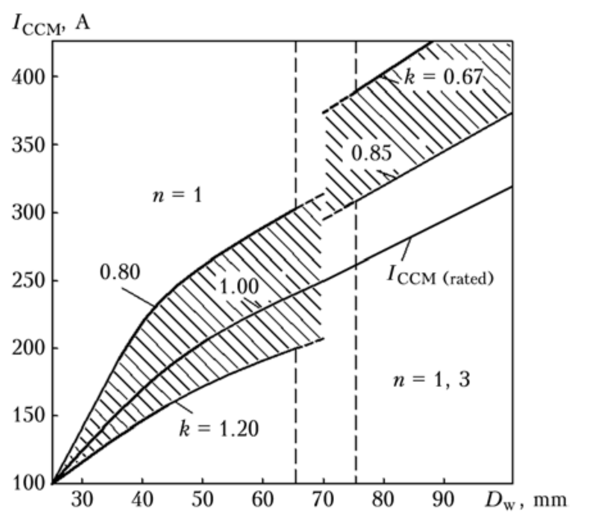


Figure 2. Nomogram of ranges of the ratio of currents, k, of current-conducting section, I_{CCM}, to hollow electrodes, I_e, versus workpiece diameter D_w: n — quantity of hollow electrodes

Analysis of the results of modelling of the potential field, as well as the experimental data made it possible to establish that the above parameters should correspond to the following condition in order to provide a satisfactory formation of the deposited metal:

$$h_l + H_{rated} + 2 \le D_s - 0.5d_e, \quad (1)$$

where D_s is the mean diameter of the slag pool.

The value of H_{rated} can also be calculated by using the following formula:

$$H_{rated} = bD_w + h, \quad (2)$$

where b is the proportionality coefficient equal to 0.17, and h is the required minimal depth of the slag pool at diameter of the workpiece end surface equal to 25 mm.

If non-equality condition (1) is met, the distribution of heat in the slag pool can be controlled by adjusting the current in each cladding loop. The ratio is determined by coefficient $k = I_{CCM} / I_e$ in ranges of 0.8–1.2 [7] and 0.67–0.85, this ensuring stability of the process of ESC of the ends surfaces 25–60 and over 60 mm in diameter, respectively (see Figure 2).

Investigation of the current and voltage topology on a physical model of the ESC process shows that the electric field in the slag pool of a mould is non-uniform (Figure 3). Regions of the slag pool with the highest potentials are located in the vicinity of a hollow electrode and near the wall of the current-conducting section of the mould, current density in the slag region adjoining the electrode being 30–50 % higher than at the surface of the current-conducting section.

According to the calculation data, this effect causes a four-fold increase in the heat released in the near-electrode region of the slag pool, compared with that released in the slag region adjoining the lower part of the current-conducting section of the mould. This determines the prevalent role of the hollow non-consumable electrode as a heat source in the bulk of the slag, which contacts the electrically neutral cladding consumable.

The amount of the heat released in the slag in cladding of large-diameter parts can be increased either through using large-size hollow electrodes with a corresponding increase of the current supplied to them, or through simultaneously increasing the currents at the current-conducting section of the mould and hollow electrode. In the first case it is impossible to provide the required current density to form a high-temperature region in a spherical cavity of the slag, and in the second case an increased value of the current at the hollow electrode leads to overheating and splashes of the slag. It was established that the thermal field in the bulk of the slag pool, whose diameter D_s

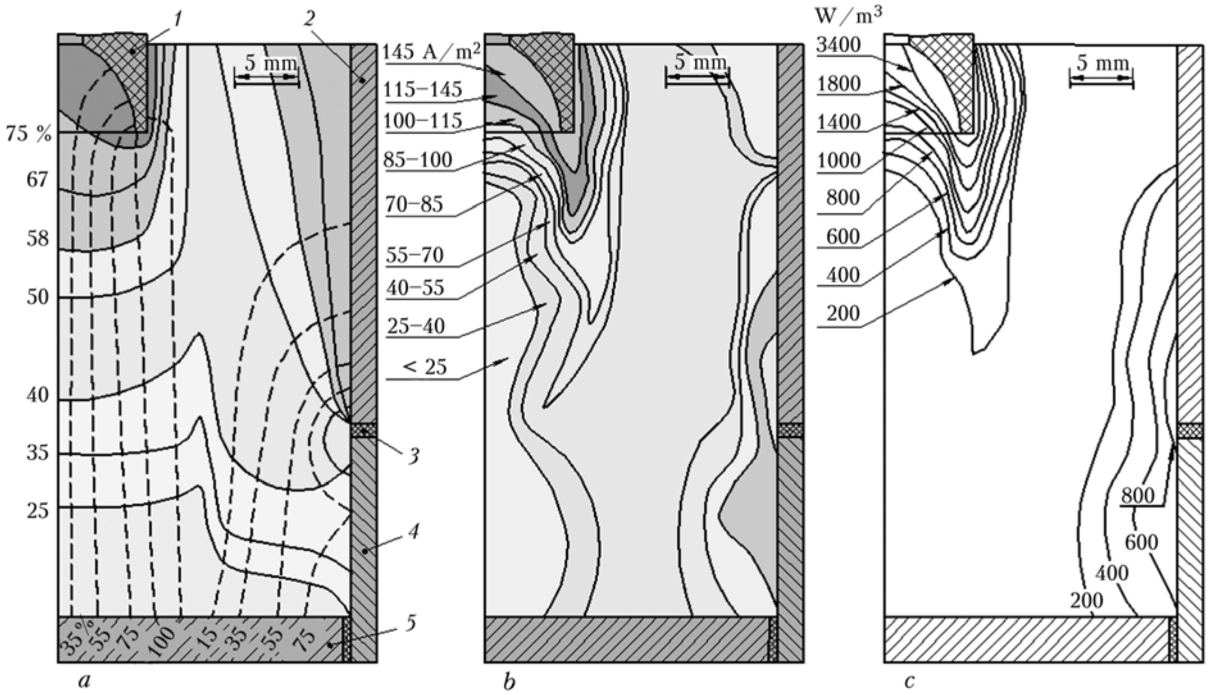


Figure 3. Schematic of distribution of current (dashed curves) and voltage (solid curves) of the electric fields (*a*), current density (*b*) and volumetric heat sources (*c*) in slag pool at $k \approx 1$: *1* — electrode; *2* — current-conducting section; *3* — insulator; *4* — forming section; *5* — workpiece

is half of the workpiece diameter, can be levelled by adding to it two or three hollow electrodes located on the circumference at distance l equal to $\pi D / n$ between their centres [5]. This arrangement of the electrodes guarantees overlapping of the high-temperature regions in the slag pool, which are formed in the zone of immersion of the hollow electrodes at their reciprocating rotary movement at a frequency of 30–33 min^{-1} and amplitude $A = 2D\pi / n$. Here $k < 0.85$.

As the overall power supplied through the current-conducting section and hollow electrode is released in the slag pool in the form of heat, it is apparent that the ratio of power q_e consumed for the ESC process to the slag volume can be regarded as a specific characteristic of the degree of the efficiency of utilisation of the thermal power realised per unit slag volume in the case of variations of the workpiece diameter. Figure 5 shows that with a 3 times increase of the workpiece diameter the required specific power of the slag pool is 5 times as low. This effect allows the specific power consumption in cladding to be decreased by decreasing the power supplied to the slag pool through the cladding current-conducting section–workpiece loop. A probable reason of the effect of decrease in the q_e values is that viscosity of the CaF_2–Al_2O_3 system slag at 1350 °C no longer depends upon the temperature [8]. Therefore, in cladding of parts more than 60–70 mm in diameter, where the initial stage of ESC is realised with the liquid start, the power fed to the slag through the current-conducting section is required only to maintain its temperature at 1800 °C.

After pouring and heating of the slag (Figure 5, *a*), voltage at the slag decreases, and current in the current-conducting section–workpiece loop grows to its working value (Figure 5, *b*). The power supplied through the second cladding loop overheats the slag in the near-electrode region to 3300–3400 °C. The ratio of powers in the cladding loops required for cladding the end surface of a specific diameter is determined by the value of coefficient k.

It was established that utilisation of ESC in CCM with a hollow electrode provides a good deposited metal and defect-free formation of the zone of its fusion with the substrate metal (Figure 6, *a*, *b*). Formation of a shallow metal pool with a straight-line solidification front in it results in a vertical arrangement of dendrites (Figure 6, *c*), which prevents formation of the liquation zone at the centre of the deposited metal. According to the results of metallographic examinations, the base to deposited metal transition region is of an insignificant size (no more than 50–80 μm). The absence of dangerous solidification and diffusion interlayers in it is attributable to delayed diffusivity of

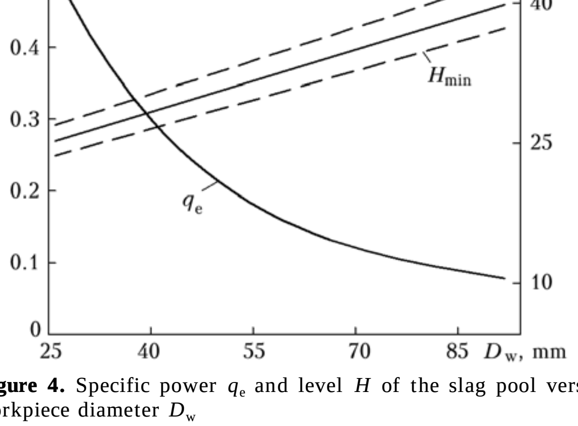


Figure 4. Specific power q_e and level H of the slag pool versus workpiece diameter D_w

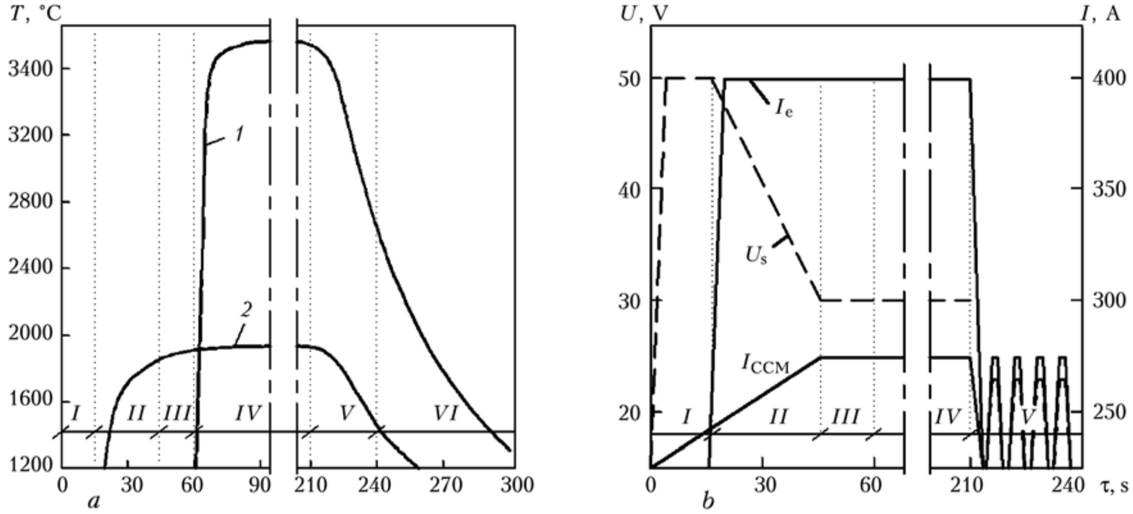
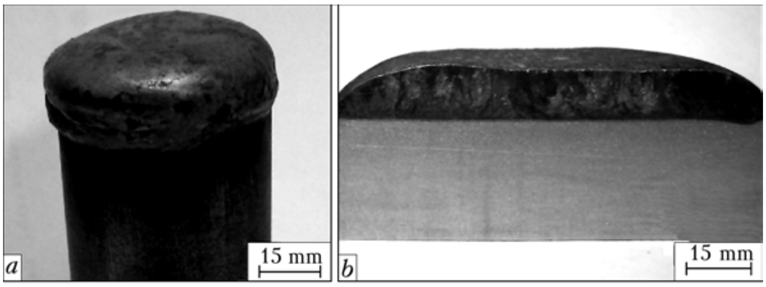


Figure 5. Cladding thermal cycles (*a*) in near-electrode region of the slag pool (*1*) and in the slag pool at a level below the edge of the current-conducting section (*2*), and cyclogram of the process of ESC of cylindrical end surface of a workpiece 90 mm in diameter (*b*): U_s — voltage in the slag pool; *I* — pouring of slag; *II* — unstable electroslag process; *III* — beginning of rotation of the slag pool; *IV* — feeding of wire to the slag; *V* — formation of deposited metal; *VI* — cooling of metal after cladding



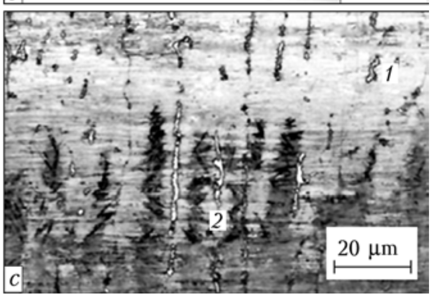


Figure 6. Appearance of clad end of a sample 55 mm in diameter (*a*), section of the clad sample 90 mm in diameter (*b*), and microstructure of transition zone (*c*): *1* — deposited metal; *2* — steel 40KhNM

impurity atoms in the thermodynamically stable metal matrix based on γ'-Ni_3Al.

CONCLUSIONS

1. Utilisation of a double-loop circuit powering the slag pool at comparable values of the electric current flowing through non-consumable electrodes was found to lead to a 4 times increase in the heat released in the near-electrode region of the slag pool, compared with the slag zone adjoining the CCM surface.

2. It is shown that to avoid defects and provide a satisfactory formation of the fusion zone in ESC of end surfaces of the parts up to 30 mm in diameter, specific power in the slag pool should be 0.5 kW / cm^3, while in cladding the end surfaces of the parts up to 90 mm in diameter this value decreases 5 times, thus allowing reduction of the specific power consumption in cladding large-size parts.

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EFFECT OF ALLOYING OF HIGH-STRENGTH WELD METAL WITH TITANIUM ON ITS STRUCTURE AND PROPERTIES

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It is suggested that an integrated parameter, which allows for the level of alloying of solid solution with manganese, silicon, titanium and aluminium, as well as the content of titanium oxides in inclusions located in the bulk of ferrite grains, should be used to evaluate the effect of alloying of metal of the submerged-arc welds on their mechanical properties.

Keywords: steel, alloying, structure, weld, titanium

One of the outstanding achievements in the field of metallurgy of the 20th century is, undoubtedly, the development of high-strength low-alloy (HSLA) steels. Some investigations into properties and peculiarities of the metallurgy of welding this class of steels had been conducted earlier as well, but the breakthrough in this field began in the 1960s. The above steels are characterised by an optimal combination of strength and cost effectiveness, which is achieved through refining and sparse microalloying of steels, as well as thermomechanical treatment of rolled stock.

Modern high-strength steels are a high-technology product featuring the balance of numerous metallurgical and physical processes. Study [1] presents a scheme showing the strengthening mechanisms used to produce HSLA steels. For example, whereas it is enough to strengthen solid solution with manganese or silicon to achieve yield strength $\sigma_y < 275$ MPa of the steels, to produce a higher level of strength properties it is necessary to subject the rolled stock to thermomechanical treatment and strengthen the structure through microalloying, and to ensure the yield strength value above 400 MPa it is necessary to apply dispersion or dislocation strengthening.

Titanium is one of the alloying elements widely applied to strengthen solid solution of ferrite. In a low-alloy weld metal, it promotes increase in strength (approximately by $\Delta\sigma_t = 220C[\mathrm{Ti}]$ [N / mm^2], where C is the weight content of [Ti], %, [2]). The addition of titanium alone, without other alloying elements, has no marked effect on the $\gamma \rightarrow \alpha$ transformation temperature. However, it promotes transformation of lamellar ferrite into acicular ferrite, the content of hypoeutectoid ferrite remaining almost unchanged [3]. The optimal content of titanium in metal depends upon the content of oxygen, nitrogen and strengthening elements (silicon, manganese, molybdenum, nickel, chromium, etc.) in it. Normally, it is 0.01–0.05 wt.% [4].

As oxygen is always present in the weld metal, alloying elements may be contained not only in solid solution of ferrite, but also in non-metallic inclusions.

Distribution of alloying elements between these two phases is determined by their activity, as well as by the activity of oxygen in metal, and it affects the conditions of formation of its structure in cooling (Figure 1).

In welding, mostly three morphological types of non-metallic inclusions are formed in the weld metal on low-alloy steels: nitrides, oxides and multi-component complex of the type of aluminosilicates. The first two types of non-metallic inclusions have a sharp-cornered shape, and the third type — a globular shape. It is thought that crack initiation energy A_3 at fracture of metal depends upon the shape of non-metallic inclusions. A_3 decreases in the case of the sharp-cornered shape of inclusions, properties of the weld metal being affected by the total content of non-metallic inclusions independently of their composition [6]. Proceeding from the above-said, the formula

$$D_{max} = 4R / 3f$$

was derived to determine the maximal size of grain of the ferritic matrix with volume content f of non-metallic inclusions having mean radius R [7]. This relationship allows the authors to assume that chemical composition and shape of non-metallic inclusions have no effect on structure of the weld metal.

Studies dedicated to investigations of the conditions of formation of AF report of the formation of

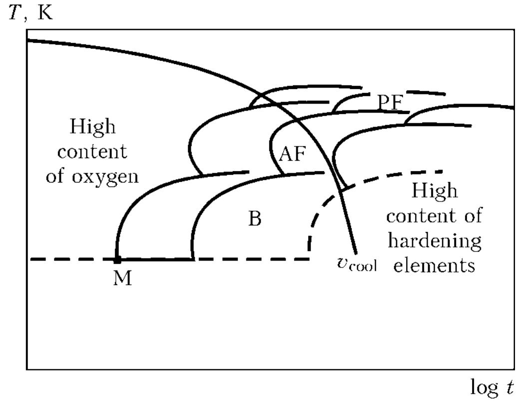

Figure 1. Effect of composition of the weld metal on phase transformations in cooling [5]: M — martensite; B — bainite; AF and PF — acicular and polygonal ferrite, respectively; v_{cool} — cooling rate

Table 1. Chemical composition of welding fluxes (wt.%) used in the study

Welding flux	Na_2O	CaO	MgO	CaF_2	MnO	Al_2O_3	Fe_2O_3	SiO_2	ZrO_2	Others
AN-348À	--	2.1	4.7	5.0	35.2	3.8	0.9	42.8	–	–
348K	2.5	2.0	4.5	4.7	34.5	3.5	0.8	41.7	–	–
AN-72	--	17.0	–	45.0	–	22.9	0.2	16.5	1.0	–
19	2.3	4.5	30.4	20.0	–	35.2	--	8.0	–	0.6Al
19 Ì	2.0	4.1	28.0	19.1	–	33.6	--	8.6	–	0.5AlFeMn

ferrite needles on non-metallic inclusions (or nearby) 0.3–0.8 μm in size [8, 9]. As shown by analysis of composition of non-metallic inclusions promoting formation of AF, most of them contain titanium [9]. This allowed a conclusion that structure of AF nucleated on inclusions of titanium nitride or monoxide [10, 11]. The above conclusions were grounded on theoretical studies by Bramfit [12], who established, on the basis of the results of investigations of overcooled iron, that the smaller the mismatch of crystalline lattices of a heterogeneous nucleus and forming phase, the higher the growth of potential heterogeneous nucleation. Among the non-metallic inclusions present in the low-alloy welds, it is TiO and TiN (3.0 and 3.8 %, respectively) that have the smallest mismatch of the crystalline lattices with α-iron [9]. In contrast to them, Al_2O_3 and ZrO_2 are characterised by the highest mismatch with nucleating ferrite (approximately 30 %).

It follows from the above-said that the problem of selection of the optimal content of titanium in the weld metal on low-alloy steels is very topical in terms of creation of conditions for the formation of structure that would provide its high performance.

In development of the submerged-arc welding processes much consideration is given to the problem of selection of such a combination of flux and wire, which can guarantee the specified level of performance of welded joints. Normally, solution to this problem is based on empirical approaches. In this case, a decision on the efficiency of one of the variants studied is made on the basis of the results of tests of several welded joints produced by using different combinations of fluxes and welding wires. The drawbacks of this approach include, first of all, the fact that there is no absolute certainty that the combination selected is optimal and, second, that with an increasing level of requirements to one or several parameters of performance of the weld metal it is necessary to perform this work over again. Moreover, no data are available, which could help to determine those characteristics of fluxes and wires that can lead to achievement of the required result.

In addition, of interest is the problem of selection of flux (fused or agglomerated) and substantiation of application of fluxes having certain basicity in terms of conditions of alloying and microalloying of metal of the welds, as well as formation of their microstructure.

The purpose of this study was to work out conceptual approaches to selection of a type of flux and composition of wires to develop the processes for welding low-alloy steels.

The effect of alloying with titanium on structure and properties of the weld metal on low-alloy steels was studied in the course of the investigations. Alloying of the weld metal was provided through a flux and / or solid welding wire. Submerged-arc welding was performed using fluxes of the two types —- fused and agglomerated ones, each containing fluxes of different basicity in its composition.

Table 1 gives composition of fused fluxes AN-348A (alloyed with manganese and silicon, basicity BI = = 0.6) and AN-72 (alloyed with silicon and aluminium, BI = 2.0), as well as agglomerated fluxes 348K (flux AN-348 was made by the agglomerated flux technology), experimental flux 19 (alloyed with aluminium, BI = 2.0), and experimental flux 19M (flux 19 with 5 of wt.% ferromanganese).

Welding wires with a different titanium content (EP934 and Sv-10G1NMA) (Tables 2 and 3) were chosen for the investigations. The samples of metal deposited by using flux (see Table 1) in a combination with wires of the above types, according to the ISO 14 171 procedure, were used as the investigation objects.

Specimens for determination of chemical composition and metallographic examinations were made from the deposited metal. Chemical composition of the deposited metal was determined by the method of spectral analysis using the Baird unit equipped with the IBM PC. From three to five determinations were made for each specimen, and then the results were averaged. Chemical composition of metal of the welds made by

Table 2. Chemical composition (wt.%) of metal of welded joints made by submerged-arc welding using flux and wire EP934

Welding flux	C	Si	Mn	Ni	Mo	Al	Ti	S	P
AN-348À	0.028	0.758	1.82	1.20	0.25	0.0082	0.005	0.023	0.043
348K	0.021	0.672	1.81	1.20	0.24	0.0009	0.016	0.023	0.016
AN-72	0.054	0.310	1.28	1.11	0.22	0.0070	0.008	0.009	0.018
19	0.053	0.701	1.19	1.03	0.21	0.0230	0.036	0.008	0.018

Note. Chemical composition of wire EP934 (wt.%): 0.087 C, 0.342 Si, 1.62 Mn, 1.38 Ni, 0.25 Mo, 0.044 Al, 0.075 Ti, 0.01 S and 0.021 P.

Table 3. Chemical composition (wt.%) of metal of welded joints made by submerged-arc welding using flux and wire Sv-10G1NMA

Welding flux	C	Si	Mn	Ni	Mo	Al	Ti	S	P
AN-348À	0.027	0.344	1.32	0.60	0.50	0.0456	0.019	0.011	0.017
348K	0.024	0.530	1.31	0.54	0.55	0.0080	0.009	0.022	0.015
AN-72	0.053	0.310	1.28	0.53	0.50	0.0070	0.008	0.006	0.016
19	0.053	0.497	1.34	0.58	0.50	0.0481	0.054	0.005	0.018
19M	0.032	0.242	1.71	0.60	0.50	0.0255	0.037	0.009	0.017

Note. Chemical composition of wire Sv-10G1NMA (wt.%): 0.07 C, 0.48 Si, 1.5 Mn, 0.66 Ni, 0.59 Mo, 0.0158 Al, 0.161 Ti, 0.012 S and 0.021 P.

Table 4. Mechanical properties of metal of the investigated welds made by submerged-arc welding using flux in combination with different welding wires

Welding flux	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Reduction in area, %	Impact toughness, J / cm^2, at temperature, °C	
					+20	–20
EP934						
AN-348À	597.1	709.4	21.0	57.8	32.9	16.8
AN-72	584.9	702.9	21.5	35.7	122.1	96.4
19	582.8	725.3	22.9	66.0	112.3	52.5
348K	533.0	638.9	21.7	57.6	71.7	46.7
Sv-10G1NMTA						
AN-348À	626.6	690.5	23.1	60.4	59.6	37.9
AN-72	582.8	652.0	24.4	62.5	90.5	51.5
19	708.4	812.2	20.4	66.4	16.9	67.0
19 Ì	598.9	683.6	22.4	52.3	164.6	163.8
348K	512.5	611.5	25.3	60.9	66.1	37.2

using the above combinations of welding consumables is given in Tables 2 and 3.

Welding was performed at a direct current of reverse polarity by using the A1416 device under the following conditions: the first layer (three passes) — I_w = 510–520 A, U_a = 28–29 V, v_w = 22–23 m / h; the second layer (three passes) — I_w = 560–570 A, U_a = = 30–31 V, v_w = 22–23 m / h; and the third layer (four passes) — I_w = 610–620 A, U_a = 32–34 V, v_w = = 22–23 m / h. Mechanical properties of metal of the resulting welds are given in Table 4.

The content of components of microstructure of the weld metal, its element composition and volume content of non-metallic inclusions were determined by metallographic examinations. Structure of the weld metal was examined by the methods of optical and electron metallography by using the light microscope «Neophot-32» and JEOL scanning electron microscope JSM-840 equipped with the MicroCapture board for capturing of images, followed by displaying the images on the computer screen. Quantitative determination of microstructure components was carried out by using the IIW procedure [13]. Element composition of non-metallic inclusions was revealed by X-ray spectral microanalysis using the Link System energy-dispersive spectrometer «Link 860 / 500» and wave-dispersive spectrometer «Ortec».

Chemical composition of non-metallic inclusions in metal of the investigated welds is given in Tables 5 and 6.

As established as a result of metallographic analysis, structure of the weld metal consists of different morphological forms of ferrite (PF, AF, intragranular ferrite (IGF), OSF — ordered second phase ferrite,

Table 5. Chemical composition of non-metallic inclusions in metal of the welds (wt.%) made by submerged-arc welding using flux in combination with wire EP934

Welding flux	Volume content of non-metallic inclusions, %	At grain boundaries				In bulk of grain			
		Al_2O_3	SiO_2	MnO	TiO	Al_2O_3	SiO_2	MnO	TiO
AN-348À	0.45	1.030	2.040	3.840	7.290	1.246	44.001	52.291	1.67
348K	3.00	0.963	38.981	54.563	2.332	1.022	42.140	52.566	4.22
AN-72	0.20	58.889	7.903	31.610	13.293	57.179	12.595	21.891	8.74
19	0.19	63.082	7.401	28.681	1.349	87.358	2.283	5.031	10.11
19 Ì	0.18	37.686	2.413	36.333	20.197	29.797	3.204	45.812	19.14

Table 6. Chemical composition of non-metallic inclusions in metal of the welds (wt.%) made by submerged-arc welding using flux in combination with wire Sv-10G1NMTA

Welding flux	Volume content of non-metallic inclusions, %	At grain boundaries				In bulk of grain			
		Al_2O_3	SiO_2	MnO	TiO	Al_2O_3	SiO_2	MnO	TiO
AN-348À	0.905	3.121	29.669	61.079	3.335	3.177	31.666	59.42	5.42
348K	1.900	0.641	39.253	51.630	5.049	0.111	41.439	50.321	3.01
AN-72	0.320	12.041	11.292	46.07	18.323	21.867	13.438	36.002	3.26
19	0.500	74.502	3.029	15.917	3.760	89.646	2.857	4.33	2.78

UOSF — unordered second phase ferrite, pearlite (P), bainite (B) and MAC-phase). The contents of individual components in the weld metal are given in Tables 7 and 8.

As shown by the investigation results, the content of non-metallic inclusions in metal of the welds made by submerged-arc welding using acid fluxes was substantially higher than in the case of using basic fluxes. It was noted that, whereas inclusions in the first case consisted mostly of manganese silicates, in the second case they contained considerable amounts of aluminium and titanium oxides.

The content of titanium in the weld metal in the case of using both grades of the wires grows with increase in the flux basicity. As follows from the above-mentioned literature data, increase in the titanium content should cause a corresponding increase in the volume content of AF in structure of the weld metal and weight content of titanium oxides in inclusions located in the bulk of primary austenite grains. Our results (Figure 2) indicate that this relationship has an implicit form and can be presented in the form of a certain domain.

Figure 3 shows the effect of the content of AF in structure of the weld metal on the level of its impact toughness. Comparison of the data presented evidenced the absence of any direct relationship between these two parameters. It can be concluded on the basis of analysis of chemical composition of the investigated weld metal (see Tables 2 and 3) that changes in the basicity of the welding flux and titanium content of the welding wire are accompanied by changes in the level of alloying of the weld metal not only with titanium, but also with manganese, silicon and aluminium. These elements are known to have a substantial effect on mechanical properties of welded joints on low-alloy steels.

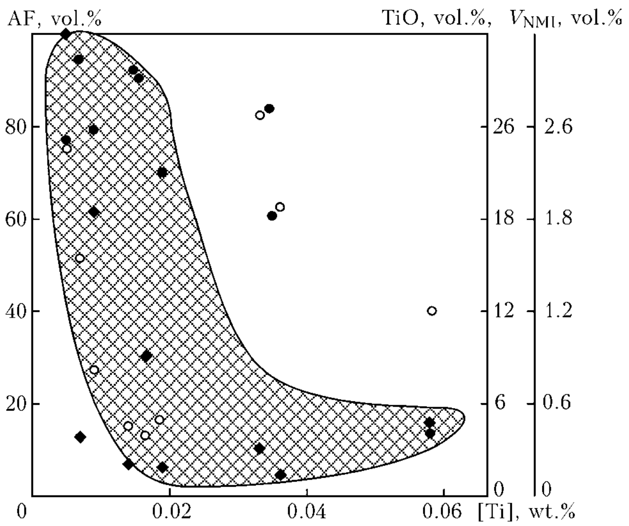

Figure 2. Effect of content of titanium in weld metal on volume content of AF (●) and non-metallic inclusions V_{NMI} (○) in its structure, as well as on content of titanium oxides (◆) in inclusions located in the bulk of primary austenite grains

Silicon has a substantial effect on the strength of austenite, and no effect on the temperature of ferrite transformation. At the same time, it increases the temperature of pearlite transformation. Most researchers are inclined to believe that a change in toughness of the weld metal is a result of the strengthening effect of silicon on solid solution of ferrite. The special role of silicon in changing toughness of the weld metal is caused, in our opinion, by its ability to decrease the degree of diffusion of carbon. The process of diffusion of carbon is determined by local equilibrium at the ferrite–carbide interface. Silicon is not a constituent of carbides of steel. Therefore, the decisive role is played by the mechanism of diffusion of silicon from microvolumes of carbides forming during cooling. In some cases the effect of silicon on the degree of diffusion of carbon shows up in its ability to increase hardenability of the ferritic matrix, thus leading to the formation of laminated and acicular structures.

Table 7. Content (vol.%) of structural components in metal of the welds made by using welding wire EP934

Welding flux	PF	P	AF	OSF	UOSF	B	IGF	MAC-phase
AN-348À	4	0	95	0	0	0	1	0
AN-72	3	0	95	2	0	0	0	0
19	1	0	70	11	9	6	3	0
348K	12	0	79	0	0	0	9	0

Table 8. Content (vol.%) of structural components in metal of the welds made by using welding wire Sv-10G1NMTA

Welding flux	PF	P	AF	OSF	UOSF	B	IGF	MAC-phase
AN-348À	9	0	90	0	0	0	0	1
AN-72	0	0	60	17	0	20	0	3
19	0	0	16	40	19	24	0	1
19 Ì	3	0	85	6	5	0	0	1
348K	7	0	80	0	0	0	13	0

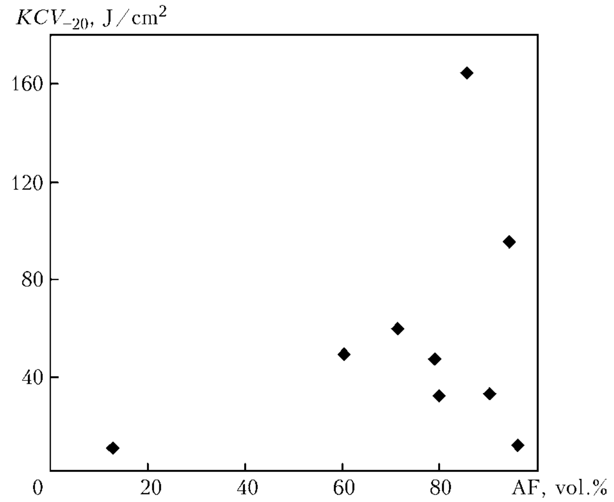

Figure 3. Effect of content of AF in structure of metal of the investigated welds on its impact toughness

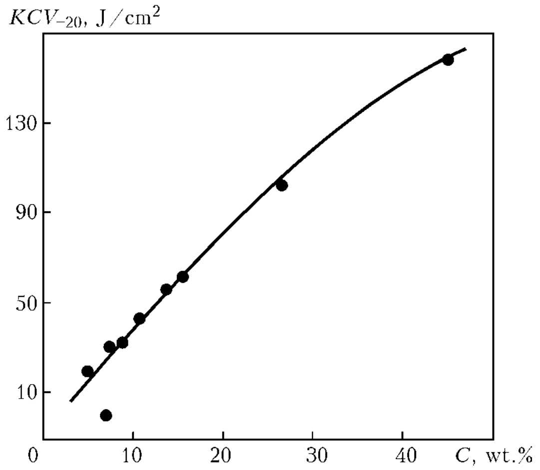

Figure 4. Effect of composition *C* of metal of the investigated welds on its impact toughness (C = {TiO + [Mn + 50 Ti]} / [Si + 10 Al])

Another active deoxidiser of molten metal is aluminium, which is widely applied in metallurgy for deoxidising of steel. Alloying of the low-alloy weld metal with aluminium causes a change in its structure — from AF with hypoeutectoid ferrite to ferrite with a laminated MAC-phase. Aluminium in solid solution has the most marked effect on austenite. The temperature of martensite transformation grows, and the content of retained austenite decreases with increase in the weight content of aluminium.

For adequate evaluation of the effect of the level of alloying of the weld metal on its structure and mechanical properties, it is necessary to take into account not only the content of titanium and its oxides in it, but also the content of manganese, silicon and aluminium. Mathematical processing of the data generated during the investigations allowed determining the relationship between these parameters. As seen from Figure 4, the substantial effect on the level of impact toughness is exerted by the content of titanium in metal, alloying of the welds with manganese, and content of titanium oxides in non-metallic inclusions located in the bulk of ferrite grains. In this case it is necessary to allow for the negative effect of alloying of the welds with silicon, and especially with aluminium.

The use of the integrated parameter makes it possible to choose with a higher degree of confidence the combination of welding consumables for welding increased- and high-strength low-alloy steels.

CONCLUSIONS

1. Investigations of the effect of the level of alloying of the weld metal on low-alloy steels with titanium in submerged-arc welding by using fused and agglomerated fluxes made it possible to establish that the content of non-metallic inclusions in the weld metal produced by using acid fluxes was much higher than by using basic fluxes. At the same time, whereas in the first case the inclusions are mostly manganese silicates, in the second case they contain substantial amounts of aluminium and titanium oxides.

2. Increase in the flux basicity causes increase in the content of titanium in the weld metal in the case of using welding wires alloyed with titanium.

3. To evaluate the effect of alloying of the weld metal on low-alloy steels in submerged-arc welding on its mechanical properties, it is necessary to use the integrated parameter that allows for the level of alloying with manganese, silicon, titanium and aluminium, as well as the content of titanium oxides in inclusions located in the bulk of primary austenite grains.

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INFLUENCE OF MANUFACTURING TECHNOLOGY ON THE STRUCTURE AND PROPERTIES OF FUSED FLUXES

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The method of X-ray diffraction was used to study the granulated solid and molten welding fluxes of the grades of AN-67 type. Presence of crystalline phases in some of them is indicative of violation of the flux manufacturing process and the resultant deterioration of their quality (in complete compliance with the specification requirements).

Keywords: arc welding, fused flux, diffraction, X-ray, flux quality, manufacturing technology, amorphous phase, crystalline phase, spinel, matrix, nanomicelle, solution, cation, anion

In automatic welding, surfacing and electroslag remelting the welding flux has a very important role. Selection of the flux type in order to produce a sound welded joint is an extremely labour-consuming task. The flux should ensure a reliable protection of the arc zone and liquid weld pool from the impact of nitrogen, oxygen and water vapours from the air, guarantee good weld or deposited bead formation, easy slag crust detachability, absence of pores, cracks and other defects in welds. To satisfy the above requirements, the fluxes should be characterized by a certain set of physico-chemical properties, which are determined not only by their composition, but also manufacturing technology. Thorough performance of individual technological operations is of paramount importance [1], particularly at melting out of the flux and its granulation. Violation of the technology of these operations performance can lead to adverse consequences in welding.

At the final stage of flux manufacturing quality control of the finished product is performed, and its compliance to the requirements of the currently valid codes and standards is established. Flux quality is controlled in batches consisting of flux of one grade, made from certain charge materials by an approved technology. Such flux characteristics as uniformity, grain structure and colour, composition, humidity and volume fraction are controlled. In the opinion of V.V. Podgaetsky [1], these values are sufficient to determine the flux quality. However, known are the cases, when the welding flux met the requirements made of it, but still gave rise to customer criticism, which was, probably, related to violation of its manufacturing technology.

In works [2, 3] examination by X-ray diffraction method of granulated solid and molten welding fluxes, which were manufactured in the USSR before 1991, was conducted. Note that all the granulated fluxes in the solid state yielded a diffraction pattern characteristic for their amorphous and glass state, i.e. the diffraction pattern featured a complete absence of the crystalline peaks. Thus, the technology of manufacturing the welding fluxes, and particularly the melting and granulation operations, envisages producing flux with a completely amorphous grain structure, this improving the flux quality and being one of the purposes of this work.

Welding is known to be a fast and non-equilibrium process, during which the flux fulfills its functions, so it should be as reactive as possible. Let us consider some aspects of interaction of the flux and molten metal in the weld pool zone. Several types of their interaction can be singled out here: 1st is in the arc zone, where the conditions of the molten metal and slag are close to that of the plasma; 2nd is between molten metal and molten slag in the weld pool zone; 3rd is between molten slag and solid metal; 4th is between solid slag and solid metal.

The most effective are the 1st and 2nd types of interaction. This is due to the fact that the dimensions of the interacting particles are very small: in the first case these are the highly ionized atoms or molecules, in the second case — particles of liquid type of the size of about 1 nm [2]. At first sight interaction in the arc zone is the most intensive, but because of the low particle concentration interaction of molten metal and slag is more effective. Appearance of crystallites at interactions of the 3rd and 4th type in which the ordered regions are by an order of magnitude larger than the size and quantity of particles, greatly reduces the probability of interaction of metal and slag particles, because of the need for pre-fracture of the crystalline lattice, which takes additional time and energy.

Hence the question whether the flux is uniform, if it is in the partially solidified state? Presence of the amorphous (glassy) component and crystallites is indicative of the fact that the flux is multiphase, and its properties depend on the qualitative and quantitative composition of the present phases. If the crystalline inclusions are contained in the amorphous phase matrix and do not contact each other, the flux properties will be mainly determined by the properties of this matrix. Now, if the crystallites contact each other forming a continuous frame, a two-frame structure can be realized on the basis of the amorphous and crystalline phases, and then the flux properties are determined by the frame properties, depending on their quantity. At an increased concentration of crystallites, the amorphous phase inclusions can form in the crystalline matrix, and this, unlike welding, belongs to the equilibrium processes. However, the molten flux properties at short-time processes running in a moving weld pool, do not change essentially without occurrence of major structural transformations, the development of which requires time and additional energy. It should be noted that the properties of the amorphous and crystalline phases of the same composition can differ essentially.

Let us consider some issues related to solidification, as this is exactly what influences the flux reactivity. The flux reactivity, in its turn, depends on the average energy of the atoms and molecules included into it. Figure 1 shows the mean energy of the atom in the crystalline and molten state [4]. As is seen from the Figure, the mean energy of the atom in the molten state ε_m is higher than its mean energy in the crystalline state ε_c by value ΔH [4]. In addition, at transition from the crystalline into the liquid state it is necessary to overcome an energy barrier — steel mean energy E. Thus, energy $\Delta H + E$ should be consumed in atom transition from a crystal into the liquid. It is possible at a certain temperature, when quite stable molecule groups appear, which form the new phase nuclei. It is highly essential for the solidification process that the instantaneous arrangement of atoms in the nuclei in the pre-solidification period corresponded to their arrangement in the crystalline lattice. According to [5] at initiation of the crystalline nuclei certain energy is consumed in the interface formation. If the nuclei size is smaller than a certain critical value, its fracture is beneficial in terms of energy, as in this case the surface energy exceeds the energy gain associated with transition into a stable state. If the nuclei size is greater than a certain critical value, then its growth is beneficial in terms of energy. Overall change of system free energy ΔF is equal to the difference between surface energy (result of the change of interface energy obtained by roentgenography method) and energy associated with the change of the bulk free energy at liquid–crystal phase transformation, and is expressed by the following formula:

$$\Delta F = 4\pi r^2 \Delta f_s - \frac{4}{3}\pi r^3 \Delta f_v, \qquad (1)$$

where r is the nuclei size; Δf_s is the change of free energy per a unit of interphase area; Δf_v is the change of free energy at phase transformation in a unit of the material volume per a unit of interfacial area. As is seen from Figure 2, reduction of ΔF after achievement of a critical size is due to an increasing contribution of the second term of equation (1), as value r^3 rises faster than r^2. At flux melting formation of liquid microbunching of a subcritical size requires consumption of energy of liquid–crystal transformation, ΔF_{l-c}, which is the higher the greater the crystallite size.

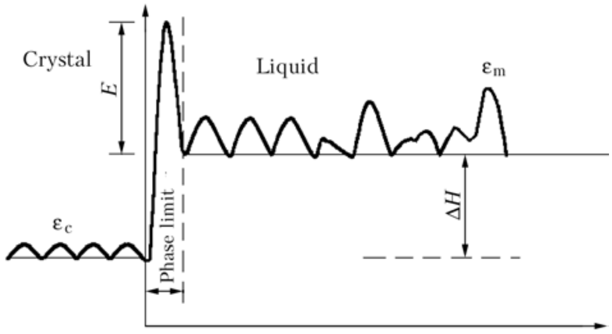

Figure 1. Mean energy of an atom in the crystalline and molten state [4]

It is obvious that in manufacture of granulated flux it is necessary for its microbunching to be of liquid type and preferably of a subcritical size. In welding with such a flux there is no need to consume additional energy and time for crystallite melting and establishment of an equilibrium state. Power (voltage and current) and time (welding speed) mode parameters can be more cost-effective, and weld formation can be better. This is related to the fact that a flux with an amorphous structure preserves a certain similarity with the melt properties, which is positive for the welding process running.

As indicated by our data [2, 3], most of the welding fluxes form atomic bunching of nanometric size in the molten state, which essentially differ from their crystalline analogs. In the opinion of the authors of [6], the structure of such a particle is close to the colloid micelle. Based on experimental data (on isothermal dependence of density, surface tension, relative activity of oxygen, solubility of water vapours and other parameters), one may come to the conclusion that at the change of melt concentration or temperature the nanomicelle composition is transformed. Restructuring of the entire nanomicelle under the impact of temperature starts in its peripheral zone with decomposition of its upper layers, this leading to formation of a finer nanoparticle of a simpler structure, which is thermally stable. Thermal softening is achieved at the temperature of complete fracture of silicon-oxygen

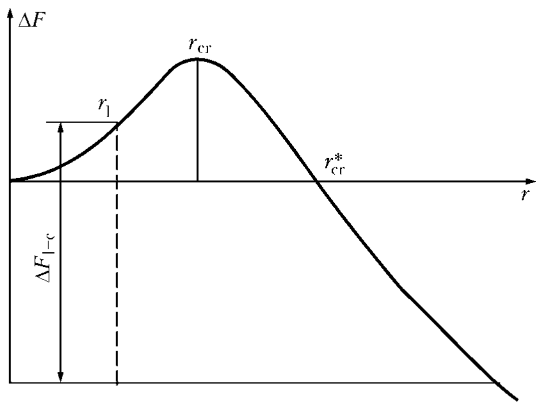

Figure 2. Dependence of variation of free surface energy ΔF on nucleus size

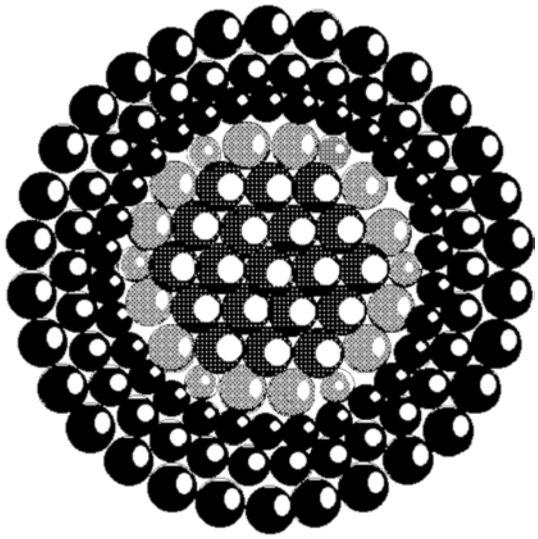

Figure 3. Structure of nanomicelle aggregate

part of the nanomicelle aggregate. The melt properties are described by the ideal solution laws.

Located immediately near the nucleus are the atomic complexes associated with it, which may be regarded as undissociated molecules, and a rarefied diffuse layer consisting of relatively free ions is located closer to its peripheral part. The main difference from the colloid systems consists in that the intermolecular liquid is absent in it, while the diffuse layer is overlapped and forms a continuous matrix.

Our model of the oxide melt is based on the conclusions of [2, 3], from which it follows that after melting a medium is formed which consists of nanomicelles with a common diffuse layer. The micelles only slightly interact with each other, but there exists an equilibrium exchange of particles with the diffuse medium, if the temperature and external pressure do not change. Number of atoms in the nanomicelles varies from one thousand up to several thousand, and micelle size from 1.2 to 10.9 nm. Nanomicelles can be regarded as gigantic molecules in the diffuse (quasigas) medium. The nanomicelle aggregate has a complex structure (Figure 3). Its middle consists of atoms, which correspond to the composition of the most resistant compounds, and can have the role of a crystalline nucleus at solidification, while the periphery consists of spherical layers by the type of dense packing. In the spherical layers the oxygen--oxygen spacing increases at transition from the center to periphery of the particle. Cations, which the most readily fit into the tetra- and octahedral cavities are located in the cavities between the oxygen layers. Small-sized cations will be located closer to the aggregate center, and larger-sized cations will be on its periphery. The micelle particle includes anions, which are rigidly bound with the nucleus, move together with it in the electric field and make up the colloid particle. Other anions form a diffuse layer. They are relatively free, and do not move in the electric field to the anode.

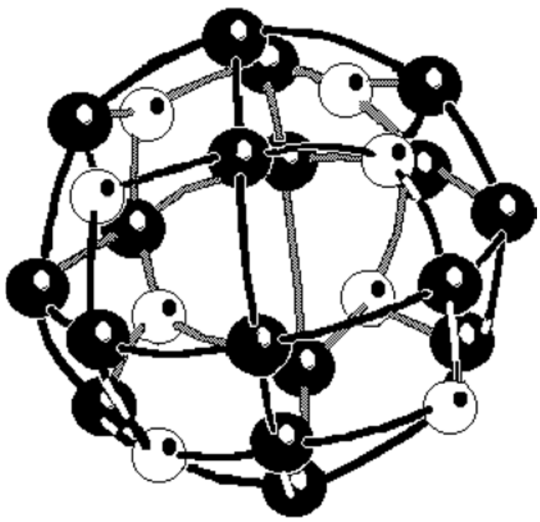

Figure 4. Schematic of spherical layer consisting of oxygen atoms of minimum size

Thus, the proposed nanomicelle structure meets all the requirements of colloid chemistry. However, unlike the colloid system, the oxide micelles are not in the solution (intermicellar liquid), which does not interact with the micelle and forms its charge or solvate shell, thus ensuring the system stability.

A dense spherical packing of liquid-type oxygen atoms can be realized by different methods, for instance, by the fullerene principle. A simpler method of its implementation can also exist. Figure 4 shows a spherical layer of oxygen atoms of a minimum size, in which the atoms form a spherical net made up not of the regular pentagons and hexagons (as in the fullerenes), but of distorted rectangles. Several spherical layers of such a type located one above the other with shifting of the atomic node into the center of the lower layer rectangle, can realize a dense packing of atoms, similar to a dense cubic packing of crystals, but unlike the dense crystalline packing, the oxygen--oxygen spacing in such formations is not constant.

Oxide nanomicelles are located in a discontinuous diffuse medium, where particle concentration is close to that of a compacted gas in dynamic equilibrium with the diffuse medium, while the composition of the micelles and the diffuse medium depends on the outer parameters, namely temperature and pressure. Oxygen included into the composition of the diffuse medium, can be regarded as free oxygen. For illustration of the above, we have restricted ourselves to just the oxygen layers.

In melting out fluxes from charge materials the CaF_2 and SiO_2 molecules can draw closer to each other, so much that running of the reaction

$$2CaF_2 + SiO_2 = 2CaO + SiF_4\uparrow \qquad (2)$$

will become possible. The moisture present in the charge materials also promotes running of reaction (2) [7]. However, after formation of the micellar structure it can only run at a high temperature at fracture of micelles will release of silicon dioxide from the aggregate lower levels. This reaction ensures gas protection of the arc zone from deleterious impact of

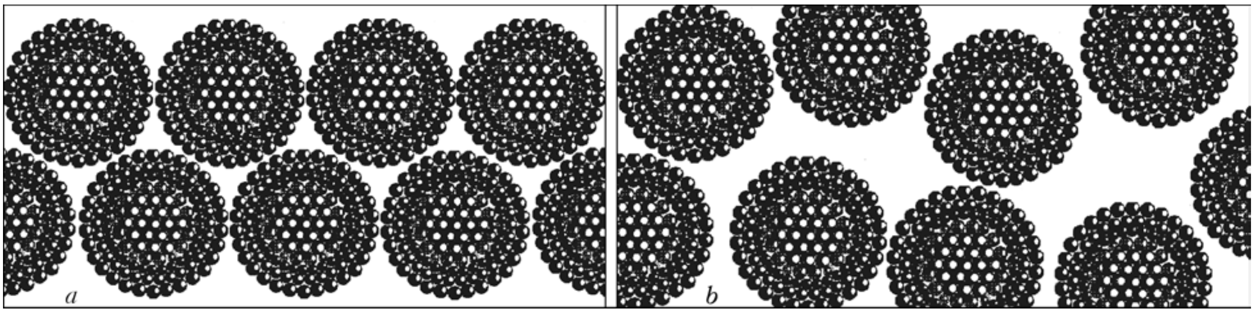

Figure 5. Structural schematic of melt based on oxygen atom close packing nanomicelles at low (*a*) and high (*b*) temperature

atmospheric air. These issues are considered in greater detail in [2, 3].

Figure 5 gives the structure of the melt based on nanomicelles of densely packed oxygen atoms at low (Figure 5, *a*) and high (Figure 5, *b*) temperatures. After slag interaction with the gas or molten metal environment the composition of the diffusion space can vary and can become close to that of the sulphide, sulphate, water or other vessels or to the products of slag interaction with the metal phase, depending on the priorities of interaction with the contacting phases. It is possible that the composition of the diffuse medium, which is closer to one of the contacting phases, will be more saturated by interaction products coming from the contact zone. Figure 6 shows the possible structure of peripheral tetrahedral layers of micelle aggregate, where the lower layer is formed by smaller tetrahedrons, and the upper layer — by larger tetrahedrons. Cations are not shown in the Figure.

We have studied fluxes of AN-76 type from different batches. Fluxes produced recently, were compared with similar fluxes, but produced more than 15 years ago. Solid granulated fluxes were studied in Dron-3 diffractometer using CuK_α-radiation, molten fluxes — in the diffractometer for melt investigation using MoK_α-radiation. Figure 7 gives the diffractograms of different batches of fused fluxes of AN-67B type manufactured by Nickopol Ferroalloy Plant with batch numbers 137, 2, 3, 4, 5, 6, 71. In the Figure the diffractograms of fluxes of AN-67U and AN-67A type made approximately 20 years ago, are shown on the top. As was anticipated, they have an amorphous structure.

In Figure 8 the diffractograms of flux of AN-67B type obtained at room temperature and at 1350 °C are compared. As is seen from the Figure, the crystalline peaks do not completely disappear even at high temperatures.

Thus, the majority of AN-76B welding fluxes manufactured lately (except for batch 71, see Figure 7) are not amorphous. Crystalline peaks in the diffractograms are identified as two phases, namely one based on aluminate spinel (melting temperature above 1520 °C), the second is fluorite CaF_2 (melting temperature of about 1418 °C). Exclusively aluminate spinel is identified only in 137 sample (Figure 9). CaF_2 crystalline peaks disappear after the temperature of 1450 °C has been reached and after isothermal soaking at this temperature for 40–60 min. At rapid cooling in the mode of furnace power switching off starting from 1450 °C, CaF_2 peaks in the remelted slag are not restored. It was not possible to conduct experiments with a higher temperature phase of spinel type, as the slag melt started boiling, which greatly distorted the surface of X-ray reflection and the diffractogram. It may be assumed, however, that after achievement of 1600–1650 °C, isothermal soaking at these temperatures and subsequent quenching of the slag melt, a completely amorphous flux can be produced.

Probably, in case of following of the technological parameters, the atomic microbunching in the solid

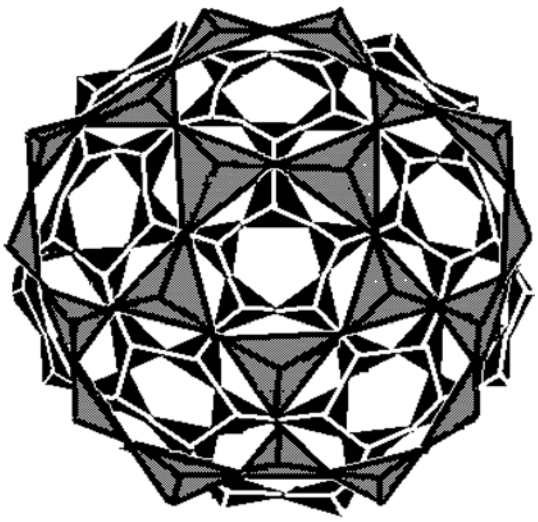

Figure 6. Possible structure of peripheral tetrahedral layers of micelle aggregate

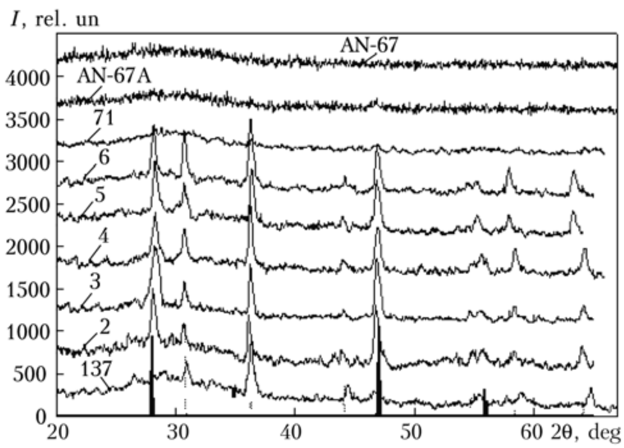

Figure 7. Diffractograms of different batches of fused fluxes of AN-67B type: θ — angle of X-ray scattering; *I* — their scattering intensity

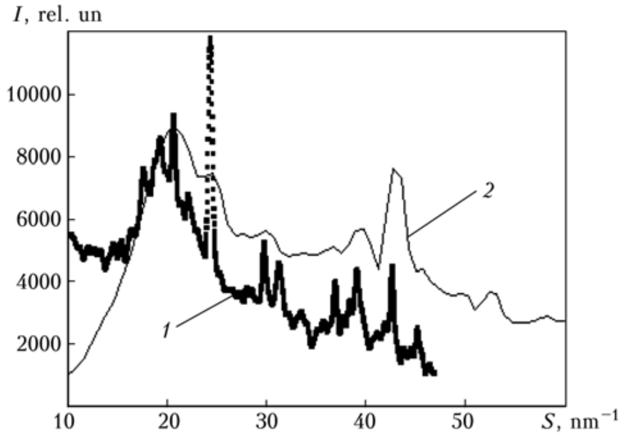

Figure 8. Diffractograms of AN-67B fluxes obtained at room temperature (*1*) and at 1350 °C (*2*): *S* — scattering vector

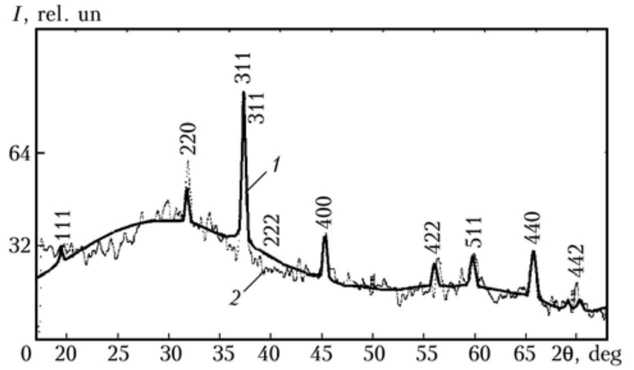

Figure 9. Total profile description of the diffraction curve derived by Ritweld method for a flux of AN-76B type (batch 137) using σ-Al_2O_3 lattice: *1* — Al_2O_3 spinel; *2* — test flux

granulated flux will be close in its dimensions and structure to the melt nanomicelles, while CaF_2 will be located on the bunch periphery. Such a structure close to the equilibrium liquid structure, will enable avoiding additional energy losses at melting, making maximum use of reaction (2) and physico-chemical properties of the molten slag.

For comparison, the basicity of welding flux AN-67B and its temperature dependence are determined proceeding from the results of X-ray diffraction experiment [8]. Earlier we have shown that for aluminate fluxes of AN-67 type, a monotonic increase of basicity is found at temperature rise [2], which correlates with the processes proceeding in the weld pool. This research, however, was devoted to amorphous fused fluxes. The obtained results are indicative of the fact that in partially solidified flux of AN-67B type, the temperature dependence of bacisity differs essentially from the amorphous one, which may detract from its welding-technological properties. Therefore, the furnace temperature at melting out of the fluxes was below 1418 °C, or the soaking time at maximum temperatures of the slag melt was limit small, which was the consequence of violation of the technology mode in manufacturing of fused fluxes.

Thus, the X-ray diffraction method allows establishing the presence of unfavourable crystalline phases in the fluxes, which are indicative of violation of its manufacturing technology.

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E.O. PATON ELECTRIC WELDING INSTITUTE TECHNOLOGY PARK — OPERATION EXPERIENCE AND PROSPECTS

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The features of forming and development, as well as economic aspects of the activity of the «E.O. Paton Electric Welding Institute» Technology Park are considered. Information on innovation projects fulfilled over the recent years, their novelty and value is given. Subjects of the future promising projects are mentioned, as well as possible conditions under which technology parks will be developing.

Keywords: technology park, structure, innovation projects, state support, project subjects, economic indices, promising directions

The «E.O. Paton Electric Welding Institute» Technology Park was established in 2000, in keeping with the Law of Ukraine «On Special Conditions of Technology Park Activities» #991 of June, 1999. The Technology Park includes: the Institute proper, PWI Scientific-Technical Complex, PWI Pilot Plant of Welding Equipment, Simferopol Electrical Engineering Plant-Company SELMA, Kakhovka Plant of Electric Welding Equipment, Zaporozhie Plant of Fluxes and Glassware, and a number of other enterprises.

Innovation projects fulfilled within the Technology Park framework have the following kinds of state support, in keeping with the current legislation:

- entering the profit tax sums into special accounts;
- exemption from import duty on new equipment, systems and components, as well as materials, which are not produced in Ukraine, but are required for project fulfillment;
- VAT payment at equipment import for project needs using a tax bill redeemable on 720th calendar day, and for materials — on 180th calendar day;
- accelerated depreciation of capital stock;
- exemption from obligatory sale of currency earnings;
- extension of the settlement period on export-import operations from 90 up to 150 days.

In addition, in 2007 the state budget envisaged a budget program for financial support of technology parks, which offered:

- complete or partial (up to 50 %) interest-free loans;
- complete or partial compensation of interest paid to performers of technology park projects, commercial banks and other financial-credit institutions for project crediting.

Application of special terms allows compensating to enterprises up to 10–15 % of all costs of development and organization of manufacturing of innovation products. Terms of project return-on-investment are thus reduced from 5–7 to 3–5 years. In PWI Technology Park the purpose-oriented subsidies entered into special accounts, are used for 90 % for upgrading and development of pilot-production facilities, as well as purchasing the scientific and production equipment required for implementation of the innovation project.

PWI Technology Park projects, as a rule, include a complete innovation cycle: from fundamental and applied research up to organization of production and marketing the innovation product. Maximum validity period of the special terms for an individual project is 5 years, for the technology park as a whole — 15 years.

Technology Park projects should meet the following requirements:

- correspond to priority areas of its activity;
- have the required degree of novelty and patent protection;
- be competitive and lend themselves to practical realization with results beneficial for Ukraine, solve important national economy and science-technology problems;
- have the required financial support and effective demand in the market;
- have (or create during project fulfillment) the scientific-technical facilities required for practical realization;
- ensure positive budget balance (excess of budget deductions over the total sum of subsidies and privileges);
- enhance the export potential of the country and lower the degree of its export dependence.

All the projects undergo preliminary examination by a special commission of the National Academy of Sciences of Ukraine, ministries and departments interested in the State scientific-technical expertise, and are registered as Technology Park projects only in the case of positive statements by the decision of the Working Group of the Ministry of Education and Science and Special Commission of the Cabinet of Ministers.

The State ensures strict control of project fulfillment and correct calculation of the subsidies and their use according to the purpose.

Over the past years Technology Park participants have fulfilled 14 projects on development and introduction into Ukrainian and world markets of new technologies, equipment and materials incorporating the most recent advances of welding science and technology.

The main projects taking up 95 % of the total volume of Technology Park scope of work are the following:

• *high-frequency welding of soft live tissues*. With involvement of US capital, technology and equipment have been developed, medical aspects of application of the new method in medical and veterinary science have been verified. So far, more than 10 thous patients already have had successful surgery in Ukraine. US specialists called this project «a breakthrough into surgery of XXI century», and the work received the State Award of Ukraine. The project is protected by patents of Ukraine, USA, and Australia;

• *machines for flash-butt welding of high-strength rails of high-speed railway*s, taking up the leading positions in the world markets. More than 40 patents were used in the project, which are maintained in the countries — potential buyers, namely the USA, EC, China, India, Brasilia, Russia, etc.;

• *technology of melting out high-quality welding fluxes*, having no analogs in the world practice, which allow replacing by half the deficit and expensive imported raw materials in the charge by slag wastes of the metallurgical industry. Up to 85 % of the manufactured fluxes are exported;

• *up-to-date power-saving equipment for arc welding*. More than 70 % of the developed equipment is exported abroad;

• *novel technologies of magnetic separation and magnetic-flotation ore dressing*, which allowed bringing iron content in the concentrate from 63 up to 68–69 %, which corresponds to the product characteristics of the best ore mining and processing enterprises using richer ores. This allows 10–15 % lowering of the cost of cast iron and steel production, and protecting the national market from expansion of foreign exporters.

In addition, projects were fulfilled on stamp-welded oil-filled radiators (KPEWE, Kakhovka), power-saving glass («Tekhnoluch», Kiev), laser welding, plasma-arc welding of aluminium alloys, pulsed-plasma surface modification, strengthening of working tools of agricultural machinery.

In keeping with the worldwide accepted classification, PWI Technology Park projects include:

• by the degree of their novelty: 40 % of pioneer, 30 % of world level, 30 % of modified projects;

• by technology categories: 33 % belong to the 3rd category; 22 % — to the 4th and the most high-tech and science-intensive 5th and 6th categories, respectively;

• by market value: 40 % are on world level, 40 % — on the national and 20 % — on branch level (for comparison, in Polish Technology Parks, acting within the EC framework, the fraction of projects of world level is 1.9, national — 14 and branch — 84.1 %, respectively).

At present new innovation projects with SELMA Company, Simferopol Motor Plant and Zaporozhie Plant of Flux and Glassware are being prepared.

Special mention should be made of the project on establishing in Ukraine the manufacturing of a modern equipment system for construction and operation of high-speed all-welded trunk-railways. This will allow increasing the velocity of railway transportation up to 140–160 km / h (furtheron up to 200 km / h and more), which is important for a reliable operation of East–West transit corridor running through the territory of Ukraine. In addition, a great number of workers (railway equipment makes up 35 % of capital funds of the main railways and is maintained by 25 % of all the railway workers) will no longer have to perform hard manual labour. Czeckia and Russia are now participating in project development. Furtheron foreign investors and international financial organizations will be widely involved by the Ministry of Transportation in the work on construction and reconstruction of the Ukrainian railways.

PWI is currently pursuing new areas, which can well become the basis for new innovation projects, among which the following should be primarily mentioned:

• solving the problem of non-polluting processing of hazardous (including medical) wastes using vapour-plasma and other high-temperature technologies;

• development and organization of manufacturing of magnetic nanofluids for medicine;

• development of functional and structural nanomaterials and coatings, in particular for aerospace engineering;

• development of local power-saving and explosion-safe light sources based on LEDs;

• improving the throughput of trunk gas pipelines at the expense of advanced engineering solutions for gas-pumping compressors and gas cooling.

On the whole, it should be noted that the PWI Technology Park now is one of the major and most successful innovation structures.

An Internet-poll of top managers on the subject «Which Ukrainian company or structure is the most innovative?» was recently held in Ukraine. The results were as follows: the first place was given to «Kvazar-Micro», which starting from 1990s has had co-operation with Company «Intel» whose principle is «Always one step ahead». When the second place was awarded, PWI Technology Park, Kievstar and PrivatBank got an equal number of votes. Selection was made in favour of the Technology Park, as this is exactly the structure which promotes not only generation of powerful ideas, but also their practical implementation with a successful commercial result.

Economic indices of the Technology Park activities are quite worthy of it. Realization of innovation products by the Technology Park participants grew practically from zero in 2000 up to UAH 1.6 bln in 2006. Just in six years UAH 5.4 bln of innovation products have been sold, which are in demand both in the inner and world markets (export is more than 20 %). Technology Park projects ensured a positive export-import balance of Ukrainian manufacturers of welding equipment and consumables.

Working under the special terms enabled PWI Technology Park, owing to tax and customs preferences, to ensure state support of innovation activity in the scope of more than UAH 150 mln from the centralized special account of the Technology Park, into which more than UAH 3 mln were entered over these years for additional support of the projects without the Technology Park getting any direct budget funding. More over, the Technology Park transferred UAH 454 mln to the budget. Thus, budget effectiveness of PWI Technology Park activity, i.e. excess of budget deductions over the scope of government support was equal to UAH 304 mln over these years.

Another indication of the effectiveness of Technology Park operation accepted in world practice, is the proportion of innovative product output and scope of government support. In China it is believed to be normal, when 6 yuans of innovative products are produced per 1 yuan invested by the government into the technology parks. The results of PWI Technology Park activities over seven years are 29 UAH per 1 UAH of government support.

Government support was used for 90 % for material support of innovation activity (establishing the test and pilot-production facilities, purchase of unique equipment), and for 10 % — for intellectual support (research, development, patenting, technical preparation of production). The means from special accounts were used strictly within the framework of approved Technology Park projects.

Despite all the obvious successes the Technology Parks fate is hard. In 2005 as a result of «technical error of the Government» the economic basis of technology park activity was completely eliminated, placing them on the verge of liquidation. They had to live through several dozens of audits by different organs — by Control-Revision Administration, Public Prosecutor's Office, National Security Service. The tax authorities tried on several occasions to accuse the Technology Park and its participants of incorrect entering of privileges into the special accounts and their use not for the purpose. The Technology Park won absolutely all the lawsuits.

In January 2006 the systems of preferences was restored legally, i.e. the system of government support of technology park projects, thus allowing their activity to be restored. In addition, the program of the coalition of democratic forces of Ukraine «Ukrainian breakthrough for people, not politicians» which has, even though a minimal, but still a majority in the Verkhovna Rada of VI convocation, envisages:

- ensuring development of innovation structures — technology parks, technology complexes, technology incubators;
- approval of the new version of the Law of Ukraine «On Special Terms for Technology Park Activity» (after its first reading the Law was adopted already in Verkhovna Rada of V convocation).

So let us hope for the better, the more so, since the results of our Technology Park activity are a quite convincing evidence of the positive contribution of technology parks into development of the economy of the country as a whole, and science, in particular.

ENSURING THE STABILITY OF SUBMERGED-ARC WELDING PROCESS AT LOW CURRENT DENSITY

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The paper deals with the influence of energy parameters of «arc–power source» system at a combined volt-ampere characteristic of the power source and constant electrode wire feed rate on the stability of the welding process under the impact of disturbances along the arc length.

Keywords: arc welding, power source, self-regulation of the welding arc, process stability, technological disturbances, combined volt-ampere characteristic, current density

During performance of automatic submerged-arc welding the stability of the arc process [1] and consistency of geometric dimensions of the weld, are one of the main conditions of producing a sound welded joint.

Lowering of current to a limit, at which a stable arc process is still in place at v_f = const, with preservation of the required depth of metal penetration is urgent for many practical tasks (welding and surfacing of dissimilar metals, welding of root welds in multi-pass joints, welding of two-layer steels, welding of heat-hardenable steels, etc.). To ensure the welding process stability power sources with flat and drooping external characteristics are used, and if it is necessary to lower the current density — special schematics of welding heads with systems of arc length stabilization [2]. However, the stability of the submerged-arc welding process at current densities below 40–30 A / mm^2 is not ensured in these cases, either, because of instability of the arc–power source system (A–PS) [2].

The purpose of this work is ensuring the process stability and weld parameters in submerged-arc welding at currents of less than 30 A / mm^2 density, allowing for the influence of technological disturbances (change of electrode extension), due to errors of joint assembly for welding, presence of tack welds or unevenness of the processed surface.

It is known [3] that the stability of A–PS system as a necessary condition of stability of the arc welding process is achieved at a positive value of the coefficient of dynamic stability K_{st} in the working point and sufficient intensity of self-adjustment. Therefore, stability of arc welding process at low current densities can be achieved by changing the relative position of static characteristic of the arc (SCA) and volt-ampere characteristic (VAC) of the source at preservation of $K_{st} > 0$. This work is a study of the possibility of implementation of a stable process of automatic submerged-arc welding with 2–5 mm diameter wire at currents of density below 30 A / mm^2 by using power sources with a combined VAC.

A combined characteristic consists of two branches: steeply-falling in the range of working currents (κ = = 0.15–0.20 V / A) and drooping (κ = 0.02–0.04 V / A), automatically switching on at lowering of arc voltage to a minimum value sufficient for maintaining the arcing.

It is known that at power supply from the current source with a flat or drooping VAC at low densities of current in the electrode, at short-time shortening of the arc length an abrupt increase of current in the electrode is observed, and at increase of arc length arc breaks occur because of low open-circuit voltage $U_{o.c}$ of the source (Figure 1, *a*). At arc powering from a current source with a steeply-falling VAC and abrupt shortening of the arc length (at crossing of a tack weld), an insufficient increase of current and low intensity of the self-adjustment process lead to process disturbances caused by short-circuiting (Figure 1, *b*).

Let us consider the operation of A–PS system with a combined VAC of the source (Figure 1, *c*) at arc

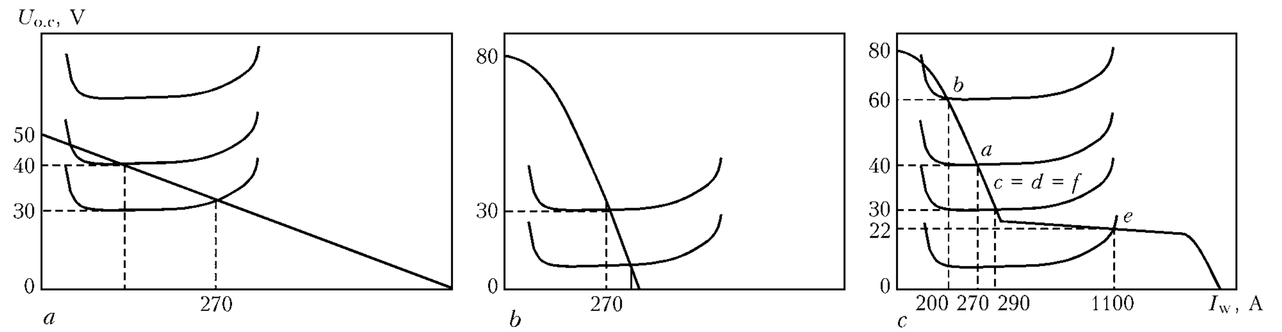

Figure 1. Change of SCA position [4] relative to VAC of the power source at different disturbances of arc length: *a* — drooping VAC (κ = 0.02 V / A); *b* — steep-falling (κ = 0.15 V / A); *c* — combined

Table 1. Sample welding modes

Electrode wire diameter d_{el}, mm	Welding current I_w, A (current density j, A / mm^2)	Arc voltage U_a, V
2	120–130 (38.2–95.5)	28–30
3	170–300 (24.1–42.5)	
4	220–500 (17.5–39.8)	30–32
5	280–500 (14.3–25.5)	

length variation. In Figure 1, *c*, point *c* corresponds to the set arc length, and points *a*, *b*, *d*, *e* — to deviations caused by variations of its length. In point *c* the value of the coefficient of dynamic stability $K_{st} >> 0$, i.e. the condition required for stable arcing is achieved automatically. At development of disturbances causing arc shortening, SCA shifts to a position corresponding to point *e*, which also characterizes a stable arcing condition. However, at system operation in the falling section of a combined VAC of the source, the intensity of arc self-regulation is extremely small, this resulting in a much slower restoration of the initial arc length than in the range of currents corresponding to a flat SCA. Such a running of the process is observed at any SCA position right up to the section of transition of a steeply-falling VAC branch into a drooping one. At shortening of the arc length to a critical value, the system moves into an operating mode using a flat section of VAC, in which a high intensity of self-regulation is ensured, which prevents short-circuiting of the arc gap. In this case, the position of point *e* will only be determined by the value and rate of disturbance increase. At development of disturbances causing an elongation of the arc, the high open-circuit voltage of the source ($U_{o.c}$ = 80 V) maintains the stability of A–PS system, not leading to arc break.

Thus, the combined VAC of the power source ensures a stable arc process in the region of low current densities in the electrode.

Experimental studies were performed to confirm the effectiveness of application of a combined VAC.

Welding was performed by TS-77 tractor with a constant wire feed rate. The combined VAC for arc powering was formed by parallel connection of two thyristor rectifiers: VDM 25-630 with a block of ballast resistances (steep-falling) and VDU 25-1202 (drooping branch of VAC).

Current and voltage oscillograms were recorded using an electron oscillograph IRIS and registered in a PC. Weld dimensions were evaluated by macrosections with 6-fold magnification.

Flat samples of 09G2 steel of 330 × 150 × 16 mm size were used to determine minimum values of current. In order to evaluate the influence of technological disturbances, special samples were prepared with a rectangular slot of 50 mm width and 5 mm depth milled out in mid-sample along the length. Welding was performed at the speed v_w = 6–47 m / h using flux OSTs-45 with Sv-08A wire (Table 1).

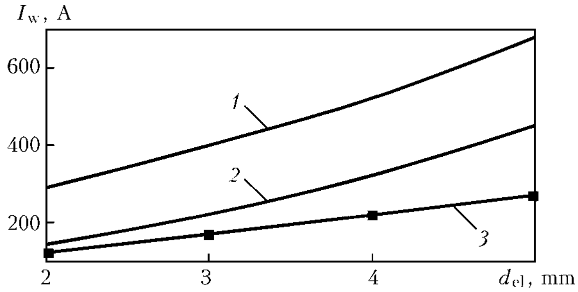

Figure 2. Dependence of minimum current on electrode wire diameter: *1*, *2* — alternating and direct current, respectively [1]; *3* — combined VAC (experimental data)

Figure 2 gives the results of determination of minimum current providing a stable welding process, depending on electrode wire diameter. The same Figure gives the data for welding heads operating at alternating and direct current earlier obtained by B.E. Paton and I.I. Frumin [1], for comparison purposes. As is seen from Figure 2, the combined VAC of the source allows lowering the admissible current for stable operation of the welding heads in the absence of technological disturbances.

Influence of experimental welding modes on weld dimensions (Figure 3) is selectively presented in Table 2 and is described by the following regression dependencies:

- penetration depth $h = 0.0088I_w - 0.0066v_w + 0.027d_{el} - 0.57$;
- deposit width $e = 0.0059I_w - 0.19v_w + 0.966d_{el} + 13.66$;
- bead depth $g = -0.0035I_w - 0.054v_w + 0.55d_{el} + 2.88$.

For evaluation of the influence of technological disturbances on welding process stability at low current densities the beads were deposited across the slot, so as to simulate an obstacle abruptly changing the arc length by 5 mm. Welding mode was as follows: I_w = 280–290 A, U_a = 30–32 V, v_w = 18 m / h.

After studying the appearance and longitudinal weld sections it was established that the deposited beads can be divided into six sections characterizing the impact of the technological disturbance (transverse slot) on weld dimensions. Section limits are denoted by markers *I*–*V* (Figure 4). Marker *I* is the start of a rectangular slot (arc elongation); *II* is the end of disturbance processing by the system and stabilization of the process after arc elongation; *III* is

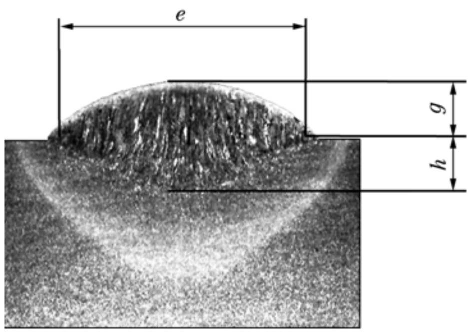

Figure 3. Macrosection of the deposited bead (for designations see the text)

Table 2. Influence of mode parameters on deposited bead dimensions

I_w, À (d_{el} = 5 mm, v_w = 36 m / h)			v_w, m / h (d_{el} = 5 mm, I_w = 400 À)			d_{el}, mm (I_w = 300 À, v_w = 25 m / h)		
h	*e*	*g*	*h*	*e*	*g*	*h*	*e*	*g*
300			15			2		
1.9	2.1	11.4	3.2	3.5	19.2	2.0	2.0	13.0
400			24			3		
2.4	2.5	12.1	3.0	2.6	14.6	2.0	2.0	13.5
500			36			4		
3.6	2.6	16.7	2.6	1.7	11.4	2.5	2.5	14.0
600			47			5		
4.2	2.8	18.5	2.4	1.2	10.0	2.8	3.5	15.3

the beginning of the zone affected by the arc shortening; *IV* is the end of a rectangular slot (arc shortening); *V* is the limit of the section affected by arc shortening. Section *A* (Figure 4) about 15 mm long corresponds to the disturbance zone at arc elongation. In this section the height of the deposited layer is reduced to 3 mm, compared to the initial one equal to 4 mm, and penetration depth — from 3 to 1 mm. However, fusion of the deposited metal with the base metal is guaranteed even at the moment of an abrupt change of the plate profile. Bead width at the end of section *A* increases from 24 to 28 mm. Changes of bead dimensions in this section are attributable to liquid metal flowing into the slot, and maintaining a stable arcing due to an increased arc voltage at rectifier operation on the falling branch of the combined VAC (see Figure 1, *c* and Figure 5, *a*).

In section *B* also about 15 mm long, between markers *I* and *II* the height of the deposited layer is restored to 4 mm, penetration depth — to 3 mm; bead width at the section start decreases abruptly to 22 mm, and then increases smoothly to the initial size of 24 mm. Section *B* is the zone of process stabilization after arc elongation. The rectifier continues operating on the falling branch of the combined VAC, but arc voltage decreases (see Figure 1, *c*).

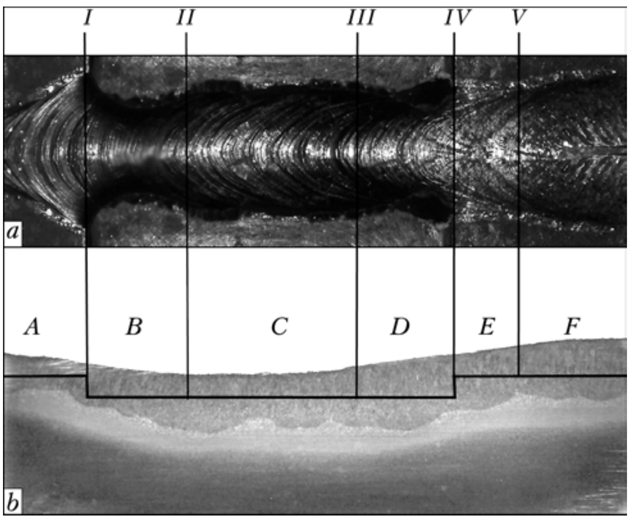

Figure 4. Formation of the deposited bead: *a* — top view; *b* — longitudinal macrosection

Section *C* of 22 mm length is the zone of deposition over the slot surface: the process runs in a stable manner, dimensions of the deposited bead coincide with the initial ones before the action of the disturbance.

Longitudinal section of the deposited layer reproduces the slot profile with the admissible deviations of weld dimensions. A stable fusion of the deposited metal with the base metal is provided.

Nature of variation of the deposited bead dimensions and depth of metal penetration at an abrupt change of the arc length can be explained using the known relationship between the change of the electrode wire melting rate v_{el} and variations of welding current and voltage [4]. For a long arc running without short-circuiting (see Figure 4, section *A*–*C*), this relationship will be written as

$$v_{el} = k_i i - k_u u,$$

where k_i, k_u are the coefficients of self-adjustment by current and arc voltage.

This means that increase of current in the arc leads to an increase of electrode wire melting rate, and voltage rise, contrarily, results in its lowering.

Arc elongation starts in section *A* as a result of molten metal flowing into a slot. This moment of time corresponds to mark *a* (see Figure 1, *c* and 5, *a*) and is characterized by 8 to 10 V increase of voltage and current lowering by 10–20 A compared to the established parameters of the deposition mode.

Displacement of the automatic welding machine and the weld pool, respectively, leads to further elongation of the arc. Voltage rises up to 60 V, current decreases to 220 A (mark *b* in Figure 5, *a*). This mark is in the region of marker *I* and corresponds to the greatest length of the arc gap. The described changes of mode parameters occur for about 3 s, and can be presented as displacement of the point of crossing of the rectifier SCA and VAC from point *a* into point *b* (see Figure 1, *c*). A smooth lowering of welding current and increase of welding voltage is what accounts for lowering of penetration depth in section *A*. The height of the deposited layer in this section decreases as a result of lowering of electrode wire melting rate, decreasing of the amount of molten metal and its flowing into the slot.

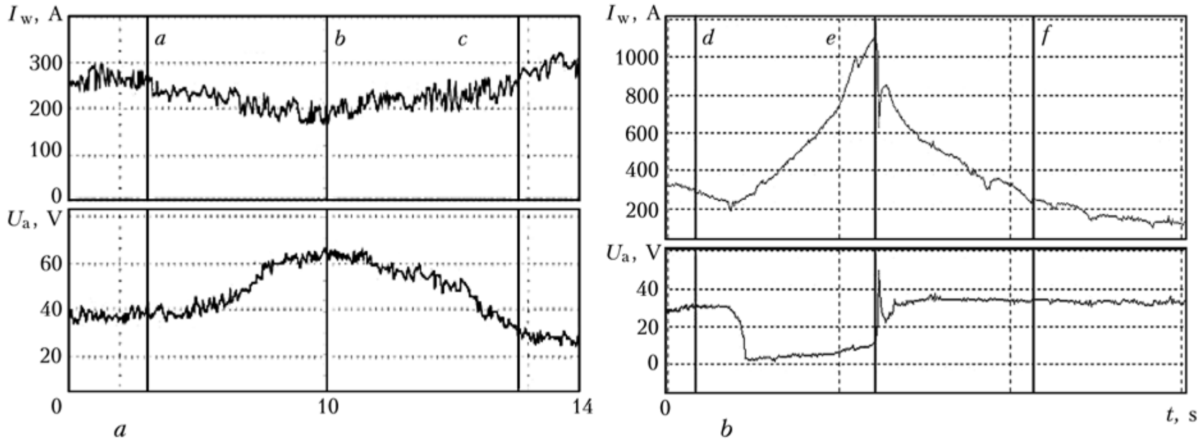

Figure 5. Current and voltage oscillograms at arc powering from a current source with a combined VAC: *a*, *b* — increase and reduction of arc length, respectively

Further welding process (section *B*), as is seen from the oscillogram in Figure 5, *a*, runs in the mode of welding parameter stabilization to the level of mark *c*, i.e. current rises up to 290 A, voltage decreases to 30 V. Process stabilization is explained by the above expression. In position SCA corresponding to point *b*, welding current and electrode wire melting rate are minimum, and, therefore, a process reverse to the disturbance action runs, namely arc shortening and restoration of welding parameters. The duration of the stabilization process is about 3 s, and it corresponds to a smooth displacement of the point of crossing the rectifier SCA and VAC from position *b* to position *c* (see Figure 1, *c*). The dimensions of the deposited bead change in complete compliance with the change of welding current and electrode wire melting rate.

Comparison of the rate of arc displacement with that of the change of mode parameters in the sections *A* and *B* leads to the conclusion that the disturbance impact and the process of mode stabilization after an abrupt elongation of the arc take a long time and may be regarded as static at each moment of time. The combined VAC of the rectifier under such conditions provides a stable running of the arc under a layer of flux.

Let us consider the variation of current and voltage in the arc at its abrupt shortening. In section *D*, as is seen from Figure 1, *b*, the impact of the disturbance causing a shortening of the arc, and mode stabilization after the disturbance are dynamic processes. Their duration does not exceed 0.6 and 0.7 ms, respectively.

Increase of penetration depth and height of the deposited layer in section *D* is attributable to increase of the molten metal volume because of the slot wall preventing metal spreading in the welding direction. On the other hand, the amount of the molten electrode metal increases due to an abrupt increase of current at arc shortening.

The cause for reduction of penetration depth directly before marker *IV*, in our opinion, is the change of the position of the arc cathode spot located on the item.

At a certain moment of time the distance from the electrode wire tip to the slot bottom becomes greater than that to the slot wall. Continuation of the welding process leads to short-circuiting. Resistance of the arc gap is abruptly reduced, the voltage drops, and the current rises (mark *e* in Figure 5, *b*). Disturbance causing shortening of the arc, ends by melting of an additional section of electrode wire. This corresponds to a jump-like (about 0.4 ms) displacement of the point of crossing of the rectifier SCA and VAC from position *d* into position *e* (see Figure 1, *c*). Further on the length of the arc gap becomes stabilized and welding mode parameters are restored. The process corresponds to an abrupt (about 0.8 ms) displacement of the crossing point of the source SCA and VAC from position *e* into position *f* (see Figure 1, *c*).

On the whole, shortening of the arc and stabilization of welding parameters after the impact of the disturbance in welding at low current densities using the combined VAC of the rectifier, run without arc break or welding process interruptions.

CONCLUSIONS

1. It is established that the combined VAC of the power source provides a stable process of submerged-arc welding with heads with a constant electrode wire feed rate at currents of less than 40 A / mm^2 density.

2. Regression dependencies were obtained correlating the welding mode parameters with weld dimensions for currents of 15–40 A / mm^2 density, when using a power source with a combined VAC.

3. Combined VAC of the power source allows stabilization of the welding mode parameters and weld dimensions under the impact of the technological disturbances without arc break or welding process interruption.

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SELECTION OF WIRE FOR MECHANIZED ARC WELDING OF SIMILAR AND DISSIMILAR JOINTS OF 10Kh13G18D STEEL

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Schaeffler structural diagram was used to substantiate selection of weld metal alloying and wire for gas-electric welding of similar and dissimilar joints on 10Kh13G18D steel. The rationality of applying Sv-08Kh20N9G7T welding wire was experimentally confirmed.

Keywords: mechanized arc welding, argon, Schaeffler diagram, structural state, welding wire

In fabrication of the carriage frame of electric and diesel trains with a skin at OJSC «HC Luganskteplovoz» low-alloyed steel 09G2S (frame) and austenitic corrosion-resistant steel 10Kh13G18D (skin) are widely used. When joining the skin sheets to each other and the skins to the frames of the roof and carriage mainframes overlap joints are used (H1 type to GOST 14771–76) of 10Kh13G18D steel 1.5 mm thick, and dissimilar overlap joints of 7 mm 09G2S steel with 1.5 mm 10Kh13G18D steel. Welding is performed by forward inclined technique in the downhand position (Figure 1, *a*) and horizontal position on the vertical plane (Figure 1, *b*) by mechanized consumable-electrode argon-arc welding with 1.2 mm diameter wire [1].

The purpose of this work is substantiation of the selection of the wire to weld similar and dissimilar joints of 10Kh13G18D steel. In terms of technology it would be rational to select one alloyed wire suitable for both the joints.

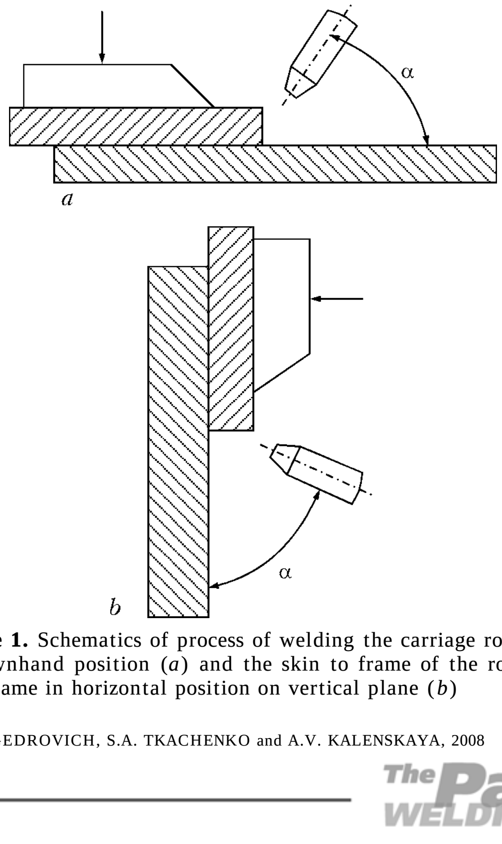

Figure 1. Schematics of process of welding the carriage roof skin in downhand position (*a*) and the skin to frame of the roof and mainframe in horizontal position on vertical plane (*b*)

Steel 10Kh13G18D pertains to metastable austenitic steels [2], and by the classification proposed by I.A. Zaks [3], it is classified as group X, which includes also chromium-nickel steels of 18-10 type and chromium-nickel-molybdenum steels of 17-13-2(3) type. 09G2S steel is classified in the pearlitic class (group II by [2]). For similar joints of X group steels welding consumables (for instance, electrodes) of E-07Kh20N9, E-09Kh19N10G2M2 type to GOST 10052–75 are recommended [4], and for dissimilar joints (group X + group II) — of E-10Kh20N9G6S, E-10Kh25N13G2 type, etc. Electrode type reflects the respective alloying of the deposited metal.

It is convenient to use the Schaeffler structural diagram (Figure 2) to make an approximate selection of welding consumable (wire, electrodes), taking into account the required alloying of weld metal, producing its required structure and physico-mechanical properties of the joints, respectively.

Figure 2, *a* shows the alloying regions corresponding to compositions of steel 10Kh13G18D (point 1), deposited metal 07Kh20N9 (2), 09Kh19N10G2M2 (3) and 10Kh20N9G2S (4). In lines 1-2, 1-3 and 1-4 the thicker sections represent the structural state of weld metal in welding 10Kh13G18D steel using materials of different alloying. Left edges of thicker sections correspond to 40 % share of base metal participation in the weld metal, and the right edges correspond to 20 %. From Figure 2, *a* it is seen that welding consumables of all three types of alloying (07Kh20N9, 09Kh19N10G2M2, 10Kh20N9G6S) are capable in case of welding similar joints of 10Kh13G18D steel of providing the austenitic structure of weld metal with a small (0.5–7.0 %) content of the ferritic phase. This is exactly the weld metal structure, which in most of the cases provides their higher physico-mechanical properties [5]. On the other hand, at a considerable fraction of base metal participation in the weld metal (more than 30–40 %) a purely austenitic structure can form, prone, as is known, to hot cracking. Producing a purely austenitic structure is less likely at applica-

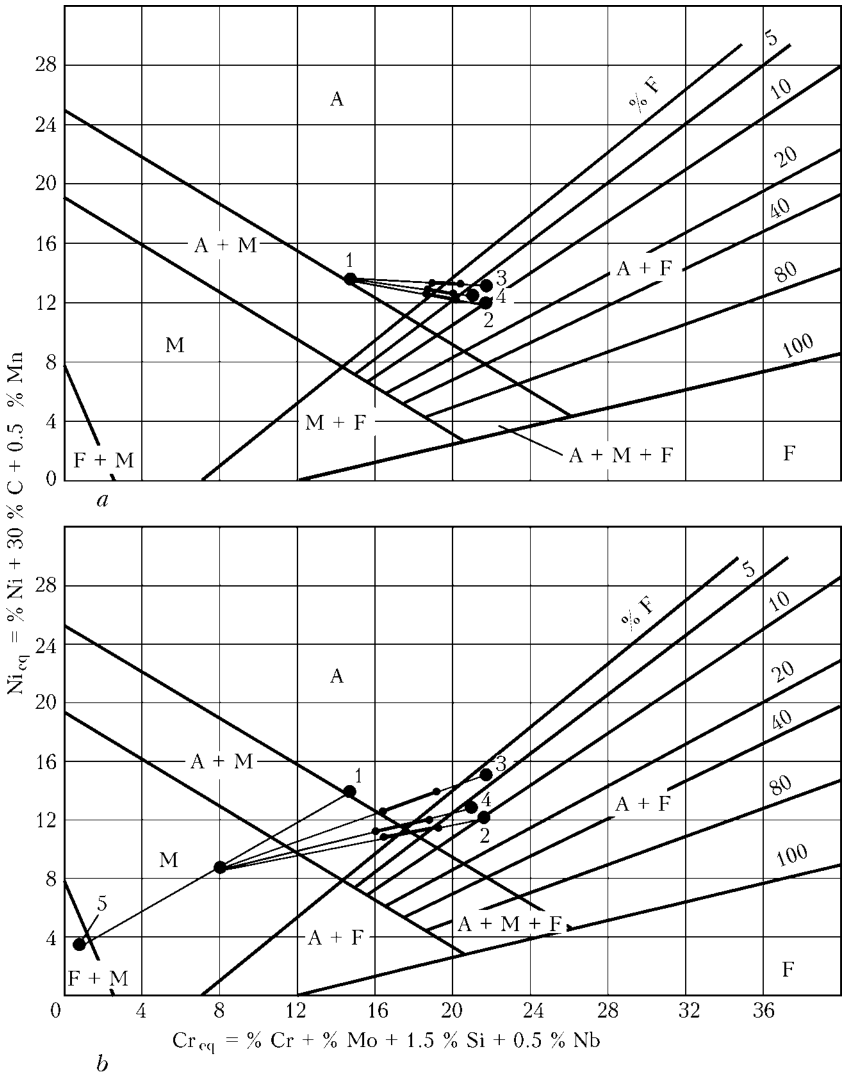

Figure 2. Determination of structural state of weld metal in welding similar joints of 10Kh13G18D steel (*a*) and dissimilar joints of 10Kh13G18D + 09G2S steels (*b*) (for designations see the text)

tion of materials of 07Kh20N9 and 10Kh20N9G6S type.

When dissimilar joints of steel 10Kh13G18D to steel 09G2S are made (Figure 2, *b*, points 1 and 5), preference should be given also to alloying systems 07Kh20N9 (2) and 10Kh20N9G6S (4), as in this case also at limiting of the base metal share in weld metal to 25–30 % producing an austenitic weld metal structure with a limited content of α-phase is anticipated (up to 10 %).

The closest in composition to electrodes of types E-07Kh20N9 and E-10Kh20N9G6S are welding wires Sv-06Kh19N9T and Sv-08Kh20N9G7T (GOST 2246–70). Preference should be given to Sv-08Kh20N9G7T wire as it has a somewhat greater austenitic margin compared to Sv-06Kh19N9T wire and in the case when a purely austenitic weld metal structure is produced, its alloying with manganese promotes an increase of crack resistance [4].

Experimental welding of three types of overlap joints has been performed using Sv-08Kh20N9G7T wire of 1.2 mm diameter: I — 10Kh13G18D steel 1.5 mm thick in the downhand position (see Figure 1, *a*) in the following mode: I_w = 110–120 A, U_a = = 18–22 V, electrode extension of 10 mm, shielding gas flow rate (argon) of 0.1 l / s, v_w = 4 m / h, $v_{w.f}$ = = 290 m / h; II — 10Kh13G18D steel 1.5 mm thick + 09G2S steel 2.5 mm thick in the downhand position (in a mode similar to that of welding joint I); III — 10Kh13G18D steel 1.5 mm thick + 09G2S steel

Structural state and microhardness of weld metal of overlap joints

Steel welded (thickness, mm)	Content of (γ + α)-phase in weld metal, %	Weld metal microhardness, MPa
10Kh13G18D + 10Kh13G18D (1.5 + 1.5)	1.5	220--240
10Kh13G18D + 09G2S (1.5 + 2.5)	2.5	228--240
10Kh13G18D + 09G2S (1.5 + 7.0)	6.0	230--250

7.0 mm thick in the vertical position (see Figure 1, *b*) in the mode: I_w = 85–90 A, U_a = 20–21 V, electrode extension — 15 mm, v_w = 16 mm / h, $v_{w.f}$ = 260 m / h, angle of welding torch inclination — 3° and 60°.

Results of evaluation of the microstructure and microhardness of weld metal in all variants of welding (Table) show that the weld metal structure is austenitic with a low content of α-phase (up to 6 %). Values of microhardness also correspond to the austenitic structure of weld metal.

Thus, design-experimental verification confirmed the rationality of application of Sv-08Kh20N9G7T as electrode wire in gas-electric welding of similar and dissimilar joints of 10Kh13G18D steel.

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REMOTE TRAINING MODEL OF BACHALOR-WELDER

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The model is suggested for training of a bachelor-welder on the basis of a package of applied programs «Navigator», which ensures possibility of remote training in welding and relative technologies.

Keywords: welding, training, model, database, interface, dynamic scenes, working station, electronic support

Within last decade social role of education has significantly increased. Nowadays a specialist should constantly improve its skill level by getting new knowledge in order to be able to solve nonstandard tasks. Requirements of continuous training determine the need in modifying its methods [1].

At present significant part in training process and scientific investigations is played by innovation technologies, the tool of which is a computer [2]. To the most distributed technologies of knowledge transfer in higher school relate:

• lecture training with application of multimedia technologies, personal computers, and video and audio equipment;

• use of training and auxiliary programs on computers;

• laboratory and practical works, in the course of which special written computer programs are used for processing of experimental data;

• electron library and electron simulators;

• testing on a computer as a method of the knowledge assessment, etc. [3].

The suggested model of remote training of a bachelor-welder unifies all listed technologies. It represents a package of applied programs, which includes a tooling of electron methodological training and corresponds to state-of-the-art requirements of training of the students for welding specialities and is of significant help for the teachers. On the way of entrance of Ukraine into Bologna process, which envisages reduction of the time of auditory classes and allocation of a significant portion of the materials for self-training work [4], this model of training of a bachelor-welder enables improvement of the education quality. We would like to note that welding department of NTUU «Kiev Polytechnic Institute» performs training according to Bologna process beginning from 2006.

Component of the model is «Navigator», developed on basis of the courses «Informatics and computing equipment», «Microprocessor systems of control», «Solution of applied tasks on computers», for welding

Figure 1. Dynamic scenes of «Navigator» showing formation of weld pool and weld

specialities and used in practice by welding department of «KPI». Implementation of «Navigator» is possible with minimal technical facilities: processor 486, RAM32Mb, Video 1Mb, HDD 1Gb, and operation system Window's 98. The package also includes database of students since 1996 with pictures; electron library, which includes text books, methodological instructions, training literature for foreign students in language of their country; more than one hundred specialized sources; a package of laboratory works and computer practical works with automatic and semiautomatic estimation of fulfilled tasks.

Dynamic scenes (Figure 1) are used in the works, for creation of which algorithm of pseudodynamics is used. Quality of these dynamic scenes is not inferior to that of the files, created in the format for review of videos [5], and allows a user direct participating in the scene (Figure 2).

«Navigator» also includes a specially developed complex program for testing the level and quality of knowledge of the students at practical lessons, at a credit, and at an exam; electronic register of progress, which corresponds to requirements of the dean's office and individual approaches of the teacher. Deserved by a student points are put automatically — they are fed from the base of fulfillment of laboratory works, practical works, and testing. Getting of hard copies, automatic calculation of certifications, taking into account requirements of standards to the forms, and printing of statistical reports in the form of tables and diagrams are envisaged.

The whole software complex is located on one working station (server), which allows using in the training process unlimited number of working places, controlling progress, and, if necessary, updating information. Such possibilities are ensured by the developed algorithm of the database, which differs from the stereotypes used in all applied programs [5]. The algorithm also allows flexible operating accumulated data and connecting new tasks, which are not envisaged at present.

The suggested model of innovation training of a bachelor-welder is built on basis of such «Navigators»

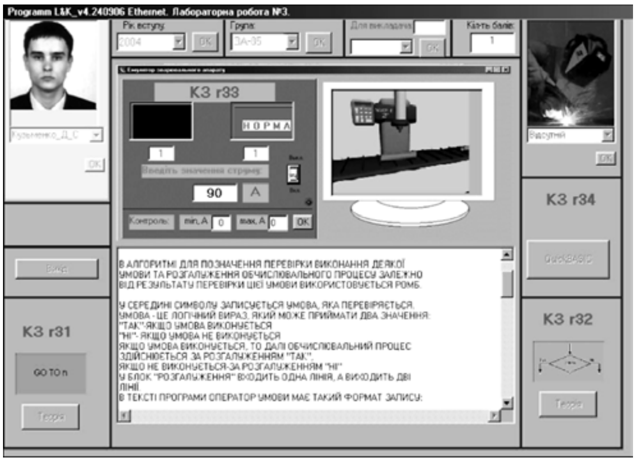

Figure 2. Mathematical model for determining weld quality in case of change of welding conditions

for each training course and subject, including possibility of remote training of a bachelor-welder in welding equipment and relative specialities. Remote training will be carried out through Internet on the site of the NTUU «KPI» welding department. For network implementation of this model the site with possibility of connection of the suggested model was developed. It should be noted that this model may be used for any discipline in any educational institution.

At present variety of ideas and principles of innovation training exist, majority of which are successfully implemented in training processes in practice [6], fulfilling their main function — quality training of skilled specialists, which meet state-of-the-art requirements of the industry.

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OPTIMIZATION OF THE GEOMETRY OF CURRENT-CONDUCTING NOZZLE TIP FOR MECHANIZED ARC WELDING

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Admissible relationships between the eccentricity of the tip of welding torch current-conducting nozzle, length of the eccentric fitting and force of electrode wire applying to it are defined.

Keywords: mechanized arc welding, shielding gases, current-conducting nozzle tip, welding wire, tip eccentricity, pressing force

Current-conducting nozzles with tips of eccentric fitting type (Figure 1) are widely spread in mechanized arc welding in CO_2 gas and gas mixtures. For providing reliable pressing of welding wire of diameter d, sliding over the surface of the tip of eccentric fitting type, its arm of length L is turned relatively to tubular part through angle α so that wire fed into the electric arc zone, is forcibly deflected from the nozzle central axis with formation of eccentricity b (Figure 2). In the shop each welder proceeding from his own experience, sets the optimum value of this deflection. When the eccentricity is available, the wire relatively tightly abuts the tip contact surface due to its elasticity properties under the influence of pressing force P thus greatly improving the current supply to it, and decreasing sparking in this zone [1–5]. At the same time, the eccentricity value should not be too high, as in this case plastic deformation of the wire can occur that, in its turn, leads to its irreversible bending and shifting into the opposite direction after contacting the tip.

In this work admissible relationships are determined between the tip eccentricity value, arm length and force with which the wire is pressed to its contact surface. Copper-coated wire Sv-08G2S of 1.2 mm diameter was used in the tests. Measuring device *1* was designed for modeling the electrode wire position in the zone of nozzle tip, with stand *2* with fastening assembly *3*, electrode wire and height gauge stand *5* placed on its base (Figure 3).

Wire samples *4* of length 50–60 mm on a section of 20–30 mm were fixed in the fastening assembly of the measuring device horizontally relative to its base plane with the extension of 10, 15, 20, 25 and 30 mm. Such values of wire extension were chosen based on structural dimensions of the arms of current-conducting nozzle tips used at the enterprises at mechanized welding in CO_2 gas and in shielding gases mixtures.

The initial position of wire tip on its extension was fixed with the help of frame *6* with measuring leg and measuring scale located on the height gauge stand *5*. Then load *7* was applied to the end of wire extension, balance weights placed on plate *8* being used as the load. The load on wire extension of length 10 mm was increased through 1 N, for other extensions — through 0.5 N.

Measuring of new wire end position by height gauge scale with the accuracy of 0.1 mm was done after each dosed loading. Values of the initial and new wire positions at the extension (Figure 3, positions *9*, *10*) enabled calculation of bending deflection under the action of transverse loading force. Loading was applied up to the beginning of elastic deformation transition into plastic deformation, which was indicated by the smallest failure of the wire to return to the initial position.

The given experimental procedure allowed identifying the wire bending deflection with the value of current-conducting nozzle tip eccentricity, and the

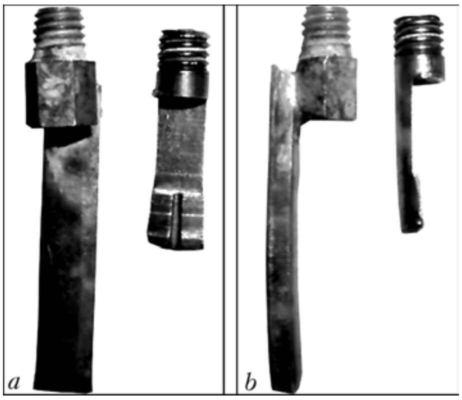

Figure 1. Typical designs of current-conducting tips of eccentric fitting type: *a* — front view; *b* — side view

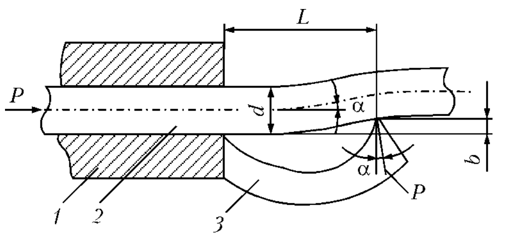

Figure 2. Schematic of contact in tip–wire system: *1* — tip tubular part; *2* — electrode wire; *3* — tip arm

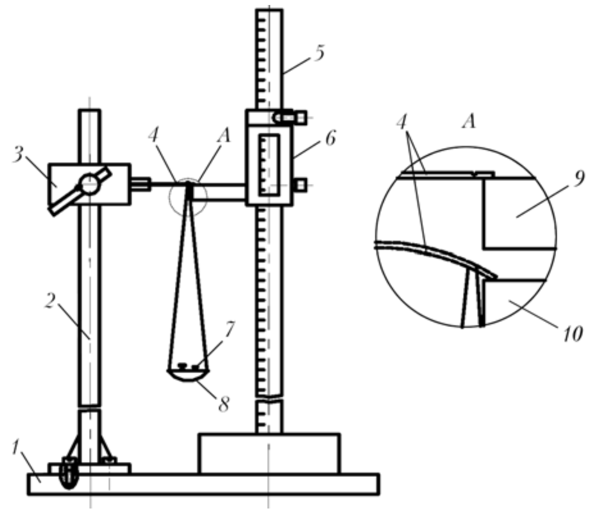

Figure 3. Measuring device design (for explanations see the text)

load applied to the end of wire extension — with the force of its pressing to the contact surface of the mentioned arm tip. The results of the performed investigations are presented in Figure 4.

At wire extension of 10 mm, the maximum bending deflection should be not less than 2.6 mm length, and the loading leading to such a wire deflection should be less than 21 N. At wire extension length of 15, 20, 25 and 30 mm, its bending deflection should not exceed 4.2, 4.8, 5.1 and 5.6 mm, and loading — 16, 12, 9 and 6 N, respectively.

It is seen from Figure 4 that one and the same load, applied to the end part wire extensions of different length, leads to obtaining different bending deflections and, vice versa, the same wire deflection at its different extensions applies different loads to the wire. So, for example, at the same bending deflection of 1.1 mm (i.e., with the same tip eccentricity) and wire extension l = 10 mm, the force of wire pressing to the tip arm would be 12 N, at l = 15 mm — 5 N, at l = 20, 25 and 30 mm — 3.0, 2.0 and 1.5 N, respectively.

Different force of wire pressing to the tip arm will create non-uniform conditions for current supply to it, and, consequently, have different influence on the spattering degree in the contact zone and its wear. It is seen in Figure 4 that the dependence between the load (force of wire pressing to the tip arm) and wire bending in the tip end part (tip eccentricity) is of a linear nature until the wire bending occurs in the area of elastic deformations. In this Figure on all the correlation curves obtained for different wire extensions, the final values are the limit loads above which the plastic deformation, undesirable in this case, develops. Its appearance, unfortunately, leads to visible deflection of the electrode wire direction from the welding torch nozzle axis and, consequently, from the welding zone. At less bending deflection the wire deformation go beyond the limits of the elastic component. The ratio of the arm length of current-conducting nozzle tip recommended for practical application, and value

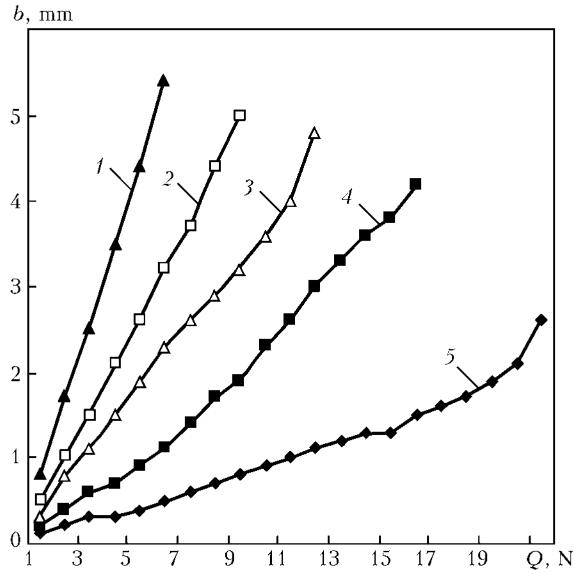

Figure 4. Relationship between loading Q applied to electrode wire extension and bending deflection b: *1* — l = 30; *2* — 25; *3* — 20; *4* — 15; *5* — 10 mm

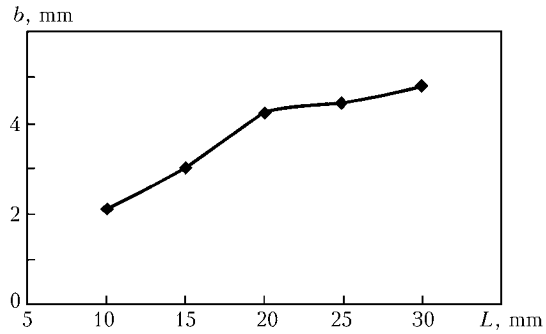

Figure 5. Recommended relationship between tip arm length L and maximum admissible eccentricity b

of its maximum permissible eccentricity is given in Figure 5. The obtained experimental data on permissible relationships of some parameters in the current-conducting nozzle tip zone are used for selection of optimum geometries of welding equipment components.

CONCLUSIONS

1. Relationship between bending deflection of electrode wire of Sv-08G2S grade 1.2 mm diameter and its pressing force to the contact surface of the arm of eccentric fitting tip in the current-conducting nozzle was studied.

2. Maximum values of bending deflection of wire at different length of its extension were determined. Exceeding of these values leads to initiation of plastic deformations in the wire and its deviation in an undesirable direction after the contact with the nozzle tip arm.

3. A relationship between the arm length of eccentric fitting and value of its maximum permissible eccentricity was recommended for practical use: eccentricity should not exceed 2.1 mm for the above-mentioned welding wire at arms length of 10 mm, and at

their lengths of 15, 20, 25 and 30 mm — 3.4, 4.2, 4.4 and 4.8 mm, respectively.

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NEWS

COMPANY NKMZ PUT INTO OPERATION A UNIQUE ROLLING QUENCH MACHINE AT «STALEVA VOLYA» METALLURGICAL PLANT

Specialists of Novo-Kramatorsk Mechine-Building Works (Kramatorsk, Donetsk reg.) put into full-scale operation a unique rolling quench machine (RQM) at «Staleva Volya» Metalurgical Plant, Poland.

RQM is designed for two-sided quenching of rolled sheets passing through the machine rolling sections, as well as sheet cooling after their heating in a pusher roller furnace of trio mill Lauta 2150.

Hydraulic equipment is based on components of prominent European companies. The automatic and control system and software were developed at the design-production center «NKMZ-Avtomatika».

RQM is a totally new kind of high-tech products of NKMZ, new generation equipment, allowing the work to be performed in the automatic mode of technological process control and having no analogs in the world as regards many parameters. The uniqueness of the machine consists in that it allows quenching sheets from 3 to 30 mm thick. Quenching of less than 6 mm sheets in such equipment was not performed earlier.

The customers were able to see that the machine operates in a stable manner, meets all the requirements and is capable of several times increasing the efficiency and improving the quality of the produced steel.

INTERNATIONAL CONFERENCE «NANOSIZE SYSTEMS. STRUCTURE–PROPERTIES–TECHNOLOGIES»

On November 21–23, at the G.V. Kurdyumov Institute for Metal Physics, NASU, International Conference «Nanosize Systems. Structure–Properties–Technologies» was held. More than 300 scientists from 65 academic and branch institutes, enterprises and companies of Ukraine and CIS countries took part in the conference; co-authors of the works were scientists from 25 countries of far abroad. Scientific centers of Ukraine were represented by scientists and specialists from Kiev, Kharkov, Donetsk, Ivano-Frankovsk, Dnepropetrovsk, etc. In work of the conference also took part scientists from Russia, Belarus, Poland, Slovakia, Czechia, Great Britain, Germany, Italy, Belgium, and other industrially developed countries. The conference was held on initiative of the National Academy of Sciences of Ukraine.

Goal of the conference was presentation of the latest achievements in the field of nanosystems, investigation of which is one of priority directions of development of science and technology in XXI century. These presentations reflected results of fundamental and applied investigations of new materials and practical examples of industrial mastering of new technologies. In the course of the conference exchange of information and scientific discussions on different aspects of development of nanotechnologies took place, including promising magnetic, functional and biofunctional materials, new protective coatings, semiconductor systems, etc. On their basis state-of-the-art priorities were formulated, general issues of strategy and organization of specialized research groups were developed, and possibility of coordination of further development of the works was determined. Participants of the conference paid special attention to the following most actual scientific directions:

- size effect and self-organization of nanostructures and nanosystems;
- structure and properties of small-size systems;
- metal and carbon nanomaterials;
- semiconductor nanosystems;
- films, coatings and surface nanosystems;
- biofunctional nanomaterials and nanosystems in biology and medicine;
- supramolecular structures, aerogels and colloid systems;
- diagnostics and modeling of nanostructures and nanosize systems;
- technologies for producing nanomaterials;
- practical application of nanomaterials.

In the course of development of main decisions of the conference it was noted that within recent years in all developed countries national priorities in the field of nanotechnologies were determined and approved connected with them scientific-technical and education programs. This proves wide recognition of significance of the new field of science and high appraisal of its potential capacities for industrial and public life.

In Ukraine also great attention is paid to development of nanotechnologies. Investigations in this field are fulfilled within the framework of a targeted comprehensive program of fundamental investigations «Nanostructure systems, nanomaterials and nanotechnologies» of NASU, program of fundamental investigations of Ministry of Education and Science of Ukraine, and joint Ukrainian-Russian scientific-technical program «Nanophysics and nanoelectronics». Priority directions are study of self-organization processes, diagnostics and modeling of nanosystems, surface phenomena, catalysis, nanoelectrochemistry, joining of structure elements, development of electronic technology materials, semiconductor structures, hybrid nanocomposites, colloid nanosystems, supramolecular structures, biocombined ceramics, etc. Carried out complex of research works, directed at study of self-organization processes, size effects, and structure and properties of nanosystems, resulted in development of a number of new materials with forecasted properties, which are used in national economy of Ukraine.

Work of the conference was opened by first vice-president of the National Academy of Sciences of Ukraine, academician of NASU A.P. Shpak. In his welcome speech he emphasized that according to numerous forecasts XXI century will be determined by nanotechnologies in the same way as discovery of atomic energy and invention of laser and transistor determined XX century. In opinion of leading specialists in next decade exactly development of nanotechnologies will be the basis of future industrial revolution. According to the forecasts, manufactured with application of nanotechnologies products will be widely used in power engineering, airspace systems, ground and space communication and information facilities, security and defense systems, etc. This is confirmed by annual investments, made into development of nanotechnology. The speaker noted that at present in more than 50 countries of the world such investments are made, which serve to scientific-technical progress at current period and are factors of the innovation component development of economies of many countries. At the end of his presentation, academician A.P. Shpak wished participants of the conference interesting, fruitful, and successful work, directed at discussion of the latest results, exchange of knowledge and sharing experience, and formation of new scientific concepts. He expressed his hope that direct communication of scientists of different countries will enable coordination of further investigations, cooperation of scientific works, and general applied use of instrumental infrastructure of Ukraine, which will enable starting interesting projects and programs.

In numerous plenary and post reports represented at the conference, first of all width and variety of technical and technological possibilities, created by new direction of science, were noted. Presented results of investigations were mainly devoted to fundamental aspects of nanotechnology implementation. The results, presented by scientists of different scientific centers showed that at present researchers pass over from observation and discovery of new phenomena to designing and production of certain nanostructure-based functional materials and compounds. Even now are evident certain ranges of application of nanotechnologies: new generation of chemical and biological sensors with monomolecular coatings; nanosize toggles, which allow increasing memory of computers; principally new system of administering medicine; development of ceramic, polymer, metal and other materials with nanostructure, which significantly improves their mechanical characteristics; development of compounds, which absorb many substances that pollute environment. Development of methods for synthesis and assembly of the nanosize structural elements in combination with methods of regulation of their composition and size already allows developing new types of consolidated nanostructures and nanocomposites, which have unique characteristics. It is expected that such methods and materials should cause revolutionary transformations in many industrial technologies.

Despite convincing success, it was noted in the course of the discussion that problems also exist, which constrain development of nanotechnologies and application of its results in practice. In opinion of majority of participants of the conference, main problem is development of new methods of investigation of nanomaterials and state-of-the-art scientific theories in material science, which would allow deeper and more detailed investigating peculiarities and character of behavior of a substance and different compounds on nanometer scale.

Of great interest for participants of the conference was presentation of academician of RAS Yu.D. Tretiakov «Development of Functional Composite Materials on Basis of Solid-Phase Nanoreactors». He formulated phenomenological definition of the ideas «nanoscience» and «physical» and «chemical» modification and on their basis suggested state-of-the-art interpretation of new methodology, which is already used by scientists of M.V. Lomonosov Moscow State University in study of a laminated ordered structure. The speaker also noted advantages of new functional composite materials, which allow their using in information devices with high density of the information recording. He also suggested to develop state-of-the-art systemic approach to nanotechnology, based on organization of interdisciplinary investigations — physics, chemistry, materials science, biology, and electronic and computer engineering.

Academician of the NAS of Ukraine B.A. Movchan informed about peculiarities of electron beam hybrid technology of deposition of non-organic materials in vacuum. He showed new approaches in carrying out regulated assembly (synthesis) of atoms and molecules according to the method of deposition of the components on a substrate for producing new nanomaterials. He noted that in implementation of different technological schemes it is necessary to pay attention to such parameters as substrate temperature and rate of deposition of components, which ensure precise regulation of the composition and size of the elements that ensures production of various types of consolidated nanostructures and nanocomposites that have unique characteristics. These achievements have already caused commercial production of multilayer thin films and foils.

V.M. Buznik — representative of Institute of Physical-Chemical Problems of Ceramic Materials, Russia — drew attention to development of promising fluoropolymer nanomaterials. He noted that at present significant success was achieved in production of nanosize polymer materials. Discovery of new topologic peculiarities of polymers (in particular, dendrimers) caused development of new classes of nanosize components, which have mechanical and optical properties. It became possible to successfully synthesize compounds with complex nanometer architecture within 10–100 nm range. Level of properties of such nanomaterials is determined by size, shape and arrangement of atoms. On basis of results of investigation of the structure and properties a new fluoropolymer material was developed — «chernoflan», which can be used in the form of coatings.

Academician of the NAS of Ukraine V.G. Bariakhtar drew attention in his presentation to problems of development of unique non-retentive and retentive nanostructure materials, which may be used is different fields, including information engineering. Close packing and small sizes of nanostructures stipulate occurrence of variable electrical and magnetic interactions between adjacent (and sometimes distant) structure elements. Physical property of such materials consists in the fact that in presence of the external field spins in alternating nanolayers orient themselves along action of volumetric and surface magnetic forces. This allows creating magnetic precipitates, particles, and structures, produced by controllable self-assembly on organic templates.

Academician of the NAS of Ukraine S.A. Firstov developed in his presentation ideas about «theoretical» strength and plasticity of nanostructures, based on new method of the investigation — nanodimpling. He noted that change of characteristics of substances and materials, formed by structural elements of nanometer size, are stipulated not just by reduction of their sizes, but also by manifestation of quant-mechanical effects, wave nature of the transfer processes, and dominant role of the interfaces — grain boundaries. Due to intensive boundary processes such materials may have not just high strength, but also significant ductility, which noticeably distinguishes nanostructure materials from state-of-the-art structural materials.

A number of presentations were devoted to strong carbon nanomaterials, which may serve as heat insulation and wear resistant coatings. Basis of such materials are carbon nanotubes or nanoparticles of different diameter and nanoporous carbon. Special technology of such materials makes it possible for them not to have free chemical bonds, that's why despite small size they do not demonstrate «surface effects» and have unique electrical and mechanical properties. Diversity of nanostructures in carbon nanomaterials makes them rather promising for manufacturing of the electron scheme elements. In some presentations ways of evolution and synthesis of an ordered structure in the process of different technologies were shown: intensive plastic strain, polymerization, etc.

In presentation of Z.R. Ulberg «Interaction of Metal Nanoparticles with Cells of Bacteria in Biotechnology of Designing of Highly Efficient Probiotics» possibility of efficiency increase of medicinal preparations by means of introduction of low concentrations of gold and silver compounds was visually illustrated. In addition to optimization of prescription of medicinal preparations, presented in the report nanotechnology allows developing on the basis of selective interaction new methods of delivery of medicines to sick organs, thus significantly intensifying degree of their curing action. Promising is also development of physical-technical technologies in nanopharmacology concerning introduction and delivery of medicine to certain places in the organism. Entering into interaction with live cells (histones and proteosoms) useful for health medicinal nanoparticles (probiotics) participate in processes of rehabilitation of the organism together with biologic components of cell structures (chloroplasts, ribosomes, and mitochondrions).

Poster presentations were devoted not just to the latest results of the investigations, but became a basis for production of some nanostructural materials and products on their basis. They included: production of multilayer films and foils with thickness of the layers regulated at atomic level of accuracy, which allows their using in devices for magnetic recording on basis of magneto-resistance effect; development of the processes for manufacturing nanoceramics and nanocomposites with fine-grained structure, which have unique

functional characteristics; development of technologies for processing and production of surfaces with nanostructure for making high-quality cutting tools with enhanced wear resistance and impact toughness; development of methods for application of nanostructural protective coatings with increased resistance to electric, chemical, thermal, mechanical and external (natural) actions; development of templates and matrices for directed growth and copying of nanostructures, which may be used in biomedicine and electronics; development of methods for diagnostics of nanostructures for their real time assessment and precise standards of reliability of items from them. A certain portion of presentations showed technological processes of developing new materials by sintering of oxide ceramics in different branches of industry. Reports, presented at the conference, suggested to the industry principally new methods for formation of materials and items from them.

By beginning of the conference a big collection of presentations was published, which was distributed among the participants. Drawing conclusions of the conference, its participants noted significance of this direction of science for human life activity. Achievements in the field of nanotechnology not just made nanostructural materials more accessible for investigation and description, but resulted in a number of cases in industrial tests and applications, enabling active development of the market of nanomaterials. Interest to nanotechnologies continues to grow, because they promise in future tremendous practical benefits, and not least important is the fact that nanoscience is able to change style of scientific thinking and give powerful impetus to development of the fundamental science and find new approaches to solution of actual problem of today.

T.M. Labur, Dr. of Sci (Eng.), PWI

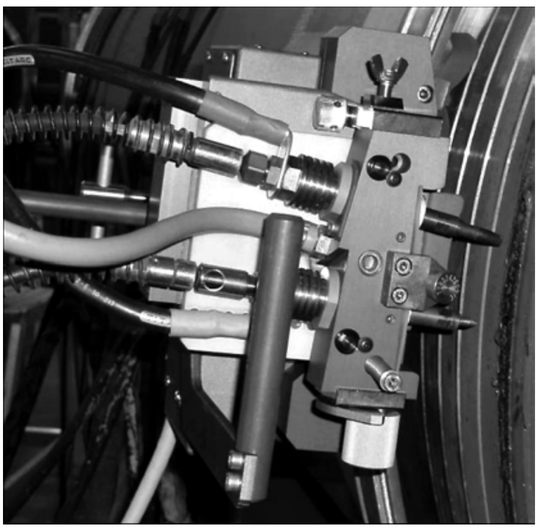
INTERNATIONAL CONFERENCE «WELDING AND ALLIED TECHNOLOGIES IN CONSTRUCTION, RECONSTRUCTION AND MAINTENANCE OF PIPELINES»

International Conference «Welding and Allied Technologies in Construction, Reconstruction and Maintenance of Pipelines» was held in Podmoskovie on November 22--23, 2007. The Conference was organized by «Territoriya NEFTEGAZ» journal, CJSC «DB Yunifos» was the general sponsor, Professor O.I. Steklov, President of Russian Scientific-Technical Welding Society, directed its work. Representatives of scientific-research centers, industrial enterprises, realizing manufacturing and delivery of welding consumables, insulation materials, equipment for construction, reconstruction and maintenance of pipelines, as well as organizations responsible for the main pipeline operation, participated in the Conference work. The list of presentations attracting the interest of welding specialists, is given below:

• *State-of-the-art and trends of welding production in Russia*. O.I. Steklov, Dr. of Sci. (Eng.), Professor, RSTWS President.

• *Welding production organization in OJSC «Gazprom». Normative documents on welding and quality control of welded joints in construction operation and maintenance of industrial and main pipelines*. E.M. Vyshemirsky, Head of Chief Welder Section, Department of gas transportation, underground storage and use of OJSC «Gazprom».

• *Program on quality assurance in welding production of OJSC «Gazprom». Research at VNIIGAZ Ltd. in the sphere of welding and non-destructive testing of welded joints of industrial and main gas pipelines*. V.I. Bespalov, Head of Welding and Control Laboratory, VNIIGAZ Ltd., T.V. Artemenko, Senior Staff Scientist of Welding and Control Laboratory, VNIIGAZ Ltd.



Saturnax system for welding with two-arc heads

• *Special features of welding high-pressure pipelines*. S.V. Golovin, Director of Welding and Testing Center, VNIIST Ltd.

• *Requirements of OJSC «Gazprom» normative documents for the technologies, materials and equipment for welding high-pressure gas pipelines from steels of higher-strength class*. D.G. Budrevich, Leading Staff Scientist of Welding and Control Laboratory, VNIIGAZ Ltd.

• *Welding by T.D. Williamson's technologies in operating gas and oil pipelines*. P. Jakoubek, A.A. Zherdev, O.T. Kondratieva, S.A. Williamson.

• *Experience of work performance using the technologies and equipment for cutting under pressure in OJSC «Gazprom» operating gas pipelines*. E.M. Vyshemirsky, Head of Chief Welder Section, Department of gas transportation, underground storage and use of OJSC «Gazprom».

• *Welding repair methods of through and not-through pipes defects and welded joints temporarily out of operation or those in operation*. V.I. Bespalov, Head of Welding and Control Laboratory, VNIIGAZ Ltd.

• *Operation experience of mobile pipe-cutting and edge-chipping machines SUPERCUTTER in construction of pipeline transportation*. A.D. Shchedro, General Director of CJSC «DB Yunifos».

• *Underwater-technical works in repair of underwater sections of gas pipelines. Repair by welding of pipe defects and welded joints of underwater sections of gas pipelines in a specialized caisson*. V.V. Paskhin, General Director of «Podvodservis» Ltd., S.A. Kurlanov, Leading Staff Scientist of Welding and Control Laboratory of VNIIGAZ Ltd.

• *Repair of defective sections of the main gas and oil pipelines by welded steel couplings in underwater passes through water barriers using a universal chamber (caisson)*. N.V. Luzanov, Head of CJSC «Podvodnik» OEF.

• *Automatic welding of pipes from high-strength steels and qualified tests of SERIMAX equipment on X80 pipes in cooperation with VNIIGAZ Ltd*. A. Walczak, L. Laurent, «Serimax».

• *New generation of «Iskra» welding equipment for gas and oil pipeline welding*. I.A. Zamyatin, General Director of Welding Equipment Plant «Iskra» Ltd.

• *ESAB in oil and gas construction: present and future*. D.N. Biryulin, Deputy Head of TEK Department, ESAB Ltd.

• *Synergetic agglomerated fluxes for pipe welding*. V.V. Golovko, V.I. Galinich, E.O. Paton Electric Welding Institute of NASU, N.Ya. Osipov, V.I. Netyaga, OJSC «ZaporozhsteklofIyus».

• *Features of manufacturing and applying seamless flux-cored wires*. I.G. Samorodov, Deputy General Director on Technical Development of «Drattsug Stain SPb» Ltd.

• *New generation of welding equipment of SPC «Tekhnotron» for position mechanized and automatic welding of gas and oil pipe lines*. B.L. Getskin, Technical Director, SPC «Tekhnotron».

• *Project PROTEUS — equipment and technology of position automatic welding of gas and oil pipelines*. D.N. Rabotinsky, Technical Director, CJSC SPC «ITS».

• *New generation of CJSC «Uraltermosvar» equipment for air-plasma cutting and welding of gas and oil pipelines*. Yu.B. Ezdakov, General Director, CJSC «Uraltermosvar».

Conference participants noted in their presentations that in Russia and in other CIS countries the market economy was favorable for appearance of dynamic non-governmental enterprises and companies manufacturing welding products and technologies. Conversion processes have a certain influence on this situation — the use of defense complex achievements for civil purposes. Attention was drawn to the increased importance of standardization and certification, harmonized with the international system.

The participants listened with great interest to presentations setting forth the main positions of the Program on quality assurance in welding production of OJSC «Gazprom», developed taking into account the requirements to the main elements of quality management system in ISO, EN, Russian standards of GOST R series, management directives of Rostekhnadzor and procedural documents of the National Association of Control and Welding, as well as the normative documents developed by OJSC «AK Transneft» for pipes and connectors of the main oil pipelines.

Automatic welding of position butts — Orbital Railtrac system

Companies such as Serimax (together with VNIIGAZ Ltd.), SPP «Tekhnotron», CJSC SPC «ITS», ESAB, Rotoweld, CJSC «PII SIT Neftegazstrojizolyatsiya» presented the information on their developments on technology of automatic welding of position butts of the main pipelines from low-alloyed steels of X70 and X80 strength classes.

Besides, a number of the presented reports were dedicated to the problems of repair of land and underwater sections of pipelines, incision of by-pass sections into working main pipe lines. Conference participants devoted great attention to the matters connected with pipe corrosion prevention, NDT of welded joint quality, improving of labour safety and protection when performing welding works in the field conditions in Siberia and Far East.

Representatives from Russia, Ukraine, USA, Great Britain, Germany, Kazakhstan and Estonia took part in discussions on the reports.

Based on the results of the work, a decision was taken, in which importance and high efficiency of the Conference was noted, and a wish was expressed to make it a regular event with the aim of further intensification of the processes of information exchange on changes in the normative and technical documentation in this branch; problems encountered in construction, reconstruction and repair of the main pipelines, as well as innovation technologies and new models of equipment designed to solve these problems.

V.V. Golovko, Dr. of Sci (Eng.), PWI

WORKSHOP-FORUM OF PII «BINZEL UKRAINE GmbH» IN KIEV

On 22 of November 2007, in Kiev at the enterprise of ABICOR group — PII «Binzel Ukraine GmbH» — annual workshop was held on topic «Strategic Aspects of Sale of the ABICOR BINZEL products in 2006–2007 in Ukraine». The workshop was dated to 10th anniversary of the Kiev enterprise activity in Ukrainian market. The workshop was organized by director Yu.A. Didus and managers of the enterprise. About 50 specialists, representing daughter companies of PII «Binzel Ukraine GmbH» and exclusive partners from 19 towns of different regions of Ukraine and Kiev, took part in work of the workshop.

Program of the workshop included both analysis of sales of the products in 2006–2007 by main groups of the commodities and characteristic peculiarities and differences of sales by regions; prospects of the enterprise PII «Binzel Ukraine GmbH» development in 2008; demonstration in operation of the installations for plasma and air-plasma cutting and MIG welding with application of the ABICOR BINZEL welding torches and cutters.

At the beginning of the workshop's work Yu.A. Didus made historical digression into origination, formation, and development of the German company. Really, its achievements and successes within a little more than 60 years of work in the field of welding and cutting are rather impressive. Entrance of ABICOR BINZEL into the number of the most known in welding production world brands is demonstrated by the following milestones:

1945 — *establishment of the enterprise in Hissen, Germany*;

1963 — *development and production of welding torches for gas-shielded welding (MIG/MAG)*;

1969 — *beginning of production of TIG welding torches*;

1973 — *development and introduction of adopted later as a Eurostandard system of central connectors and pins*;

1973 / 1974 — *first generation of torches with liquid cooling (MB series)*;

1974 — *introduction into the market of torches with a system for removal from the weld formation zone of harmful aerosols (RAS series)*;

1975 — *the BIKOX hose package together with a torch of MB series conquer the world*;

1976 — *development of the first series of BINZEL torches Puch-Pull (on a long 8–12 m hose with feeding mechanism in the handle)*;

1978–1979 — *beginning of development of the systems for robotized welding in parallel with application of first robots in automotive industry*;

1984 — *addition of plasma cutters to the production program*;

1997 — *welding torch with feeding of two welding wires*;

1998 / 1999 — *development of the MFS wire feeding system, which allows introducing welding of aluminium in industrial production*;

2001 — *new generation of welding torches and plasmotrons — ABIMIG/ABITIG/ABIPLAS CUT*;

2004 — *new line of the ABIROB robotized torches*;

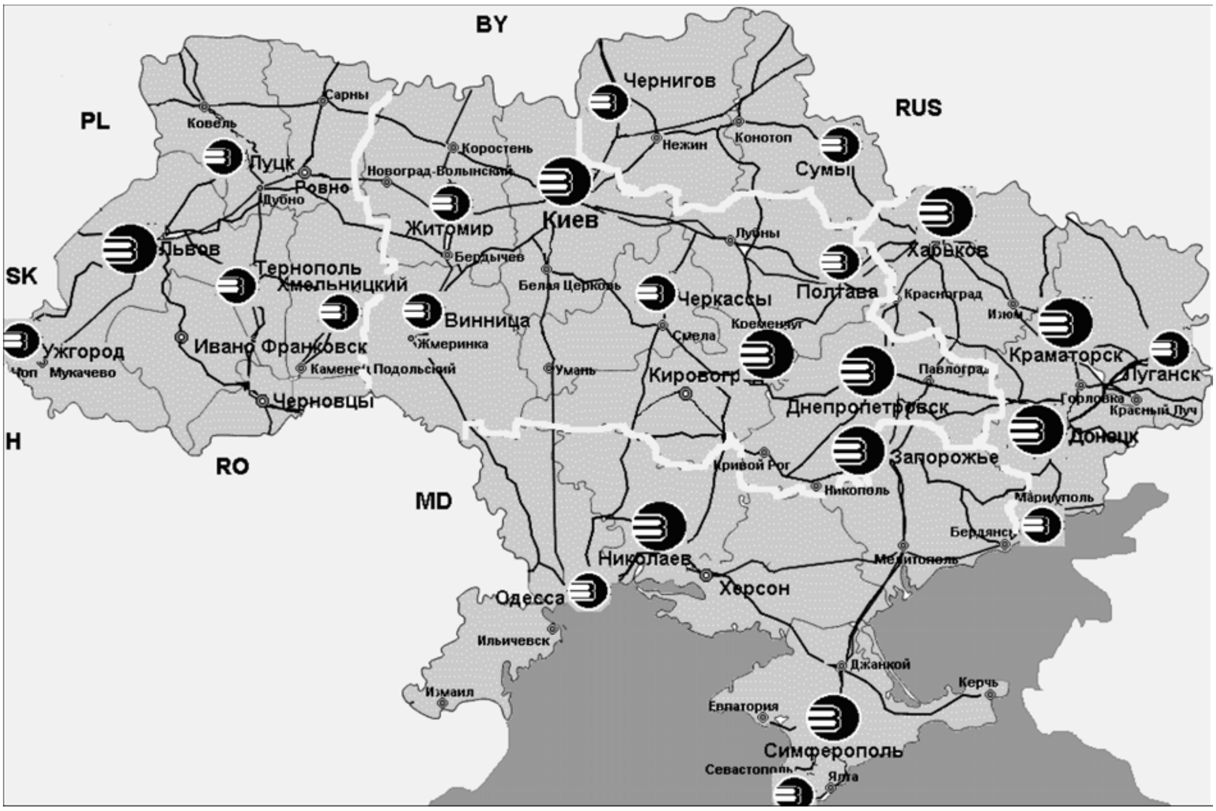
2005 — *the MB GRIP welding torches — confirmation of status of the «legislator of the fashion»*;

2006 / 2007 — *volume of production achieves about 650 thou torches per year*.

At present a little more than 1000 specialists are employed at enterprises of the ABICOR BINZEL group (approximately half of them in Germany). ABICOR has 30 daughter enterprises and 20 exclusive partners. There is a plan to open in near future an

Director of PII BINZEL UKRAINE Yu.A. Didus takes the floor

During work of workshop



Map-scheme of location of distributors and consumers of ABICOR products in Ukraine

enterprise in Kazakhstan. The products are produced in Germany, China, India, Brasilia, Switzerland and USA. Structure of sales covers Northern and Southern America, Europe, Asia, Africa and Australia. Due to developed network of daughter enterprises and partners share of sales of the products through them constitutes 93 %, and through direct supplies — 7 %.

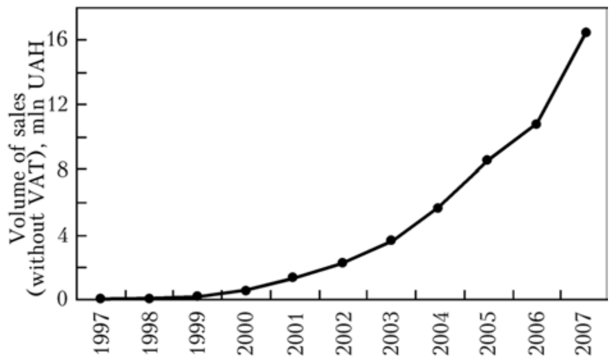
Within ten-year period significantly increased volumes of sales of the ABICOR BINZEL products in Ukraine, whereby growth of sales within the last year constituted more than 50 %. Distribution by groups of commodities in 2007 was as follows, %: MIG / MAG group — 51, TIG — 14, plasma — 8, appliances — 27.

Structure of sales of the products in Ukraine is at present as follows: more than 200 final users, 120 regional distributors, 20 producers of welding equipment.

It should be noted that successful activity of BINZEL UKRAINE GmbH became possible due to the fact that development of the enterprise proceeded with German accuracy using accumulated by the head enterprise experience and taking into account mentality of Ukrainian consumers. Great attention is paid to correct proposal of the product to the final user, because for subsequent progress and expansion of volumes of the commodity output it is important to give a buyer necessary information, which will explain him how to choose correctly necessary item and skillfully operate it. The same goal pursue held by BINZEL UKRAINE GmbH workshops. After each workshop the enterprise feels through the feedback (growth of the volume of sales) important role of the information educational program and is convinced in growth of the production culture at welding bays of visited plants-consumers.

Gratifying is also the fact of stabilization in 2006–2007 of volumes of consumption of the products by the hobby sector (welding current up to 170 A) — 40–45 %, and growth of consumption up to 55 % in industrial sector. These changes work for stabilization of the partner interrelations.

In 206–2007 significant growth of sales of the ABICOR BINZEL products is observed in all groups of commodities, %: group of MIG / MAG welding by 53, TIG welding by 20 including tungsten electrodes by 61, plasma by 77, and appliances by 66. Consumption in Ukraine of electrode holders for MMA welding (with stick electrodes), produced by enterprises of the ABICOR KURT HAUFE group, Dresden, increased by more than 25 thou pcs. Production of BINZEL spray (for spraying nozzles and tips of the torches),



Dynamics of sales of the ABICOR BINZEL products in Ukraine

Demonstration of the ABICOR BINZEL welding equipment

liquid Protec (for preventing sticking of spatters to the parts being welded), and reduction gears increases.

The only consumer of torches for robotics in Ukraine was earlier enterprise NAVKO-TEKH, which supplies equipment to Ukraine and Russia. Lately, volumes of consumption of welding robots in Western Ukraine increased, which is, probably, connected with implementation of innovation projects in this region. There are prospects of using the «AbirobTwin» system (feeding of two wires) and «Arc-Roto» (intelligent system for automatic change of welding heads).

At the end of the workshop MIG welding and air-plasma cutting were demonstrated with application of plasma and welding equipment of the companies. Technical expert of BINZEL UKRAINE GmbH A.V. Kolumbet demonstrated in operation tool sets for welding equipment of ABICOR BINZEL brand and answered numerous questions, connected with peculiarities of their operation.

Participants of the workshop expressed their gratitude to the organizers for wonderful conditions and efficient program of the event.

V.N. Lipodaev, Dr. of Sci (Eng.), PWI

TO 100th ANNIVERSARY OF V.I. DYATLOV

Vladimir I. Dyatlov was born on 28th of November 1907 in Kiev into the family of an engineer. His adolescence and youth years coincided with the time of wars and revolutions, but his parents managed to give him good education. In 1930 V.I. Dyatlov graduated from Kiev Polytechnic Institute and was sent as a metallurgist to work at Altaisky metallurgical plant. At Zlatoust plants he mastered peculiarities of production of special steels and studied works of P.P. Anosov, who recreated damask steel, and methods of investigation of D.K. Chernov — founder of metallography. In 1932 V.I. Dyatlov returned to Kiev and started to work in Ukrainian research institute of chemical machine building and participate in activity of organized by Evgeny O. Paton Welding Committee.

In 1935 E.O. Paton invited V.I. Dyatlov to work in Institute of electric welding and entrusted him with development of new technologies and welding materials. His first success was development of electrodes with high-quality coating for manual arc welding of stainless steels.

Late in 1930s one of main directions of the institute's work became automation of arc welding. Automatic machines for welding with a stick electrode and wire with wound on it paper cord, which was coated by chalk solution, wire of cross-like section with coating in the slots, etc., national method of automatic submerged-arc welding with bare electrode, in which were also engaged leading companies and institutes abroad, were suggested and introduced. By end of 1939 first flux, silicon-manganous wire and welding head for feeding a consumable electrode were developed. In 1940 V.I. Dyatlov became first chief of technological department of the institute (up to 1943). The same year resolution was made on introduction of new technology of Institute of electric welding and by mid-1941 automatic submerged-arc welding started to be employed at as much as 20 biggest plants of the country in manufacture of boilers, railway cars and a number of other special-purpose items.

V.I. Dyatlov combined work in the institute with teaching activity from the date of foundation of welding department (1935) in Kiev Polytechnic Institute. He taught a number of disciplines, which may be related to metallurgical fundamentals of welding and development of arc process technologies and consumables.

When German-fascist troops approached Kiev, V.I. Dyatlov headed evacuation of property and employees of the institute with their families. Welded in IEW experimental railway freight car, which did not have any «permit» documents, nevertheless reached safely Nizhny Tagil. Into this very town to premises of «Uralvagonzavod», where E.O. Paton decided to place the institute, soon was also evacuated the Komintern Kharkov tank plant, where the T-34 tanks were produced. At this plant under management of Evgeny O. Paton automatic welding started to be introduced. V.I. Dyatlov and employee of the Kharkov plant B.A. Ivanov solved problem of submerged-arc welding of armor steels. Discovery in 1942 by V.I. Dyatlov of the phenomenon of self-regulation of arc processes with consumable electrode made it possible to simplify design of the feeding mechanisms and develop single-motor welding heads. In October 1943, V.I. Dyatlov headed laboratory of welding of «Uralmashzavod» in Sverdlovsk, where he designed welding heads taking into account influence of self-regulation and improved technology of production of heavy tanks KV, IS and self-propelled guns. Together with ship-builders, which were evacuated during war to Urals, he moved in 1944 to Leningrad.

Department of Welding headed by V.I. Dyatlov at Central R&D Institute of Shipbuilding Technology became one of the leading organizations in the country for mastering advanced materials for engineering structures operating under extreme conditions. Technologies of manufacturing the reactor of the world's first atomic ice-breaker "Lenin" and reactors for nuclear submarines were developed here, and systematic studies of high-strength steels were conducted. In particular, welding of armour steel up to 300 mm thick (ramps, conning towers) was introduced into manufacturing of missile cruisers, nuclear submarines, etc. V.I. Dyatlov starts developing technologies of welding aluminium and titanium alloys, which attracted the interest of ship-builders.

In 1954, V.I. Dyatlov returned to Kiev and till end of his life worked in KPI — read lectures, carried out investigations, supervised post-graduate students. He taught metallurgical fundamentals of welding, heat fundamentals of welding, and technology of fusion welding. He was unsurpassed lecturer; not just students-welders came to hear his lectures, but also future metallurgists and specialists in pressure processing. Graduates kept abstracts of his lectures for many years and addressed to them when it was necessary to solve scientific and production tasks. As long as in 1935–1939, when working under first method of automatic submerged-arc welding, V.I. Dyatlov started to consider welding processes as metallurgical ones, which sometimes proceed within shares of a second. That's why V.I. Dyatlov suggested transferring welding chairs to metallurgical departments, or at least, strengthening teaching of physical-chemical subjects. He wrote big book on metallurgical fundamentals of welding, but did not manage to publish it. It was copied on the tracing paper and distributed in this way.

At KPI chair of welding V.I. Dyatlov continued to fulfill orders of ship-builders — development of optimal technology for welding of aluminium alloys. Similar task faced missile-builders. V.I. Dyatlov, having investigated several methods of welding, jointly with post-graduate student Yu.A. Deminsky, confirmed prospects of inert-gas arc welding and magnetic control of welding processes. Under guidance of V.I. Dyatlov, post-graduate student N.I. Kopersak investigated peculiarities of welding of high-temperature chrome-nickel alloys. Results of the investigations were a significant contribution into scientific fundamentals of welding metallurgy. Later in 1961–1963, post-graduate student from People's Republic of China Zhen Dzya Le developed under guidance of V.I. Dyatlov technology of nitrogen-shielded welding high-temperature steels, which was introduced into missile-building industry of the republic.

V.I. Dyatlov was notable for his culture and charming, quite, benevolent, and equable attitude to the colleagues and students. Specialists from all over the country addressed to him for consultations; his works in physics of arc, theory of transfer, thermodynamic processes, fusion and solidification of a pool, melting of an electrode, designing of welding automatic machines and other are known all over the world. He managed to solve the most complex tasks, which occurred on the way of welding production development. Found by him solutions had not analogues in the world. So, phenomenon of self-regulation of the electrode melting was used for the first time in USA 10 years after its discovery by V.I. Dyatlov.

For his contribution into ship and missile-building industries and training of specialists he was awarded with two orders «Sign of Honor».

Vladimir I. Dyatlov died on 29th of March 1969.

WELDING OF STRUCTURES MADE FROM REFRACTORY AND REACTIVE METALS

Technological processes and specialized equipment have been developed for manufacture of large-sized spatially-branched structures, including tubular and shell welded objects made from refractory and reactive metals. Conditions of fabrication of welded structures with a preset level of physical-chemical characteristics, service properties and corrosion resistance are developed. Technological processes of producing welded joints make it possible to preserve the orientation directivity of single-crystalline and structurally-oriented initial billets.

Application. Welded structures from refractory and reactive metals are used in aerospace systems, nuclear power engineering, aircraft industry and rocketry, chemical industry, and also in machine parts operating in the range of temperatures from −196 up to 2000 °C and aggressive corrosion media.

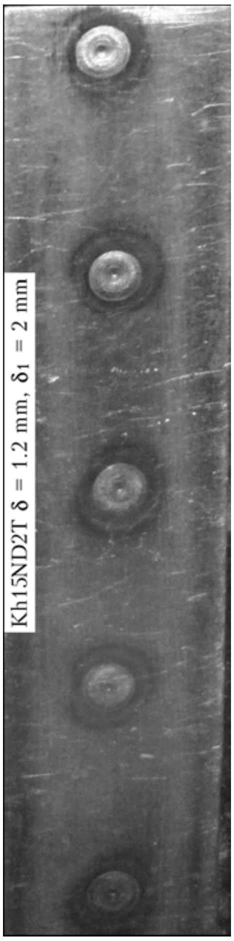
Main developers and performers: Prof. Yushchenko K.A., Dr. Zadery V.A., Dr. Polishchuk E.P.

Stamped-welded body of rocket engine made from molybdenum

Stamped-welded plate of rudder made from molybdenum

Contacts: Prof. Yushchenko K.A.
Tel./fax: (38044) 289 2202

ARGON-ARC NON-CONSUMABLE ELECTRODE SPOT WELDING



The conditions of producing joints are provided by passing of a modulated welding current of 15–500 A at 10–15 V voltage of arc, burning in a microchamber, and a low force of compression of lining, welded to the frame, by a gun nozzle.

The effect of a jump-like increase in main parameters of arc, burning under the constrained conditions, is used. There is no need in arc burning observation. Even at 1.5 mm thickness of stainless manganese steel lining, welded to steel frames of 2.5 mm, the spot joints can be produced.

To make spot joints, a gun, connected to welding current source via modulator, is used. The application of this gun does not require a special training of a welder. After pressing the gun button, the process of welding is going on completely automatically. High-frequency radio noises are absent. Controllers for resistance welding machines are used for the process control.

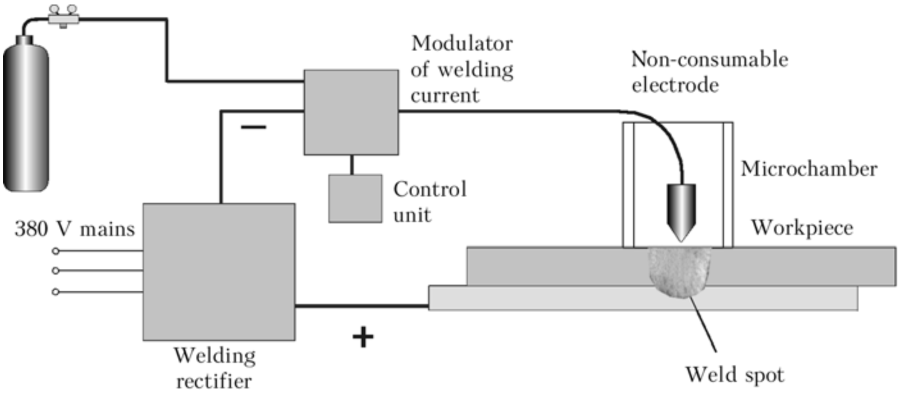
Technology provides the high reproducibility of spots of equal strength and a good appearance.

The gun, having 1.2 kg mass, is simple in operation, provides producing spot welds on several sheets and on the upper welded sheet of 0.2–1.5 mm thickness, moreover, without limitation in a pitch of welding.

The advantages of gun application: welding is feasible not only in a flat position; time of cycle is reduced by decrease in time of welding; length of cable to the gun is not limited; consumption of argon and wear of electrode are reduced to minimum; making holes is not required; single-side access to the workpiece is provided.

Purpose. Spot welding of steels, stainless steels, alloys of nickel and titanium; precision welding of metal structures, large-sized sheet metal structures and linings with frames of three-dimensional products.

Proposals for co-operation. Implementation of technology and equipment for its realization.

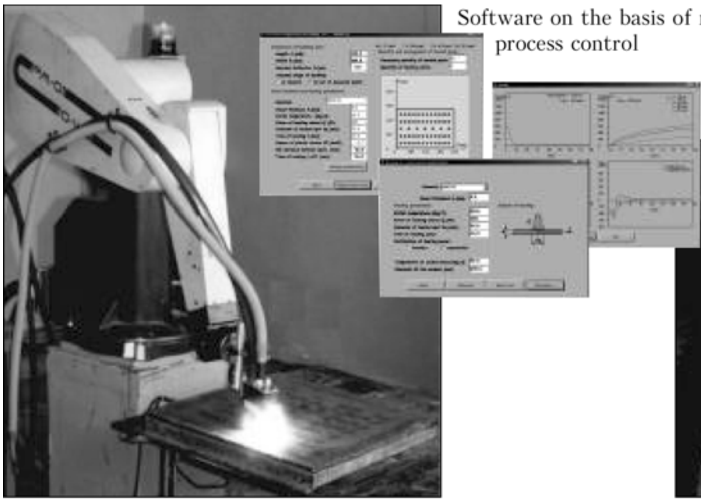


AUTOMATED THERMAL STRAIGHTENING OF WELDED THIN-SHEET STRUCTURES

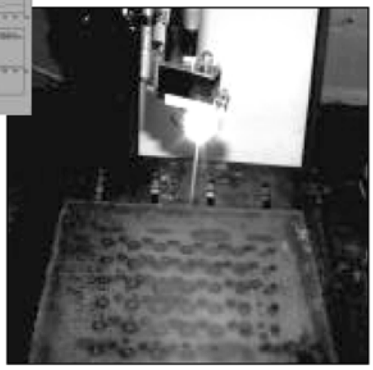
Volumes of thermal straightening by the consumption of a highly-skilled manpower are 15–50 % of the total volume of expenses for assembly and welding of body structures. To solve this problem, the automated thermal straightening of welded thin-walled structures with buckling distortions has been developed at the E.O. Paton Electric Welding Institute. The automated complex has been created on the basis of a mathematical simulation, which includes a manipulation robot, systems of measurement of distortions and a microplasma source of heating.

The automated thermal straightening makes it possible to eliminate the skilled hand operations, provides high quality of surface of the welded structure sheet, increases the efficiency of the process, reduces the power consumption, improves the ecological characteristics.

Software on the basis of mathematical simulation for process control



Developed automated complex for thermal straightening of thin-sheet welded structures



Microplasma source of heating with an indirect action torch

Purpose. Automation of thermal straightening of buckling distortions of thin-sheet welded structures.

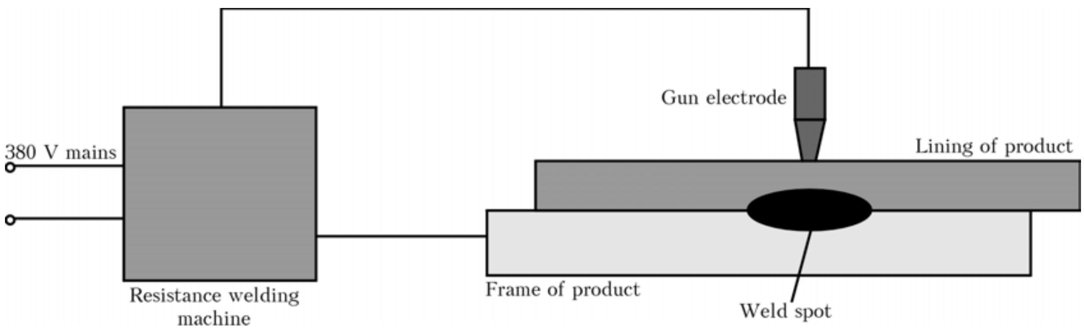
Application. Ship- and railway car building and other branches of industry, manufacturing different hull welded structures.

GUN FOR RESISTANCE SPOT WELDING

It represents a manual tool intended for making spot joints by a welder without a special training.

Conditions of the joint producing are guaranteed by welding current passing at a low electric voltage and low force of compression of lining, welded to the frame, by the gun electrode.

Welded joint is formed even at the presence of a layer of a current-conducting priming between the elements being welded.



At 1 mm thickness of lining the time of welding current passing does not exceed 0.35 s, and the frequency of fulfillment of spot joints is limited by the time of the gun reposition. The fully automatic process of welding is starting just after applying the working compression force up to 150 N. The technology provides the high reproducibility of spots in strength and appearance.

The gun of 1.2–5.0 kg mass is simple in operation, does not limit the pitch of welding and can be also used for welding in different spatial positions.

The application of the gun guarantees such advantages as the short time of the cycle due to reduction in time of welding; full absence of welding consumables; feasibility of performance of microwelding; welding of several sheets; welding of upper part, being welded, of 0.05–2 mm thickness and from 0.3 mm width; absence of distortion of parts being welded; a good appearance of the spot weld.

Purpose. Welding of multiplayer joints; precision welding of steels and alloys, zinc-plated sheets; welding of large-sized metal structures; spot welding of linings with frames of buses.

Proposals for co-operation. Implementation of technology and manufacture of equipment for its realization.

GUN FOR ELECTRIC ARC SPOT WELDING WITH WIRE IN ÑÎ$_2$

This manual tool is designed for producing spot joints by workers without any special training.

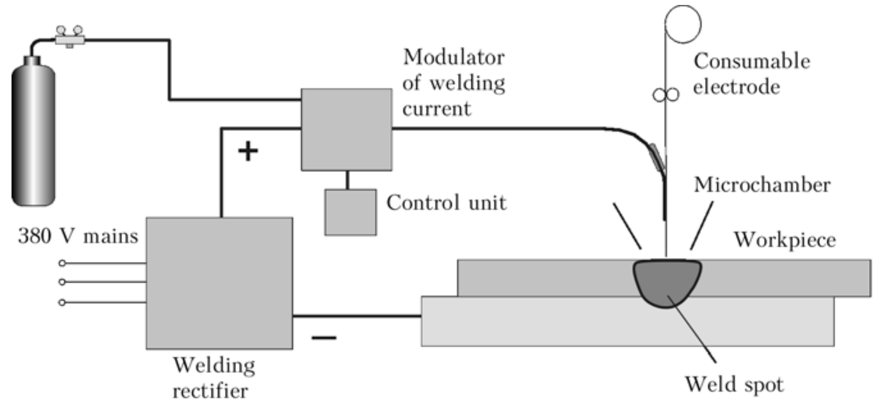
Conditions for producing joint are guaranteed by 200–500 A passing welding current at 18–30 V voltage of arc, burning in microchamber, and low force of compression of lining, welded to the frame, by the gun nozzle.

There is no need in arc burning observation.

At 0.4 mm thickness of lining the wire of 1.2 mm diameter is used. After pressing the gun button the process of welding is fully automated, providing the high reproducibility of spots equal in strength, at an excellent appearance of the spot weld.

Using the gun developed it is possible to perform welding not only in a flat position, with a short welding cycle and negligible consumption of welding consumables, without holes in products and limitation in a pitch of spots. It is possible also to weld several sheets at up to 5 mm thickness of sheet being welded.

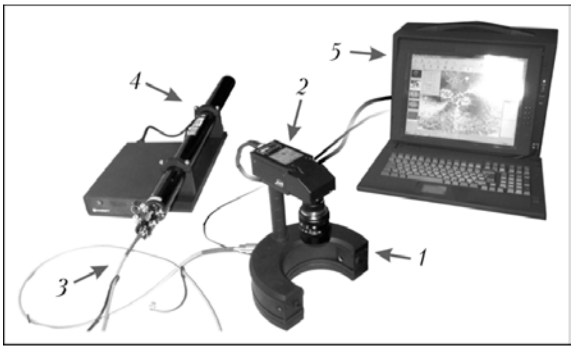
Application. Welding of multiplayer joints, precision welding of steels and alloys, metal structures, welding of large-sized metal structures, spot welding of linings with frames of three-dimensional products, including the main assemblies of roofed railway cars manufactured from hot-rolled steels, without car tilting.



Proposals for co-operation. Implementation of technology and manufacture of equipment for its realization.

MEASURING SYSTEM FOR DETERMINATION OF RESIDUAL STRESSES IN ELEMENTS OF STRUCTURES USING THE ESPI METHOD

At the E.O. Paton Electric Welding Institute a compact measuring system and technology for determination of residual stresses occurring in welded, brazed, cast and other metallic structures, have been developed. The developed system and technology can be also used for determination of stresses, caused in structures by applying the loads.



Residual stresses are determined on the basis of data on the value of in-plane displacements, measured by the method of electron speckle-interferometry in the vicinity of a blind hole. The in-plane displacements are the result of an elastic unloading of residual stresses after drilling of a blind hole. The accuracy of determination of residual stresses is 10 % of value of yield strength of the material examined.

The measuring system consists of speckle-interferometer *1*, CCD-camera *2*, light guide *3*, laser *4*, computer with a board of pattern interference fringes figuring *5*.

Main technical characteristics of measuring system

Length of radiation wave of He–Ne laser, nm	632.8
Laser power, mW	17
Size of spot illuminated by laser light, mm	10
Resolution of CCD-camera, pixel	768 × 572
Diameter of drilled hole, mm	1.0–2.0
Depth of drilled hole, mm	1.0–2.0
Dimensions, mm	205 × 205 × 250

Proposals for co-operation. Measurement of residual stresses in elements of metallic structures, parts and sub-assemblies of machines. Manufacture of the measuring system and its delivery to the Customer, training of personnel.

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