International Scientific-Technical and Production Journal

The Paton WELDING JOURNAL

December
2005
12

English translation of the monthly «Avtomaticheskaya Svarka» (Automatic Welding) journal published in Russian since 1948

Founders: *E.O. Paton Electric Welding Institute of the NAS of Ukraine*
International Association «Welding»

Publisher: *International Association «Welding»*

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State Registration Certificate
KV 4790 of 09.01.2001

Subscriptions:
$324, 12 issues per year,
postage and packaging included.
Back issues available.

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CONTENTS

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WELDING PRODUCTION OF «URALMAShZAVOD». STAGES OF FORMATION AND DEVELOPMENT

In December 2005, machine builders of Uralmashzavod, Ekaterinburg, Russia, marked a portentous event — 75th anniversary of welding production of the plant. Building of welding production started simultaneously with construction of the plant. The workshop of metal structures started to produce welded structures in 1930. Chief of the plant construction A.P. Bannikov ardently supported introduction of the technological process of welding instead of the process of riveting in manufacturing of metal structures: «Other plants bring metal structures from abroad or from south factories. We may not admit such luxury — to pay for iron and rivets with gold. We'll manufacture the structures ourselves!»

The department, which was established for designing and production of metal structures, was headed by a young engineer G.P. Mikhajlov, who shared experience of manufacturing welded structures of crane girders for cranes of 50 t load capacity and 10 m span length in March 1931 at he Third All-Union Autogenous Congress in Moscow. Welded metal structures became the first items produced at Uralmashzavod.

G.P. Mikhajlov exerted determining influence on attitude to welding during construction of Uralmashzavod. On his initiative courses for training welders and specialization of technical-engineer personnel in the field of welding were established. The most prominent national specialists in the field of welding V.P. Vologdin, K.K. Khrenov and other trained a group of specialists, which consisted of 39 persons, the first graduation of which took place in 1930. Training of specialists in the field of welding brought positive results very quickly. By mid-thirtieth of the previous century Uralmashzavod became generally recognized leader in manufacturing welded structures of big size in the former USSR.

During the war welding processes started to be extremely widely used. Uralmashzavod started practically completely produce military materiel, which required mastering new technologies and equipment within the shortest time. And again, the part played by G.P. Mikhajlov has to be marked, but this time as an outstanding electric engineer-scientist. He created a new scientific branch — high-productivity three-phase welding process. The works of this kind were not carried out abroad at that time. Three-phase arc welding was efficiently used for manufacturing welded bodies of medium and heavy tanks and self-propelled guns during the war.

Post-war period (1945–1958) is characterized by wide use of new welding processes, especially automatic and semi-automatic submerged arc welding, for production of ladles of hot-metal cars of 100 t capacity, cement kilns of 75 m length, hoisting cranes up to 175 t load capacity, the first national walking excavators ESh 14 / 65, a series of bloomings, big derricks, big number of rolling equipment for national industry and countries of people's democracy, and many other items. During these years new promising technological processes were introduced: semi-automatic oxy-gas cutting of rolled sheet, surface gas-flame hardening of spherical bearings of walking excavators, and gas-flame surfacing of babbits on parts of crushing-grinding equipment.

In 1958–1963 in Uralmashzavod a large-scale reconstruction of welding production was carried out. As a result a new separate block, consisting of 13 spans of total area 100 ths m^2 and production capacity above 100 ths t of welded structures, was constructed for manufacturing welded structures for drilling equipment, mine and walking excavators, crushing-grinding equipment, sintering machines, machines for continuous casting of ingots (MCCI), heavy presses, etc. Under roof of the block procuring and assembly-welding, acquisition, and thermal painting workshops were located. For reducing a cycle of metal structure manufacturing, a bay for machining welded assemblies up to 70 t was constructed.

Availability of high span and arrangement of bridge cranes of high load capacity in two tiers allowed manufacturing large-size items of up to 150 t mass. If necessary, structures could be subjected to thermal treatment — tempering for relieving stress or normalization after electroslag welding in heat-treating furnaces. Maximum size of assemblies and parts loaded into the furnace was $3.3 \times 5 \times 24$ m.

In that block advanced for that time processes were used: cutting of rolled sheet metal on machines with photographic master form, assembly of structures using appliances and stands, CO_2 semi-automatic welding, and automatic submerged arc surfacing. The main technological equipment-guillotine shears, plate-leveling rolls, press-shears, pipe-cutting machines — all of them were equipped with portal manipulators for loading and unloading, roller conveyers, and a system of measuring stops.

In subsequent years equipment was constantly updated and new technologies were developed and introduced. Machines for oxy-gas cutting with photocopying device were replaced step-by-step for NC machines of companies Messer Hrissheim, Tanaka and ESAB. In 1980–1990 powerful hydraulic four-roller rolls of the Hoisler company, model VRM 80-3600, and NC laser-press of model TRUMATIK 300LW of the TRUMPF company, were introduced into welding

Figure 1. Welding of metal structure using the Fronius semi-automatic machine of «new generation» with cassette of increased capacity of Marathon type (mass of welding wire is 475 kg)

production for high-precision cutting of billets from 8 mm sheets.

Process of automatic surfacing was constantly improved along with welding. By now welding production has equipment, state-of-the-art technologies, and experience of surfacing carbon steels with corrosion-resistant, non-ferrous, and hard alloys. The level of technological developments in surfacing bronze and composite alloys for manufacturing large-sized parts of friction pairs and hardening of heavily loaded parts and MCCI rollers is not inferior to advanced technologies of Russian and foreign companies. There is a special production bay for surfacing MCCI rollers.

Technology of electroslag welding of large-sized items, including cylindrical ones, is in the same demand as previously. Available equipment makes it possible to perform welding with consumable tips of the items having thickness up to 2000 mm (for circumferential welds up to 500 mm), length up to 5700 mm, diameter up to 5000 mm, and mass up to 150 t.

Within the last 15 years nomenclature of the equipment, produced by Uralmashzavod company, has significantly changed. The plant started to produce technologically complex heavy crane equipment for nuclear power plants and metallurgical plants, it manufactures new generation of MCCI, including those produced according to engineering of the leading European companies, such as SMS-Demag (Germany), equipment for reconstruction of the cascade of Volga hydro-power stations, cement industry, etc.

Passing over to manufacturing new kinds of products with increased requirements to the quality of welded metal structures required for respective technical preparation of welding production. This touched both materiel and technological processes and industrial quality management.

In the area of technical and technological achievements it is necessary to note, first of all, passing over to welding in shielded argon-base gas mixtures. Within the last five years equipment for semi-automatic welding was significantly updated in the assembly-welding bay. State-of-the-art semi-automatic welding machines of the last generation with programmable welding parameters of the companies ESAB

Figure 2. Linear accelerator UELV-10-2D-40

(Sweden) and Fronius (Austria) were introduced into production.

For manufacturing long-cut large-sized welded structures for machine-building industry, having thickness of metal to be welded up to 80 mm, high-productivity welding equipment of the Fronius company was introduced for welding in TIME-process mode in multicomponent gas mixture atmosphere. Productivity of the process achieves 12–15 kg of deposited metal per hour (Figure 1).

For high-productivity radiographic control of large-sized welded assemblies, linear accelerator UELV-10-2D-40 was introduced (Figure 2), which ensures control of welded joints with wall thickness from 100 to 500 mm.

In the procurement bay of the welding production combined CNC machine for thermal cutting (oxy-gas cutting + oxy-air plasma cutting + marking block) of model Suprarex SXE-3500 of the ESAB company (Figure 3) was commissioned. Table of the machine is equipped with ventilation system, which filters removed metal combustion products.

In 2004 automatic CNC cutting line on the basis of bi-column band saw MEBA 560 GA-3300 of the MEBA company (Germany) (Figure 4) was commissioned for cutting bars, pipes, and structural shapes. Maximum section of the cut rolled stock is 560×700 mm, length of automatically cut parts is up to 6000 mm, cutting may be performed at any angle (to the left) within the range 30–90°.

The main volume of rolled metal, designed for manufacturing welded structures, is subjected to shot-

Figure 3. Machine for thermal cutting Suprarex SXE-3500 with CNC

Figure 4. CNC cutting line on the basis of bi-column band saw MEBA 560 GA-3300

Figure 5. The Guttmann shot-blast cleaning and priming line

blast cleaning and priming on the line of Guttmann company (Germany) (Figure 5). Careful preparation of surfaces of welded structures for ensuring high-quality painting, reliable protection of rolled metal surface against corrosion, improvement of consumer properties and competitiveness of manufactured products, and reduction of labor input of oxy-gas cutting are results of introduction of the Guttmann unique equipment.

Maximum thickness of treated rolled sheet is 80 mm, width — 2500 mm. Cross-section of shaped rolled stock is 1000 × 420 mm, length — 12000 mm.

For confirming its possibilities in the field of welding and for obtaining right for manufacturing welded structures according to the requirements of international standards, Uralmashzavod has been certifying since 1994 its welding production with attraction of the DVS (Germany). In 2005 the welding production was once more certified by mentioned company and obtained Quality Certificate according to DIN EN 729-2 and Certificate on Manufacturer's Qualification according to DIN 18800-7 (class E).

Technological support of welding production, its technical re-equipment, and present technical condition are determined by the Chief Welder Department of Uralmashzavod, 60th anniversary of which will be marked in January 2006. Chief Welder Department is a team of high-skill specialists, who have huge experience in designing and manufacturing special-purpose large-sized structures for machine-building industry.

Talented engineers, organizers and managers of welding service, and known scientists in the field of welding, who worked at various time in Uralmashzavod, made their contribution into development of welding production. Among them are G.P. Mikhajlov — the first chief of the department for designing and manufacturing welded structures at Uralmashzavod, founder of the Welding Chair in the S.M. Kirov Ural Polytechnic Institute; V.V. Stepanov — Chief of the Welding Department and then for many years dean of the welding chair in UPI; N.I. Ryzhkov — Chief Welder, Director of Uralmashzavod, afterwards Chairmen of Council of Ministers of USSR; V.A. Batmanov — known specialist in the field of fundamental studies in the field of cast iron weldability, repair welding of special-purpose parts from steel and cast iron ingots; V.D. Kudinov — founder of auto-vacuum surfacing of copper-base non-ferrous alloys and composition surfacing of tungsten carbide-base wear-resistant alloys; Z.I. Fridkis — author of the method for surfacing babbits; E.A. Kirillov — Chief Welder of Uralmashzavod from 1985 through 2001, etc.

Many original scientific, technological, and design developments were introduced into welding production and brought appreciable economic effect due to reduction of labor input into production of metal structures and improvement of quality of manufactured items owing to cooperation with specialists of the E.O. Paton Electric Welding Institute, Federal State Unitary Enterprises TsNIITMASh, Prometej and Ural Polytechnic Institute.

Availability of universal welding facilities and advanced technology, possibility of producing welded metal structures of wide range of sizes, mass and complexity in agreement with requirements of Gosgortekhnadzor (State mining inspection), Gosatomnadzor (State body for supervision over nuclear power generation) and international standards, availability of intellectual potential, and high level of occupational training of engineering and plant personnel are key components of present welding production of Uralmashzavod in the field of manufacturing metal structures.

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COMPUTER PROGRAMS FOR DESIGNING EFFECTIVENESS OF PIPELINE PROTECTION BY THE METHOD OF NON-LINEAR POLARIZATION

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A computer program has been developed for calculation of electrochemical parameters and its performance has been verified in the laboratory and in the route, when testing a gas pipeline, using an electrochemical microprocessor system (ECMS). Obtained data on the rate of soil corrosion of pipeline metal correlate in a satisfactory manner with that of mass measurements. Possibility of evaluation of the rate of residual corrosion of pipeline metal in a coating defect using ECMS and developed program, allows an objective assessment of the degree of pipeline protection and taking a well-grounded decision on the sequence of repair of pipeline section with damaged insulation.

Keywords: pipelines, insulation coating, corrosion rate, potential, protection effectiveness, potentiometry, mass measurement, computer calculations

Studying the mechanism and kinetics of corrosion of steel pipelines is necessary for practical evaluation of the risk of failure of underground metal structures and determination of the effectiveness of their electrochemical protection.

Effectiveness of corrosion protection of pipelines is characterized by the corrosion rate of pipeline metal in a defect of the insulation coating. This value is calculated, using the following parameters determined by polarization curves: polarization potential E_p, Tafel slope of anode polarization curve b_a and rate of soil corrosion i_c. Thus, calculation of the effectiveness of corrosion protection of pipelines is reduced to determination of the rate of soil corrosion and polarization potential of the pipeline.

Rate of residual corrosion of pipeline metal in a defect of insulation coating, $i_{r.c}$, is determined by the following formula:

$$i_{r.c} = \bar{i}_c 10^{\bar{E}_p} / b_a, \qquad (1)$$

where $\bar{E}_p$ is the average value of polarization potential.

Determination of metal corrosion rate in any medium is the main problem of electrochemical kinetics. At present, the question of the method of corrosion rate determination is still open both in our country and beyond it. Scientists from different countries, while developing computer programs for calculation of electrochemical parameters of the corrosion process, namely the rate of soil corrosion and Taffel slopes [1–11], came to the conclusion that the validity of the processed data depends on selection of the method of measuring the polarization curves, and not on the method of mathematical processing of test results.

For most of the metal–electrolyte systems, corrosion potential E_c is located rather far from the equilibrium potentials of the anode and cathode reactions. Dependence of current density i on potential E is given by the following equation:

$$i = i_c\,[10^{2.303}(\eta / b_a) - 10^{(-2.303\eta / b_c)}], \qquad (2)$$

where $\eta = E - E_c$ is the overstress; b is the Taffel constant; «a» and «c» indices denote the anode and cathode reactions, respectively.

This equation is most often used to determine the corrosion characteristics of the metal by the data of polarization measurements.

The numerical method of calculation of the corrosion rate of metals and alloys in the inflection point can be regarded as a method alternative to Stern–Giri method of polarization resistance [12]. Its application does not require introduction of any restrictions as regards the shape of polarization curves. In most of the cases, however, a priori evaluation of the position of the inflection point is required, as the actual values of the slopes of the anode and cathode sections of Tafel straight lines are unknown for the studied system. In addition, the range of values of electrode potential, obtained through measurements, is wider than the traditional one ($E_c = -10 - +10$ mV). The method of the inflection point may be used both in the anode, and in the cathode regions of the potential. This is of great practical importance, as reliable evaluation of the corrosion rate requires knowledge of the effective values of Tafel slopes.

In order to determine the corrosion rate, it is necessary to establish the procedure of measuring the polarization curves in a constant time interval. This is necessary to check, if the instant corrosion rate value is constant during this entire study, and to establish the anomalous conditions, markedly affecting the corrosion resistance. As shown by practice, unsatisfactory results can be obtained when polarization conditions curves are measured for longer time (compared to other curves). In addition, it is very important to reduce or eliminate the influence on electrode kinetics of any factor, which essentially changes the shape of polarization curves, for instance, resistance

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of the solution between the working electrode and electrode used for comparison.

Published investigations results clearly show that successful determination of the corrosion rate also depends on the reliability of the numerical method of processing the experimental data in a real time interval. It is proved that NOLI method is unsuitable in the case, if more than two determinant processes occur, from those which make an essential contribution to the resultant reaction in the potential interval E_c = = –90 – +90 mV.

Mathematical calculations. Values of the most important electrochemical parameters can be determined, calculating the root of the respective function and the elementary relationships established between them.

In the original version of the inflection point method, the kinetic law is given by the following equation:

$$i(\Delta E) = i_c(e^{\alpha_a \Delta E} - e^{-\alpha_c \Delta E}), \qquad (3)$$

where $\Delta E = E - E_m$; E_m is the mixed potential; α_a and α_c are the values, related to the anode and cathode Tafel slopes by the following relationships, respectively: $b_a = \alpha_a^{-1}$ ln 10 and $b_c = \alpha_c^{-1}$ ln 10. In addition, relationships $0 < \alpha_a < 1$ and $0 < \alpha_c < 1$ are always valid.

Importance of law (3) is due to the fact, that the current–potential curves are used to describe the behaviour of a large class of corrosion processes of one type. As shown by experience, current–potential curves for metals and alloys, which are in different aggressive environments, are governed by Tafel equation, when the successive approximation method is used.

Proceeding from the analytical expression for the first derivative

$$i'(\Delta E) = i_c(\alpha_a e^{\alpha_a \Delta E} + \alpha_c e^{-\alpha_c \Delta E}), \qquad (4)$$

it is obvious that $i'(\Delta E) > 0$, and function (3) has a minimum in the middle of the range $(-\infty - \infty)$, as $i'(\Delta E) \to \infty$ at $\Delta E \to -\infty$ and $i'(\Delta E) \to \infty$ at $(\Delta E) \to \to \infty$. This means that the second derivative

$$i''(\Delta E) = i_c(\alpha_a^2 e^{\alpha_a \Delta E} - \alpha_c^2 e^{-\alpha_c \Delta E}) \qquad (5)$$

has the only root in point

$$\Delta E_i = 2\,\frac{\ln(\alpha_c/\alpha_a)}{\alpha_a + \alpha_c}, \qquad (6)$$

which is the inflection point of function (3).

According to mathematical analysis, the inflection point of continuous function $f(x)$ is determined by condition $f^{(2n)}(x) = 0$, where n is the positive integer number.

Analysis of equation (3) showed that $\Delta E_i > 0$ at $\alpha_a < \alpha_c$ and $\Delta E_i < 0$ at $\alpha_a > \alpha_c$. Thus, position of the inflection point depends only on the values of Tafel slopes.

Values of electrochemical parameters α_a, α_c, i_c can be determined, calculating the roots of the following equations:

$$i'(0) = i_c(\alpha_a + \alpha_c); \qquad (7)$$

$$i''(0) = i_c(\alpha_a^2 - \alpha_c^2); \qquad (8)$$

$$\alpha_a^2 e^{\alpha_a \Delta E_i} - \alpha_c^2 e^{-\alpha_c \Delta E_i} = 0. \qquad (9)$$

Combining (7) and (8) and assuming w = = $i''(0) / i'(0)$, we will obtain the following relationship:

$$w = \alpha_a - \alpha_c. \qquad (10)$$

Allowing for (10), equation (9) becomes

$$\alpha_a^2 e^{\alpha_a \Delta E_i} - (\alpha_a - w)^2\, \alpha_c^2 e^{-\alpha_c \Delta E_i} e^{w \Delta E_i} = 0, \qquad (11)$$

thus allowing α_a to be calculated with the known ΔE_i value.

The main point of the presented theory is determination of the shape of function $F(\alpha_a)$ from the following equation:

$$F(\alpha_a) = e^{\alpha_a \Delta E_i}\, [\alpha_a^2 - (\alpha_a - w)^2 e^{-2\alpha_a \Delta E_i} e^{w \Delta E_i}] \qquad (12)$$

in the range of (0, 1) to establish, if there is a root in this interval and select the numerical method of its calculation.

For simplification purposes, let us assume $\alpha_c > \alpha_a$, i.e. $\Delta E_i > 0$ and $w < 0$. Then we obtain $F(0)$ = = $-w^2 e^{w \Delta E_i}$ at $\alpha_a = 0$ and $F(\alpha) \to \infty$ at $\alpha_a \to \infty$. This shows that $F(\alpha)$ has at least one root. At the next stage it is necessary to prove that this root is the only one.

The fact that $F(\alpha)$ has only one root, is proved by introducing $G(\alpha_a)$ function, which is described by the following formula:

$$G(\alpha_a) = \alpha_a^2 - (\alpha_a - w)^2 e^{-2\alpha_a \Delta E_i} e^{w \Delta E_i}, \qquad (13)$$

and its first derivative

$$G'(\alpha_a) = \\ = 2\{\alpha_a + (\alpha_a - w) e^{-2\alpha_a \Delta E_i} e^{w \Delta E_i}[(\alpha_a - w)\Delta E_i - 1]\}. \qquad (14)$$

When analyzing expression (14), three cases can be considered: $-w\Delta E_i > 1$, $-w\Delta E_i = 1$ and $-w\Delta Ei <$ < 1. In the first two cases always $G'(\alpha_a) > 0$ at $\alpha_a \neq$ $\neq 0$. Under such conditions, function $F(\alpha)$ grows monotonically, as it has just one root. The third case is more complicated, as it is not easy to establish the analytical procedure, if always $G'(\alpha_a) > 0$ at $\alpha_a \neq 0$.

To prove that $G'(\alpha_a) > 0$, the following inequality should be used:

$$\alpha_a + (\alpha_a - w) e^{-2\alpha_a \Delta E_i} e^{w \Delta E_i}[(\alpha_a - w)\Delta E_i - 1] > 0. \qquad (15)$$

Thus, it is necessary to find an acceptable numerical method for determination of lower limit α_{a1}, as $G'(\alpha_a) > 0$, and $F(\alpha)$ is a monotonically growing function at $\alpha_a > \alpha_{a1}$. In addition, positive value of

α_{a1}, which corresponds to $G(\alpha_a)$ minimum, is smaller than $F(\alpha_a)$ root. This is due to the fact that inside $(0, \alpha_{a1})$ interval, $G(\alpha_a)$ function is monotonically decreasing and takes negative values.

It remains to show that $F(1) > 0$ for all the cases. This is easy to prove having checked, whether the following inequality is satisfied:

$$e^{\Delta E_i}(1 - (1 - w)^2 e^{-(2 - w)\Delta E_i}) > 0. \quad (16)$$

Analyzing randomly selected numerical examples, and remembering that $|w| < 1$, validity of inequality (16) becomes obvious for the case of $\Delta E_i \geq 1$. More over, inequality (12) provides direct confirmation of the fact that $\alpha_a < 1$.

From the above-said it follows that $F(\alpha_a)$ root provides a significant solution, when the condition $0 < \alpha_{a1} < 1$ is satisfied. If $\alpha_a > \alpha_c$, then $\Delta E_i < 0$, and $w > 0$, and we again come to the case, when current–potential curve $h(\Delta E_r) = -i(-\Delta E)$ is discussed, where $\Delta E_r = -\Delta E$ is the new variable.

Now it just remains to analyze condition $\alpha_a = \alpha_c$, which satisfies condition $\Delta E_i = 0$ and $w = 0$. In keeping with this hypothesis, let us calculate by identical equation (9) the third derivative $i(\Delta E)$ at $\Delta E = 0$ and obtain the following relationship:

$$\alpha_a = \sqrt{\frac{i'''(0)}{i'(0)}}. \quad (17)$$

It should be noted that if ΔE_i takes values close to zero, then correctness of inequality (16) is in question. Therefore, it is better to assume $\Delta E_i = 0$, and calculate the first approximation by α_a equation (17).

Evaluation of corrosion current density. Root of function $F(\alpha_a)$ at $\alpha_a \neq \alpha_c$ can be calculated using the Newton method. Let us give the expression for its first derivative, which, allowing for (13) and (14), becomes

$$F'(\alpha_a) = \Delta E_i e^{\alpha_a \Delta E_i} G(\alpha_a) + e^{\alpha_a \Delta E_i} G'(\alpha_a). \quad (18)$$

$F(\alpha_a)$ root is given by a limit value of numerical sequence

$$\alpha_{an} = \alpha_{a(n-1)} - \frac{F(\alpha_{a(n-1)})}{F'(\alpha_{a(n-1)})}. \quad (19)$$

Initial value can be selected randomly inside a given interval of convergence.

If values of $F(\alpha_a)$ root are known, then values α_c can be calculated from (10), and i_c values are found, using approximations of different nature. Thus, i_c can be calculated using (7). We obtain

$$i_c = \frac{i'(0)}{\alpha_a + \alpha_c}.$$

When the original version of the inflection point method is used, the expression for i_c calculation becomes

$$i_c = \frac{i'(\Delta E_i)}{\alpha_a e^{\alpha_a \Delta E_i} + \alpha_c e^{-\alpha_c \Delta E_i}},$$

where $i'(\Delta E_i)$ is the first derivative of i with respect to ΔE, obtained, when using the inflection point method; ΔE_i is the potential increment, calculated by experimental data.

Value i_c can be also calculated by another method. Assuming $S(\Delta E) = e^{\alpha_a \Delta E} - e^{-\alpha_c \Delta E}$ and considering $(\Delta E_c, i_c)$ pairs, at $k = 1, 2 \ldots, N$, we obtain

$$i_c = \frac{\sum_{k=1}^{N} i_c S(\Delta E_c)}{\sum_{k=1}^{N} i_c S(\Delta E_c)^2}.$$

The main advantage of the above relationships consists in that correctness of calculation of the corrosion rates based on experimental data, is confirmed by comparison with the data, obtained when measuring the polarization curves.

Correctness of the above mathematical reasoning was evaluated by analysis of some examples, which also enable checking the convergence of the numerical sequence (19) and influence of selection of α_0 value on effectiveness of the Newton method.

As regards the latter conclusion, even after previous processing it was decided to assume α_{a0} = = 0.1 mV^{-1}, as this is exactly the value of α_{a0}, at which the most satisfactory results were obtained in all the studied cases. In addition, note that always $\alpha_a < 0.1$ mV^{-1}. Thus, there is no need to assume α_{a0} values, which satisfy inequality $0.1 < \alpha_a < 1$ mV^{-1}.

Newton method is a powerful tool for calculation of the root of equation (11), and initial value α_a = = 0.1 mV^{-1} is correct for achievement of convergence of the numerical sequence after several iterations (19), both with the theoretical and with experimental data. Analysis of the calculated curves (8) suggests that the root of equation (8) does not depend on relative values of b_a and b_c.

The plotted curves indicate that the numerical sequence (19) is convergent even if $-w\Delta E_i = 1.25 \cdot 10^{-4}$, which is the case when b_a = 89 mV and b_c = 90 mV. If the experimental polarization curves are the most accurately described by the polynomial of the 4th degree, then calculation of the corrosion rate yields the most satisfactory results. Thus, effectiveness of the numerical processing methods depends on the accuracy and reproducibility of experimental data. Polarization measurements should be made, using the most modern electrochemical methods, while allowing for the influence of ohmic resistance on electrode potential.

Experimental results and their discussion. There exists a method of calculation of Tafel slopes and instantaneous corrosion rate, proceeding from polarization curves, using a short and simple computer program Betacrunch, written in BASIC, which is based on a successive substitution of known values of b_c, b_a

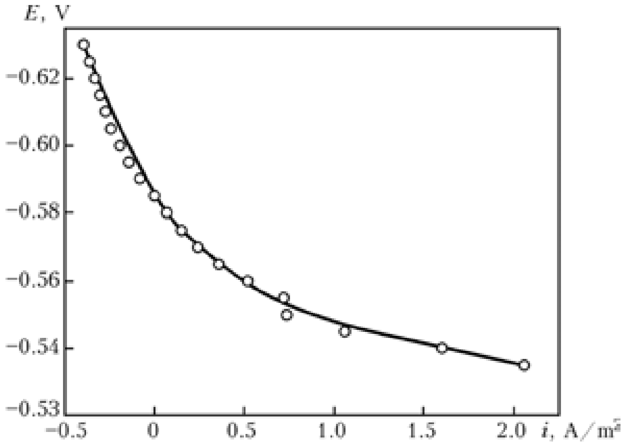

Figure 1. Polarization curves of steel in 3 % NaCl solution (pH 4)

and i_c into (2), and determination of values, yielding the smallest discrepancy between the experimental and calculated values of current density.

In this study applicability of this program for processing the obtained experimental data was investigated. An attempt has been made to use the program for calculation of b_c, b_a and i_c constants for a steel electrode in a 3 % solution of NaCl with different pH values and for a sensor of soil corrosion in an environment simulating the soil (sand + 3 % NaCl). Values of b_c, b_a and i_c obtained using Betacrunch program for the above solution, cannot be interpreted, and are, probably, devoid of physical meaning. It was not possible to calculate the value of the above parameters for the soil, as the program developed a malfunction in this case, and a message of the need to check the data was shown.

After unsuccessful attempts to calculate b_c, b_a and i_c values, based on polarization curves obtained experimentally, program operation was checked in the following case. It is known that at iron corrosion in the kinetic region with formation of ions of two-valence iron b_c = 0.12 V, b_a = 0.006 V and i_c = 0.4 A / m^2. According to (2), values of pairs of i–E points were calculated, which describe a polarization curve near the corrosion potential in the range of −(0.55±0.05) V. An attempt was made to calculate b_c, b_a and i_c, using Betacrunch program. However, this effort was interrupted, as the computer display showed a message

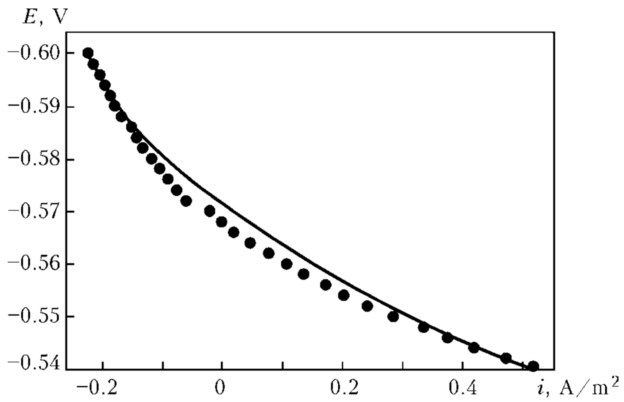

Figure 2. Polarization curves obtained from soil corrosion sensor in an environment simulating the soil

Table 1. Values of coefficients b_c, b_a and i_c obtained using Betacrunch program

Environment	b_a, V	b_c, V	i_c, À / m^2
3 % NaCl solution, pH 4	0.043	0.093	0.146
3 % NaCl solution, pH 7	0.072	0.200	0.097
3 % NaCl solution, pH 9	0.051	0.176	0.026
Sand + 3 % NaCl solution, pH 4	0.065	0.249	0.240
Sand + 3 % NaCl solution, pH 7	0.069	0.690	0.226

about deviation of the data from those obtained from (2).

When searching for other methods to calculate the necessary parameters, a new program was developed. Its algorithm is based on a combination of the methods of non-linear minimization. The effective function for this algorithm is written as a sum of squares of experimental and calculated data deviation. The method allows assigning the range of possible values for each parameter. Calculation of the first derivatives of the effective function for each of the unknowns is performed using analytical expressions, the matrix of second derivatives (Hesse matrix) is found numerically. The main program module is written in Fortran, and the graphic output module in the C$^+$ language.

The first stage of checking the program performance included calculation of b_c, b_a and i_c for a test example. Values of the coefficients were calculated with the accuracy up to the third sign after the dot. This was followed by calculation of the values of these parameters from the experimentally obtained polarization curves (Table 1).

Figures 1 and 2 show the polarization curves obtained for the solution and the soil. Points indicate the experimental data, and the solid line are the data calculated by a program. A good agreement of the experimental and calculated data for the solution is indicative of correct operation of the above program, and also of the fact that the experimental data are governed by equation (2). In the case of the soil, the calculated polarization curve deviates from the experimental one. This is, most probably, due to running of the processes, which are not allowed for by equation (2).

Measurements of the rate of soil corrosion of pipe metal were taken and residual corrosion rate was calculated in the zone with a positive anomaly of polarization potential (Table 2) as an example of this program application in combination with electrochemical micropocessor system (ECMS) [13–15].

From the results of $i_{r.c}$ calculation by (1), it follows that the pipe wall damage is the most intensive in a section located at the distance of 130 m from 262 km mark. After that, test pits were made in the studied locations, and the condition of pipeline insulation was studied. In all the three pits, insulation cracking and its delamination from the pipe surface on an area of 1–3 m^2 due to loss of adhesion strength was observed. It is obvious that deterioration of the physico-mechani-

Table 2. Results of examination of cathode protection station PSK-M-06 in Efremovka–Dikanka–Kiev gas pipeline

H, m	Å$_{ð}$ = –0.720 V Å$_{c}$ = –0.580 V (40 m)		Å$_{ð}$ = –0.750 V Å$_{c}$ = –0.560 V (115 m)		Å$_{ð}$ = –0.620 V Å$_{c}$ = –0.575 V (130 m)	
	i_c, mm	$i_{r.c}$, mm / year	i_c, mm	$i_{r.c}$, mm / year	i_c, mm	$i_{r.c}$, mm / year
0.75	0.18	0.009	0.20	0.0065	0.24	0.08
1.15	0.21	0.011	0.23	0.0071	0.27	0.11
1.50	0.24	0.015	0.25	0.0090	0.31	0.13

Notes. 1. Distance from the mark is 262 km. 2. Station operation mode: U = 268 V, I = 6 A. 3. H –– immersion depth of sensor.

cal properties of the insulation coating led to lowering of the absolute values of polarization potentials in the control points. The deepest pit-type corrosion damage of the pipe was revealed in a section located at 130 m distance from 262 km mark. This section should be the first to be repaired.

Control samples from pipe steel of 17GS grade were mounted on the level of the pipeline lower generatrix to determine the rate of soil corrosion by mass measurement method. One month after the samples were taken out of the pits and values of soil corrosion rate v_c were determined. In addition, soil samples were taken out of the pits to determine the corrosiveness according to GOST 9.602–89 (Table 3).

Comparison of the data in Table 3 with the results on soil corrosion rate obtained with EChMS shows a good agreement between i_c and v_c values.

CONCLUSIONS

1. Conducted analysis of published data on the methods of calculation of electrochemical parameters of the corrosion process suggests that the methods to calculate the corrosion rate, aimed at ensuring the reliability of obtaining and simplicity of processing the experimental data used to describe the behaviour of a large number of electrochemical systems, need to improved.

2. Use of the developed program of electrochemical parameter calculation together with ECMS, provides objective data on the rate of soil corrosion of pipeline metal and soil corrosiveness. ECMS enables evaluation of the rate of residual corrosion of pipeline metal in a coating defect, which is an important criterion in determination of the corrosion state of a pipeline, provides an objective estimate of the degree of pipeline protection and allows taking a substantiated decision on the need to repair pipeline sections with damaged insulation.

Table 3. Results of determination of soil corrosion rate of 17GS pipe metal by mass measurement method in different points of the gas pipeline in zones with a positive anomaly E_p

Parameter, mm / year (measurement method)	Distance from 262 km mark, m		
	40	115	130
i_c (under full-scale conditions on the level of the pipeline lower generatrix)	0.27	0.28	0.30
v_c (by mass measurement method)	0.52	0.50	0.57

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MODELLING OF THE PROCESS OF LASER SPRAYING OF CERAMIC COATINGS ALLOWING FOR SCATTER OF THE LASER BEAM BY SPRAY PARTICLES

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Mathematical model was developed for computer simulation of movement and heating of particles of finely dispersed ceramic materials under conditions of laser spraying of coatings. Scatter and absorption of the laser beam by the whole of the particles were allowed for in estimation of local values of the intensity of radiation along the path of movement of an individual particle. The paths, velocities, spatial distribution and temperature fields of fine SiO_2 particles under conditions of laser spraying using CO_2-laser were calculated. It is shown that powder consumption has a substantial effect on distributed and integral characteristics of the laser beam, as well as on the thermal state of the spray particles.

Keywords: laser spraying, ceramic particles, laser beam, scatter, movement velocity, thermal state, modelling

Processes of deposition of coatings using laser radiation are gaining an increasingly wide acceptance in modern manufacturing. One of such processes is laser spraying, based on injection of dispersed material particles into the laser heated zone, their acceleration by a gas flow, melting and deposition on the workpiece surface [1--3]. The process under consideration can be implemented using laser radiation of different wavelengths, different methods and radiation focusing systems, as well as methods of feeding the spray powder to the heating zone (Figure 1). In particular, CO_2-lasers are most indicated for laser spraying of coatings of ceramic materials (Al_2O_3, SiO_2, ZrO_2, etc.), as these powder materials absorb radiation with a wavelength of λ = 10.6 μm much better than the short-wave radiation of Nd:YAG-lasers [4, 5]. Moreover, in contrast to metallic particles that absorb laser radiation in a thin surface layer, particles of finely dispersed dielectric (ceramic) materials absorb it with their entire volume [6], which provides volumetric heating and full penetration of the spray particles, and, therefore, improvement of the quality of a resulting coating.

Important characteristics of the laser spraying process include the path, velocity and thermal state of the spray material particles, which in many cases are difficult to determine experimentally. The purpose of this study was to develop mathematical models and conduct computer simulation of movement and heating of fine ceramic particles under conditions of laser spraying of coatings. It should be noted that, since under the conditions considered the laser beam propagates in a dusted environment, when developing a mathematical model of laser heating of an individual particle it is necessary to allow for absorption and scatter of laser radiation by the whole of the particles.

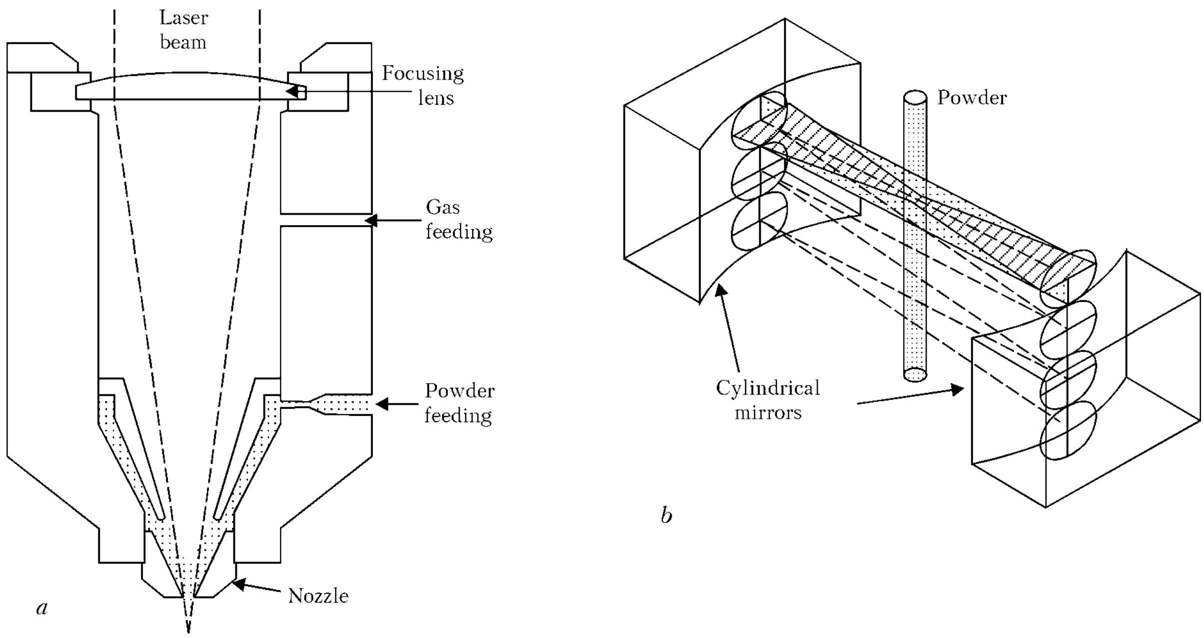

Figure 1. Methods for practical implementation of the processes of laser spraying with coaxial feed of powder to the laser beam [2] (*a*) and beam trap [3] (*b*)

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Consider the process of laser spraying of ceramic coatings implemented according to the schematic shown in Figure 2. The CO_2-laser beam focused by the optical system propagates along the axis of a cylindrical nozzle, which feeds a gas that accelerates the spray material particles to a workpiece. Ceramic particles are injected into the treatment zone through a narrow annular slot located horizontally and coaxially with respect to the system axis. Spatial distributions of the intensity of laser radiation, gas flow rate and velocity of the particles are assumed to be axially symmetric, while the particles are assumed to be spherical.

We will use the mathematical model suggested in study [7] to calculate velocity and path of movement of an individual (sample) particle. In the case where the accelerating gas jet is slightly dusted and the spray material particles do not interact (do not collide) with each other, the equations of movement of a spherical particle in a gas flow with a set velocity distribution, given in the above study, can be used to determine current values of radius-vector $\mathbf{r}(t) = (\bar{x}, \bar{y}, \bar{z})$ and velocity $\mathbf{v}(t) = (\bar{v}_x, \bar{v}_y, \bar{v}_z)$ for any particle of the whole of the spray particles, which differ only in the conditions of their injection into the jet, i.e. initial conditions (here and below all the values are given in the co-ordinate system shown in Figure 2).

To analyse the thermal state of a sample particle, we will also use the model of study [7] describing heating of a spherical ceramic particle in the laser beam with a known distribution of radiation intensity $S(x, y, z)$. To close this model, it is necessary to determine spatial distribution of the intensity of laser radiation within the treatment zone, allowing for multiple scatter and absorption of the initial beam with the whole of the spray particles. Assuming that scatter occurs at discrete inclusions (dielectric particles), which are larger in size than the laser radiation wavelength, and considering that effective complex permittivity $\hat{\varepsilon}$ of such a dusted absorbing environment hardly changes at distances of about λ, we will use the method of parabolic equation to find S [8]. Allowing for the earlier assumption of axial symmetry of distribution of the radiation intensity, the parabolic equation for complex amplitude $E(r, z)$ of the electric field of the laser beam propagating in the dusted environment can be written down as follows:

$$-2ik\,\frac{\partial E}{\partial z} = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial E}{\partial r}\right) + k^2(\hat{\varepsilon} - 1)E, \qquad (1)$$

where i is the imaginary unit; $k = 2\pi/\lambda$ is the wave vector of laser radiation; and $r = \sqrt{x^2 + y^2}$ is the distance from the system axis. The unknown quantity of $S(r, z)$ is a time-average value of axial component of density of the electromagnetic energy flow of the beam [9]

$$S = \frac{1}{2}\sqrt{\varepsilon^0/\mu^0}\,|E|^2, \qquad (2)$$

where ε^0 is the permittivity of vacuum; and μ^0 is the universal magnetic permeability.

Initial (input) and boundary conditions for equation (1) can be written down in the following form:

$$E|_{z=0} = E^0(r);\quad \left.\frac{\partial E}{\partial r}\right|_{r=0} = 0;\quad E|_{r=R} = 0,$$

where R is the radius of the calculation area $\{0 \le z \le L;\ 0 \le r \le R\}$. To set the explicit form of $E^0(r)$, assume that the focused Gaussian radiation beam (TEM_{00}-mode), having minimal half-width r_F in plane $z = F$ (see Figure 2) at the absence of powder, is fed through the nozzle orifice into the treatment zone. Spatial distribution of a complex amplitude of the field of such a beam, meeting equation (1) at $\hat{\varepsilon} = 1$, is determined by the following expression from study [10]:

$$E = E_F\,\frac{r_F}{r_z}\exp\left[-\frac{r^2}{r_z^2} + i\left(k\,\frac{r^2}{2R_z} - \varphi_z\right)\right]. \qquad (3)$$

Here

$$r_z^2 = r_F^2\left[1 + \frac{(z - F)^2}{z_F^2}\right];\quad R_z = (z - F)\left[\frac{1 + z_F^2}{(z - F)^2}\right];$$
$$\varphi_z = \mathrm{arctg}\left(\frac{z - F}{z_F}\right);\quad z_F = \frac{kr_F^2}{2}, \qquad (4)$$

and constant E_F is found from an integral relationship for the total radiation power:

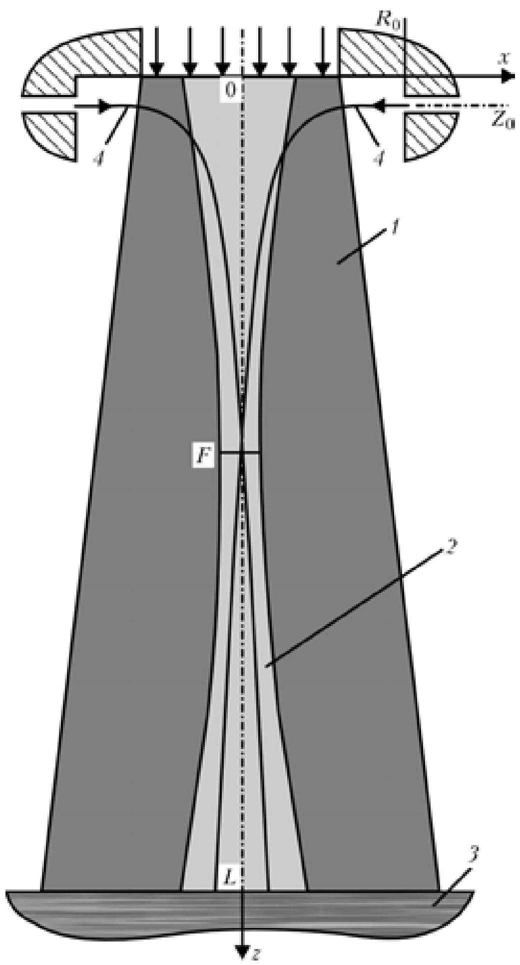


Figure 2. Schematic of the investigated process of laser spraying of coatings: *1* — accelerating gas jet; *2* — laser beam; *3* — workpiece; *4* — paths of movement of spray particles; R_0 and Z_0 — co-ordinates of particle entry points; L — spraying distance; F — distance of focal plane of the beam from exit section of the nozzle

$$Q = 2\pi\int_0^{\infty} Srdr, \qquad (5)$$

which, allowing for (2), yields

$$E_F = \sqrt{\frac{4}{\pi}\frac{Q^0}{r_F^2}\left(\frac{\mu^0}{\varepsilon^0}\right)^{1/2}}, \qquad (6)$$

where Q^0 is the power of the initial laser beam. Therefore, expressions (3), (4) and (6) with $z = 0$ substituted to them determine the total radial distribution of amplitude of the electric field of the beam in an initial section of the calculation area.

Equation (1) is solved by the finite difference method allowing for spatial distribution of the effective complex permittivity of the dusted environment, $\hat{\varepsilon} = \hat{\varepsilon}(r, z)$, which can be written down in the following form [8]:

$$\hat{\varepsilon} = 1 + 4\pi nP.$$

Here $n(r, z)$ is the spatial distribution of the concentration of spray particles; $P = \frac{\pi}{6} d^3p$ is the polarisability of a particle; and d is its diameter. Polarisability coefficient p for ceramic (dielectric) particles can be calculated from the Lorentz–Lorenz formula [11]:

$$p = \frac{3}{4\pi}\frac{\varepsilon - 1}{\varepsilon + 1},$$

where $\varepsilon = \varepsilon' + i\varepsilon''$ is the complex permittivity of the particle material.

To calculate $n(r, z)$, we will use the method of individual paths. For this, we will break down the entire flow of the spray material (assuming that it is monodisperse) into individual paths corresponding to particles with different directions of the vector of the initial velocity (the absolute value of the initial velocity for all particles is assumed to be identical and equal to v_0). In this case, it is considered that particles are injected into the treatment zone from each point of the annular slot in a direction of the system axis

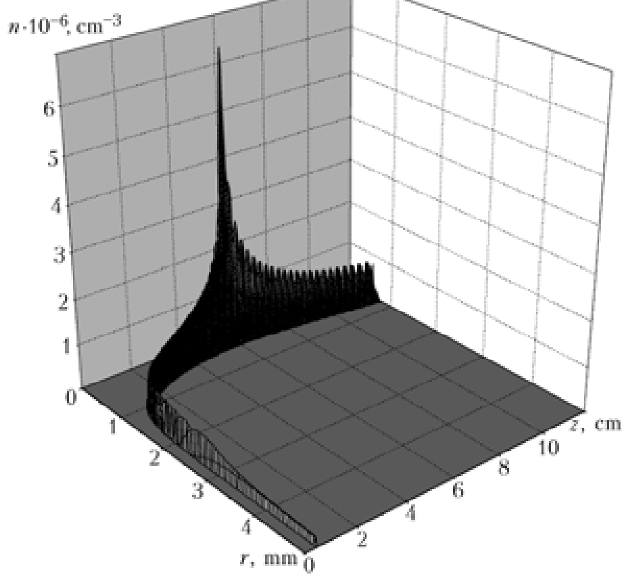


Figure 3. Spatial distribution of the concentration of spray material particles (SiO_2) accelerated by a gas jet

(see Figure 2), meaning a random orientation of the velocity vector with respect to the said direction in some solid angle $\Omega = 2\pi(1 - \cos\vartheta_m)$, where ϑ_m is the maximal deviation angle. Then, allowing for an assumption of axial symmetry of spatial distribution of the spray particles, to calculate $n(r, z)$ it is enough to consider only the paths of the particles injected through one point of the slot and average the result over all points of injection of the particles, i.e. on the circumference.

The number of the particles injected to the accelerating gas jet per time unit is determined by the following relationship:

$$N = \frac{6M}{\pi d^3\rho},$$

where M is the mass powder consumption; and ρ is the material density. By dividing the obtained number by the quantity of the considered paths, we obtain number N_1 of the particles entering per time unit to one path. By calculating time τ_j needed for a particle to achieve the workpiece surface in movement along the j-th path ($j = 1, 2, ..., J$, where J is the quantity of the considered paths), we can find number $N_1\tau_j$ of the particles located simultaneously in the said path, as well as their co-ordinates. Then, by selecting the grid in the cylindrical co-ordinate system, we determine the number of the particles in each cell of the selected grid, corresponding to a given path. And, finally, by dividing this number by the volume of the cylindrical cell and summing up the corresponding results for all of the paths considered, we find the unknown value of $n(r, z)$.

Figure 3 shows spatial distribution of the concentration of SiO_2 particles ($d = 20$ μm) injected to the accelerating gas flow, as shown in Figure 2 ($R_0 = Z_0 = 5$ mm) at $v_0 = 9$ m / s and $\vartheta_m = 5°$, calculated by this method. Argon was used as such a gas, the submerged jet of which flows out from the cylindrical nozzle with a diameter of 6 mm at a gas flow rate of $G = 47$ l / min (these values of the parameters were selected proceeding from a condition that particles with a zero angle of deviation from the main injection direction at each point of the annular slot intersect the axis of the laser beam in focal plane $z = F$). The calculation data shown in Figure 3 correspond to a mass powder consumption of $M = 1$ kg / h. They were obtained at $J = 100$ (further increase in the quantity of the paths considered does not lead to a marked improvement of the calculation accuracy). It should be noted that within the framework of the used model of a slightly dusted gas jet the change in consumption of the spray material can be reduced simply to a proportional change of $n(r, z)$.

The effect of powder consumption on integral and distributed characteristics of the focused laser beam interacting with the whole of the spray particles under the considered conditions is shown in Figures 4–6. In particular, Figure 4 shows attenuation of the Gaussian beam ($Q^0 = 5$ kW, $F = 6$ cm, $r_F = 0.5$ mm) due to its absorption by the spray material particles. As follows from the Figure, the total power of laser radiation, $Q(z)$, calculated by substituting solution of equation (1) to equations (2) and (5), begins to markedly de-

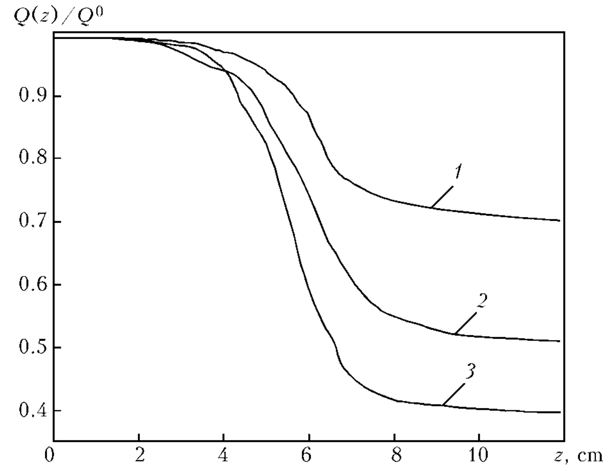


Figure 4. Effect of powder consumption M on attenuation of the beam due to absorption of laser radiation by spray particles: *1* — M = 0.5; *2* — 1.0; *3* — 1.5 kg / h

crease at z > 3 cm, its decreasing rate growing with powder consumption. As a result, at a selected spraying distance of L = 12 cm, the power of the radiation reaching the workpiece surface greatly depends upon M and can be more than 2 times lower than Q^0. This should be taken into account not only in modelling of heating of the particles under conditions of laser spraying of coatings, but also in estimation of the thermal effect of laser radiation on the workpiece surface.

Another important factor is scatter of the laser beam propagating in a dusted environment, along with its absorption by the spray particles. For example, scatter of the focused Gaussian beam with parameters F = 6 cm and r_F > 0.5 mm by the whole of the considered particles at z > 3 cm leads to a substantial

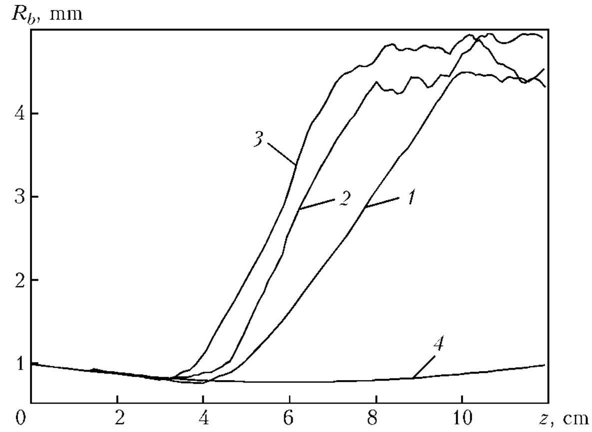
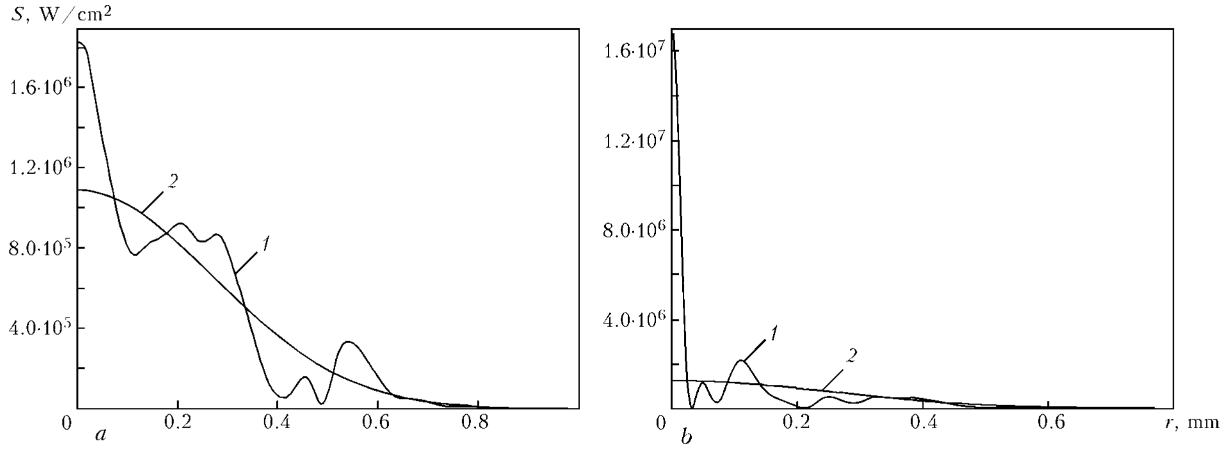


Figure 5. Variation in effective radius of the laser beam, R_b, scattered by the spray material particles (SiO_2) with d = 20 μm: *1*–*3* — see Figure 4; *4* — M = 0 (initial beam radius)

increase in effective beam radius $R_b(z)$ defined as a radius of the circumference within which 99 % of the laser radiation power is concentrated, compared with the corresponding radius of the initial beam (see Figure 5). Moreover, scatter of laser radiation together with its absorption by the spray material particles causes substantial redistribution of the radiation intensity (see Figure 6). In particular, the resulting power density on the beam axis at $z = F$ can be more than 10 times in excess of the maximal value of S for the initial laser beam (Figure 6, b). This circumstance should be taken into account in analysis of the process of heating of a powder under the conditions of laser spraying of coatings.

Comparative numeric analysis of heating of one particle in the initial laser beam (F = 6 cm, r_F =



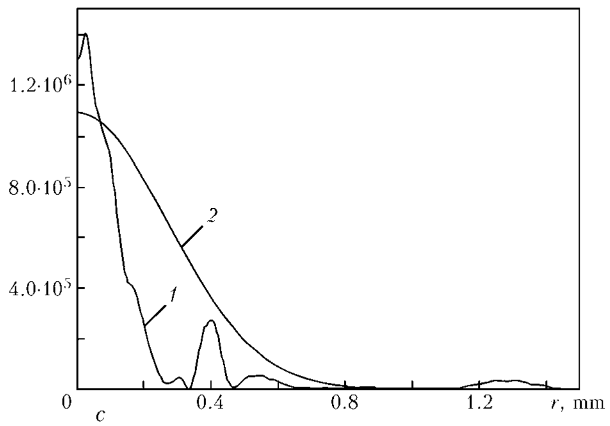


Figure 6. Redistribution of radiation intensity S across the laser beam section (Q^0 = 5 kW) at z = 3 (a), 6 (b) and 9 (c) cm due to its interaction with spray particles (SiO_2, d = 20 μm): *1* — M = 1; *2* — 0 kg / h (initial Gaussian beam)

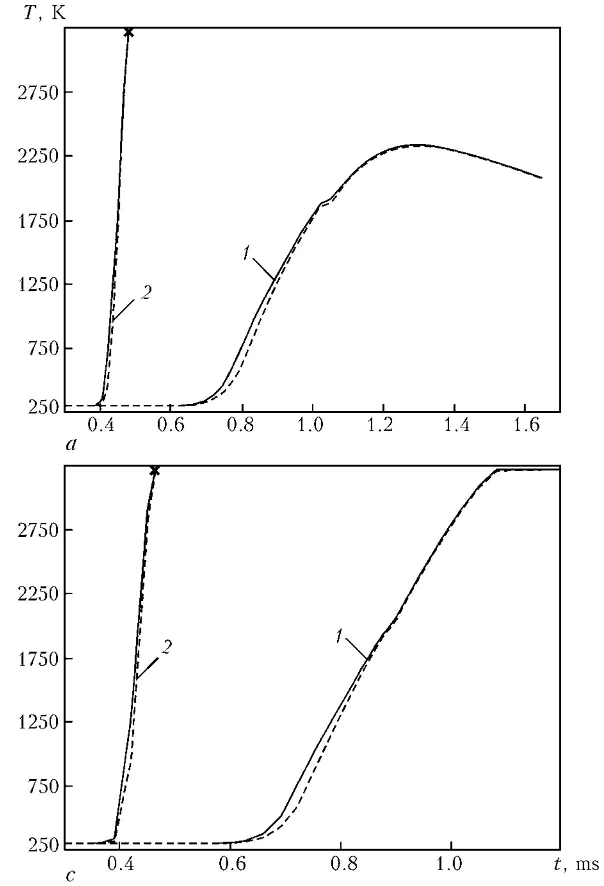


Figure 7. Time variation of temperature of a sample particle heated in the initial laser beam (curves *1*) and laser beam (curves *2*) interacting with the rest of the particles: *a* — Q^0 = 1; *b* — 3; *c* — 5 kW; solid curves — temperature at the centre of the particles; dotted curves — temperature on the surface of the particles; × — thermal explosion of a particle

= 0.5 mm) was conducted to estimate the effect of the considered redistribution of the intensity of laser radiation on the thermal state of SiO_2 particles (d = = 20 μm) under the laser spraying conditions, i.e. at M = 0, and allowing for absorption and scatter of the laser beam by the whole of the spray particle at M = = 1 kg / h. A particle which is injected into the treatment zone normal to axis 0z and intersects it in plane $z = F$ (see Figure 2) was selected as a sample particle. Time dependencies of the temperature at the centre of such a particle and temperature on its surface are shown in Figure 7.

As might be expected, the maximal temperature of the particle achieved in heating by the initial laser beam grows with increase in the laser beam power (curves *1*, Figure 7). Allowing for interaction of the beam with the rest of the particles, the sample particle is heated to a boiling temperature much quicker. This is accompanied by a thermal explosion of the particle [6, 7], which occurs at $z \approx 4$ cm even in the case of low values of Q^0 (curves *2*, Figure 7). This is caused by increase in the intensity of laser radiation near the beam axis as a result of its scatter in the dusted environment (see Figure 6). Therefore, by varying consumption and conditions of injection of a powder into the treatment zone, i.e. varying $n(r, z)$ and, hence, spatial distribution of the intensity of laser radiation interacting with the spray particles, it is possible to locally control their heating, melting and splitting resulting from the thermal explosion. This will enable the efficiency of the process considered to be raised not through increasing an expensive power of laser radiation, but through its targeted redistribution and optimal utilisation for heating of the spray particles.

In general, the results of mathematical modelling of the process of laser spraying of ceramic coatings, performed in this study, are indicative of the necessity of allowance for absorption and scatter of laser radiation by a spray material in analysis of the thermal state of particles that form the coating.

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DEVELOPMENT AND APPLICATION OF BRAZED LATTICE AND HONEYCOMB STRUCTURES IN AIRCRAFT ENGINEERING (RETROSPECTIVE REVIEW)

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The paper presents the background of emergence, development and application of lattice and honeycomb structures of flying vehicles. An abrupt improvement of the quality of structural alloys and aircraft and missile manufacturing technologies occurred in the second half of the XX century. In view of the increasing sophistication of the structures and difficulties of applying other technologies, brazing is becoming the most promising joining process. Brazing filler metals and technologies have been developed, which ensured high performance of aircraft and space vehicles.

Keywords: brazing technology, aircraft engineering, rocket production, lattice wing, honeycomb structure, structural materials, history of engineering

History of science and engineering knows many examples when separate scientific ideas find their practical application in many years after their development and publication. Development, creation and manufacturing of lattice and honeycomb structures employed for production of aircrafts, helicopters, rockets, ships, railcars, automobiles, buildings and others may serve as such example.

Lattice structures are aerodynamic poly-plane surfaces with considerable advantages as compared to single-plane ones. They are very promising for using in new types of aircrafts. Depending on the sizes and purpose they can be produced both by welding and by brazing, the latter being predominant.

Honeycomb structures (panels) are supporting structures of small medium density (in some cases less than $1\cdot10^3$ kg / m^3) having, as a rule, casing and filler material of different shape. In most cases they are joined with brazing because extended closed cavities do not allow introducing a welding tool inside.

A lattice wing of the aircraft is a space system composed of a big number of shaped or flat planes connected with each other by side plates. There are two basic types of lattice wings — framework (with planes perpendicular to the side plates and parallel to each other, Figure 1, *a*) and honeycomb with diagonal and parallel set of planes. However, wing with square and hexagonal honeycombs when a diagonal set of planes composes with side plates an angle of 45° (Figure 1, *b*, *c*).

Sufficient number of works is devoted to the development and design of structures and operation of aircrafts with lattice and honeycomb units, but only a few journal publications deal with peculiarities of the production technology using brazing. The authors of [1] give a detailed description of technology for production of aviation structures of titanium alloys, while a special chapter is devoted to the welding technology, however, brazing is not mentioned.

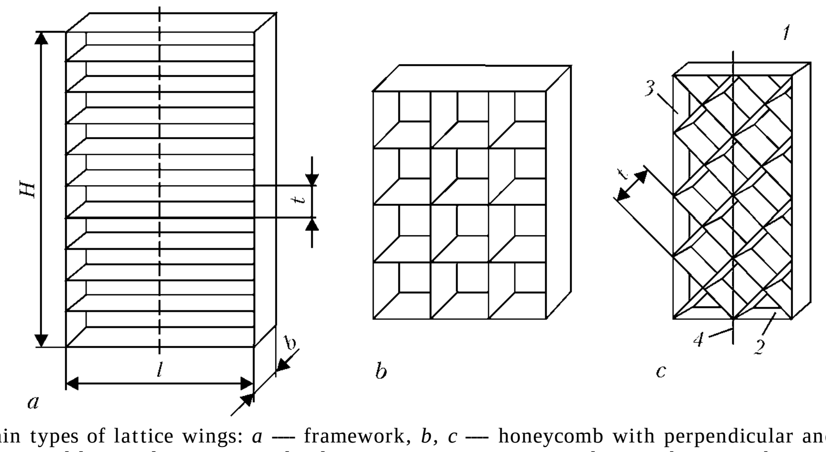

Figure 1. Scheme of main types of lattice wings: *a* — framework, *b*, *c* — honeycomb with perpendicular and diagonal set of planes, respectively: *1*, *2* — upper and lower planes; *3* — side plate; *4* — wing axis; *H* — distance between the upper and lower plane; *l* — distance between the end side plates of lattice wing; *b* — distance between the plane profile points mostly remote from each other (wing chord); *t* — distance between the corresponding points of two neighboring planes

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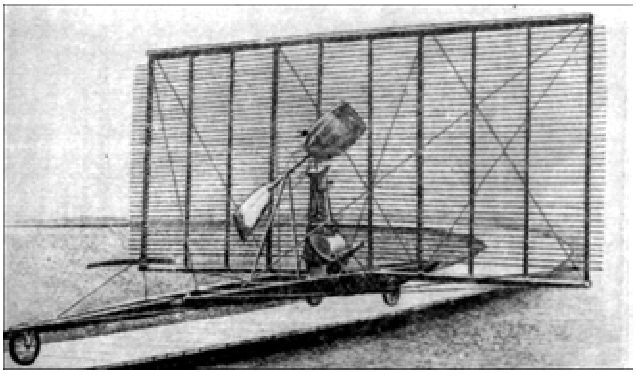

Figure 2. Aircraft of H. Phillips

The aim of this work is to give a historical analysis of the development of lattice and honeycomb aviation and rocket structures produced by brazing with presentation of new structural materials and materials for brazing. In view of continuously complicating operational conditions and increasing requirements to heat resistance, strength and other characteristics of the material it becomes especially important to estimate possibilities and to determine perspective for applying brazed aviation and rocket-space structures. Welding of complex-alloyed steels, titanium and aluminium alloys is complicated, therefore brazing remains the main method for joining complex structures of difficult-to-weld alloys.

The considered structures found their application as early as in 1883 in the flying machine of the English engineer H. Phillips. The plane of this flying machine was made in a form of a vertical lattice with a great number of light wooden planes joint by vertical bars and cross-brasses, total area of this lattice being 13 m^2 (Figure 2). The same year H. Maxim constructed a flying machine of multi-plane type (Figure 3).

S.A. Chaplygin wrote in 1911 the article «Theory of the Lattice Wing» [2] that was published in 1914. Early last century N.E. Zhukovsky together with his disciples initiated a series of theoretical and experimental studies on lattice wings for aeronautics [3]. In the 1920s the Commission of the Supreme Council of National Economy of the USSR headed by N.E. Zhukovsky designed a heavy aircraft by the triplane scheme with a tall wing cell and biplane fins. This aircraft (it flew but was never commercially produced) became history with the name KOMTA.

With development of aircraft engineering and increase of flying speed the main attention was attached to application of the monoplane wings. It was only in the end of 1940s when the works on aerodynamics of subsonic lattice folding wings with a possibility to use them for gliding torpedos were continued. The results of these works underlay further studies on the lattice wings, which allowed since 1955 creating the whole comprehensive scientific direction headed by S.M. Belotserkovsky [4, 5]. This scientific direction included a wide range of theoretical and experimental studies on aerodynamics, design, strength, weight and production technology of the lattice wings. This problem was also explored in TsAGI and the N.E. Zhukovsky VVIA. Works carried out in a close cooperation with a number of research institutes and design bureaus permitted developing theoretical methods for calculation of aerodynamic characteristics of lattice wings for a wide range of speeds from sonic to supersonic [5]. Great achievements in this area were attained by scientists S.M. Belotserkovsky, V.S. Demidov, L.A. Odnovol, Yu.Z. Safin, V.A. Shytov, P.N. Kravchenko, B.I. Ulianov and others.

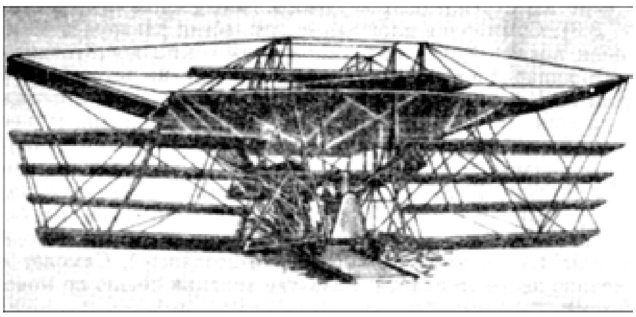

Figure 3. Aircraft of H. Maxim

Lattice wings in their modern design are a new type of supporting stabilizing and navigating surfaces with a number of advantages over conventional monoplane wings: planes are shaped so that allow obtaining a smooth floor to incidence angles of 40–50°; at supersonic speeds the lattice planes may be located sufficiently close to each other allowing a large total area of the lattice wing with considerable increase of the ascensional power [5–7].

Analysis of strength and stiffness properties of polyplane systems carried out by A.I. Tyulenev with his colleagues allowed determining the main directions in selection of the rational design of the lattice wing [8]. They also proposed new construction diagrams of lattice wings with a variable step by the wingspread, with an oblique cell, cylindrical, with hollow planes and others (Figure 4). The main target for rational development of the lattice plane was a need to provide necessary strength and minimal weight in conditions of aerodynamic heating with high temperature braking acquisition. The works were reduced to a search for a comprehensive variant of constructive forms combining properties of the selected structural materials and rational technology for producing a lattice wing. The results of the performed studies allowed detecting peculiarities and advantages of the lattice wings, developing methods of their practical design and manufacturing when the use of conventional monoplane wings is complicated in designing of a number of objects [5, 9–11].

First specimens of lattice wings were produced by riveting, welding, gravity die casting. There are examples when steel lattice wings were milled out from one-piece forgings, which was extremely labor-consuming. In this case loss of metal for chips was up to 90 % of the initial blank. Appearance in the middle of the last century of the honeycomb (truss) scheme of lattice wings, which was more complicated than the frame structure necessitated the research and development of a rational method of production with elaboration of a standard technological process on its basis allowing to produce the mentioned articles with the highest technical and economical effect [5, 6, 11, 12]. A selection of structural materials for production of the lattice wings is very important.

Welding and brazing (together with riveting) have been the most important technological processes for joining elements of aviation structures for more than 90 years [13]. Attitude to different methods of welding during the first half of the last century changed depending on the materials used in the aircraft engineering and development of the welding equipment [14]. At the same time application of brazing by acetylene-oxygen flame grew in volume. Brazing with brass filler alloys competed with arc and gas welding of steel structures, while brazing of structures and repair of engines of aluminium alloys were carried out with the low-temperature aluminium filler alloys. Brazing for repair was most widely used during the Second World War. Important theoretical and experimental results for different operational conditions of the wings and brazing technology for their production were received in the after-war period by the Prof. V.P. Frolov [15–18].

Lattice wing in the modern aircraft engineering are produced by different methods using different technological processes. Along with the cold treatment methods (riveting, glueing, machining and electric-erosion treatment) hot treatment methods are widely used, such as welding, brazing, casting and blanking. Besides, it is possible to use a combination of different technological processes [5, 9–12, 19–24]. It is noteworthy that since the middle of the last century a close correlation has been established between creation of new specimens of aircraft engineering, rocket complexes, development of special structural materials and welding technologies.

In the 1960s metallurgical plants on processing of non-ferrous metals and alloys of the Ministry of Aviation Industry of the USSR (the V.I. Lenin Kujbyshev Metallurgical Works (KMW), Verkhnyaya Salda Metallurgical Association, Belaya Kalitva Metallurgical Works, Stupino Metallurgical Integrated Works and Kamensk-Uralsk Metallurgical Works) launched into operation a number of domestic vertical hydraulic presses with a power from 6 to 74 ths tf, the world most powerful hydraulic press with a power of 75 ths tf being first launched at the V.I. Lenin KMW.

This equipment allowed producing different lattice and honeycomb structures of aluminium and titanium alloys by the method of hot pressing. High accuracy in production of such structures with minimal final machining (but with wall thickness of more than 2 mm) opened wide opportunities for introduction of lattice and honeycomb structures into machine-building, construction and ship-building. However, thickness of planes and honeycombs in similar structures of airspace engineering is less than 1 mm, so it is practically impossible to produce them by the hot-pressing method. In this situation the technology of

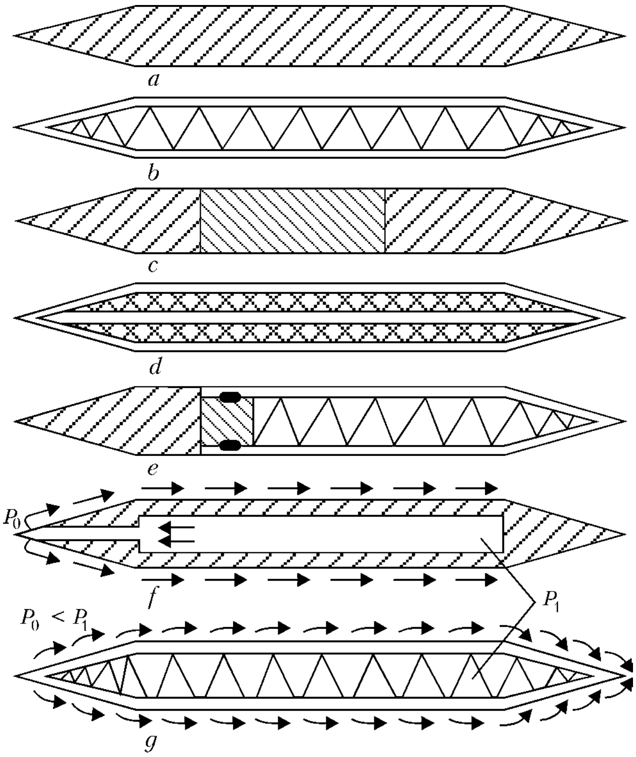

Figure 4. Design variants of lattice wing planes: *a* — conventional with solid section; *b* — hollow; *c* — composite; *d* — multilayer; *e* — combined; *f*, *g* — cooled, where P_1, P_0 — pressure of cooling medium and environment, respectively

brazing and adhesion of the components of lattice and honeycomb structures came to the fore.

Alloys on the basis of aluminium, magnesium, iron, titanium, nickel, beryllium, vanadium, tungsten, niobium, molybdenum, tantalum, chromium are used for production of lattice wings by brazing. Such alloys include: on Al-base — AMg6, AMg2, AMg, D16AT, ATsMU; on Fe-base — 30KhSA, 12Kh18N9T, 12Kh18N10T, 08Kh25N16G7AR (EI 835), 10Kh16R4BA (EP 56, EP 258); on Ti-base — OT4, VT6; on Nb-base — VN2; on Mo-base — VM1; on Ta- and W-base — VV1, and others [5, 9, 10].

The standard brazing filler alloys PSr40, PSr37.5, POS 61, as well as comparatively new grades of fillers applied in the industry, are used for brazing of the above materials, namely for aluminium alloys — Nos. 48 (Zn–7Al–3.9Cu–0.5Co), 34A (Al–28Cu–6Si), 36A (Al–20Cu–20Zn–3.5Si); for titanium alloys — Ag–17Cu, Ag–20Ti–15V, Ag–20Pd–5Mn type; for refractory alloys — Hf–20Ti–16V, Zr–25Nb, Zr–20Nb–3Mo, Hf–20Ti–6Mo; for heat-resistant steels and nickel alloys — Cu–20Mn–19Ni, G70NKh (Mn–23Ni–5Cr–2Fe–0.8Si–0.3C), VPr1 (Cu–30Ni–2Si–1.5Fe–0.3B), PZhK-35 (Ni–35.5Mn–18.5Cr–9Co–1.5Fe–0.8Si–0.1B), 6MA (Ni–23Mo–15Cr–7Si–0.4B), No.3 (28Mn–28Fe–14Ni–0.1Si–0.1B). Filler alloys 6MA and No.3 are especially developed for brazing of lattice wings [5].

Flow chart of the standard technological process for production of solid-brazed lattice wings is presented in Figure 5. Technological process, basic conditions and parameters of brazing of structural mate-

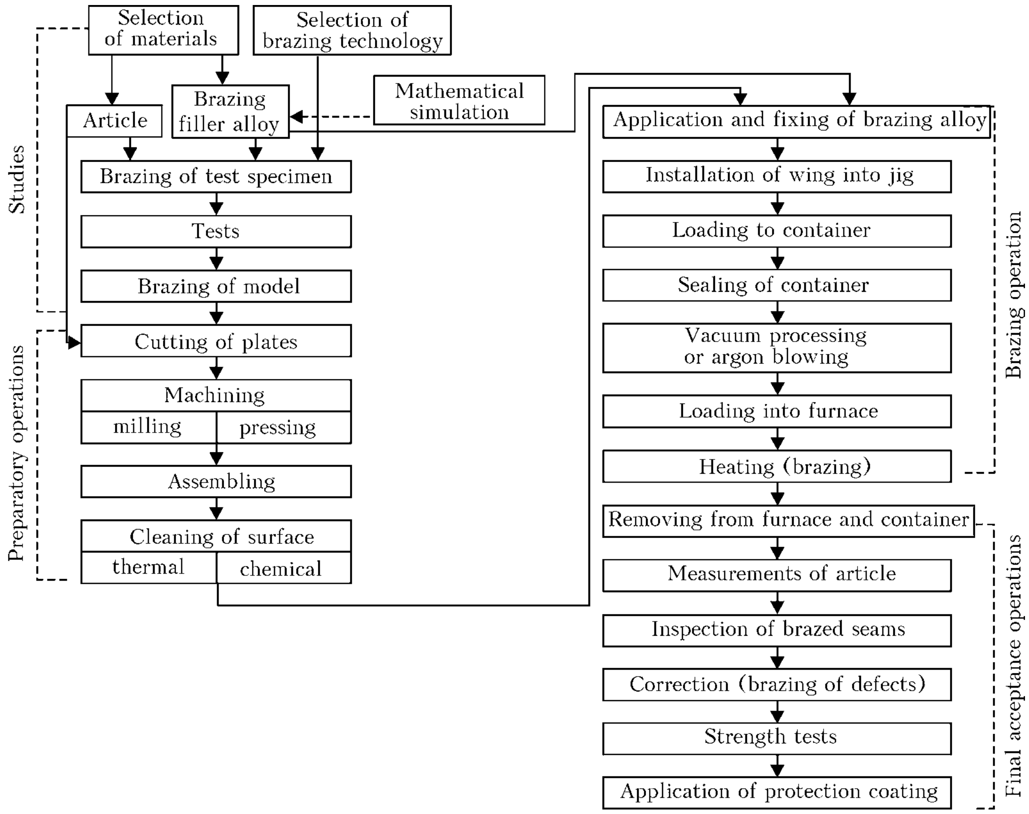

Figure 5. Flow chart of standard technological process for production of solid-brazed lattice wings

rials widely used in the aircraft engineering are presented in the works [5, 25–28].

When performing the works on creation of the missile RVV-AE (air-to-air, air-to-ground) the E.O. Paton Electric Welding Institute was assigned in 1984 to create an optimal technology for production of the lattice rudders of the missile. This work headed by Prof. V.F. Khorunov was done together with the «Artyom» Production Association and Scientific and Production Association «Vympel». New design of the rudder, filler alloys, brazing technology and equipment were proposed for the shortest time period. This work resulted in creation of highly productive robotic technological line [29–33]. A light brazed structure was proposed instead of a heavy head part of the rudder produced by milling from a massive billet. Lock assembling of lattices was replaced by a robotic assembling of special profiles («zig») without side flanging and with application of special brazing paste [30, 31]. High-productive carousel-type vacuum furnace [32] with five articles being loaded simultaneously with load-unload periodicity of 30 min was created for brazing of blanks. Brazing was performed at the temperature 1100–1120 °C, which allowed preserving mechanical properties of the parent metal (as against brazing at 1180–1200 °C using brazing alloy VPr10).

Development of stresses and strains in the lattice structure in the non-uniform temperature field [34] was analyzed to justify the choice of the heating conditions, the use of which allowed producing articles of high quality and accuracy.

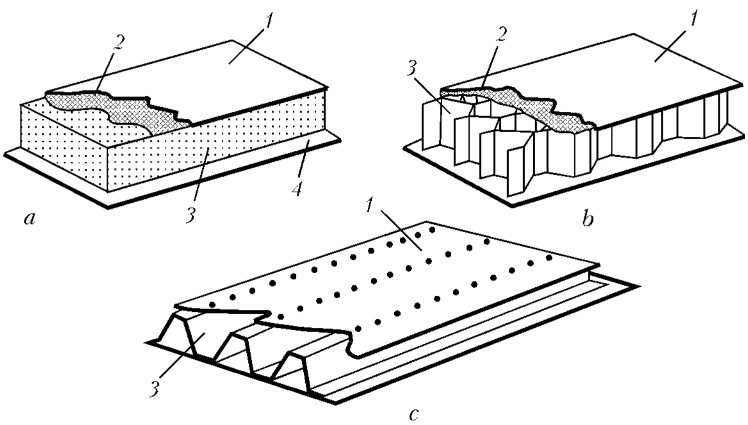

Figure 6. Types of laminar panels with solid (*a*), cell (*b*) and corrugated (*c*) fillers: *1, 4* — first and second casing, respectively; *2* — adhesive interlayer or brazing alloy; *3* — filler

Bench and full-scale trials showed a considerable advantage of the rudders produced by the PWI technology. Reactance of the rudder decreased, thus improving by 10 % tactical and technical characteristics of the missile.

Components and units of plate material joined using adhesives, by welding and brazing with profiles of different shapes for rigidity are widely used in the structures of modern machines. In recent years such elements are often replaced by laminar structures (Figure 6). They are especially widely used in aircraft engineering [27, 28]. Perspective of such structures is in the first place related to their high relative rigidity and strength. Honeycomb structures are one of the types of laminar structures being a combination of casings and honeycomb filler located between them [26, 27]. Total rigidity of honeycomb structures many times exceeds rigidity of the plates as its components. This allows designing these structures without a supporting set of stringers even with an increased distance between ribs and frames. Shapes of cells for fillers may be square, rhombic, sinusoidal, hexagonal and biased hexagonal (Figure 7).

Structures with honeycomb fillers are widely used in modern aircraft engineering for production of wings, panels, flaps, rudders, rear end of the center wing, brake flaps, floor plates and tail compartments, helicopter blades, fuselage panels and other structures. By using honeycomb fillers with different volume weights, i.e. with different sizes and shape of the cell, as well as with different materials and foil thickness, it become possible to considerably increase strength of the structure (Figure 8) [27, 28].

Honeycomb structures have a number of advantages over structures made of casings supported by stringers and ribs, namely high specific strength, rigidity and stability under longitudinal compression, good fatigue characteristics, a decreased number of components in the article, good properties of surface, decreased labor consumption of assembling operations and weight of the structure, much better heat and soundproof properties. For example, mass ratio of the supersonic US bomber Hussper B-58 where honeycomb structures are used (Figure 9), is less by 16.5 % than that of the aircrafts RR-66C, RB-45C, B-57E, this index being 25.1–25.9 % for them [25]. The North-American Company used brazed panels with honeycomb fillers for a number of units and accessories for production of the intercontinental bomber XB-70 «Valkyrie». Honeycomb panels occupy the area of more than 1800 m^2 or 50 % of the total aircraft surface (Figure 10). These structures are rather loaded and exposed to the effect of temperatures of about 330–350 °C. Similar structure was used at the S.A. Lavochkin Scientific and Technical Association for creation of the Soviet intercontinental bomber «Burya» [35].

Application of honeycomb structures for brake flaps in the aircraft B-86 allowed decreasing their weight by 30 %. Their use in the blade compartments of the helicopters Boeing, Sikorsky S-61, S-5, Vertol-107 allowed increasing the operational resource of the blades from 500–600 to 1000–1500 h. Components of the structure have been widely used in the aircrafts of the series Boeing, DC, Conver, Phantom, Lockheed, Concord, Taon, Vickers, airbuses of the Airbus company, domestic aircrafts of An series, Russian aircrafts of Tu, Il, Yak, Su, Be series, helicopters of the Mi, Boeing, Sikorsky, Vertol series and in other aviation equipment.

Theoretical developments of the Soviet scientists and practical application of lattice and honeycomb structures in the rocket and aircraft engineering in the second half of the last century was one of the factors specifying high tactic and technical qualities of arms materiel exceeding similar indices of the Western countries. Soviet missiles and aviation equipment served as a restraining factor and balanced the armors of the Soviet and American armies [36].

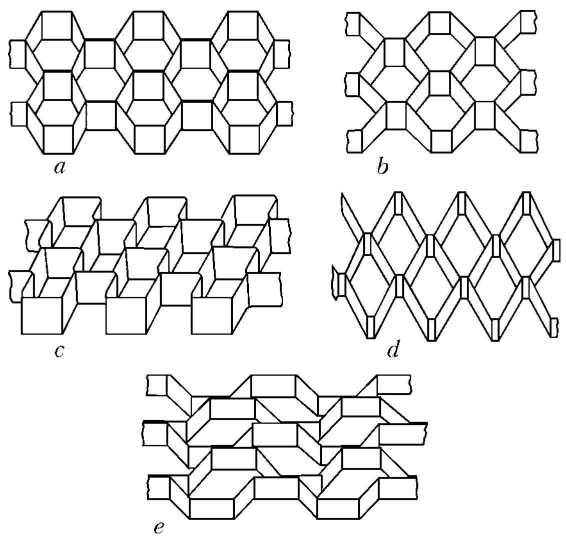

Figure 7. Shapes of cells for honeycomb fillers: *a* — hexagonal; *b* — rhombic; *c* — square; *d* — sinusoidal; *e* — biased hexagonal

Missiles of different purposes with lattice wings — polyplane panels developed at the Design Bureau of the former Soviet Union were considerably more superior in their tactical and technical characteristics than similar missiles of the Western countries. As examples of good design solutions one can mention cruising missile carrier «Strela» (OKB-52, now NPO Mashinostroenie, Chief Designer — V.N. Chelomej), a system of tactic and operational-tactic missiles of S-300 type (NPO Antej, Chief Designer — G.A. Efremov), a missile system S-400 improved at the Design Bureau Almaz (Chief Designer — A.A. Lemansky) and others [23]. There is no shock stall at any incidence angle and break-offs in lattice rudders of the Soviet missiles, thus providing a high degree of destruction, which has not yet been achieved by missile systems of other countries. The use of such wings in the design of emergency recovery of astronauts, which is not yet in use in the US space vehicles is worth of special attention. The same situation is in the aviation. For example, MiG-23 hits targets at a distance from 50 m up to 25 km. These fighter jets were successfully countervailing the American most recent F-15 and F-16 in 1982 in Lebanon [35].

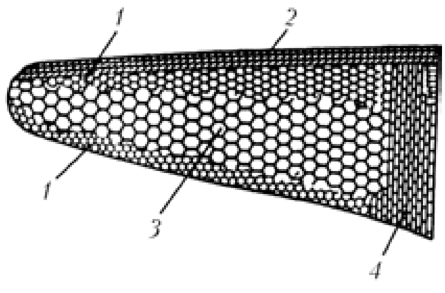

Figure 8. Arrangement diagram of honeycomb fillers with different cell sizes: *1*, *3* — small and large cell sizes, respectively; *2*, *4* — cells stretched in the longitudinal and transversal directions, respectively

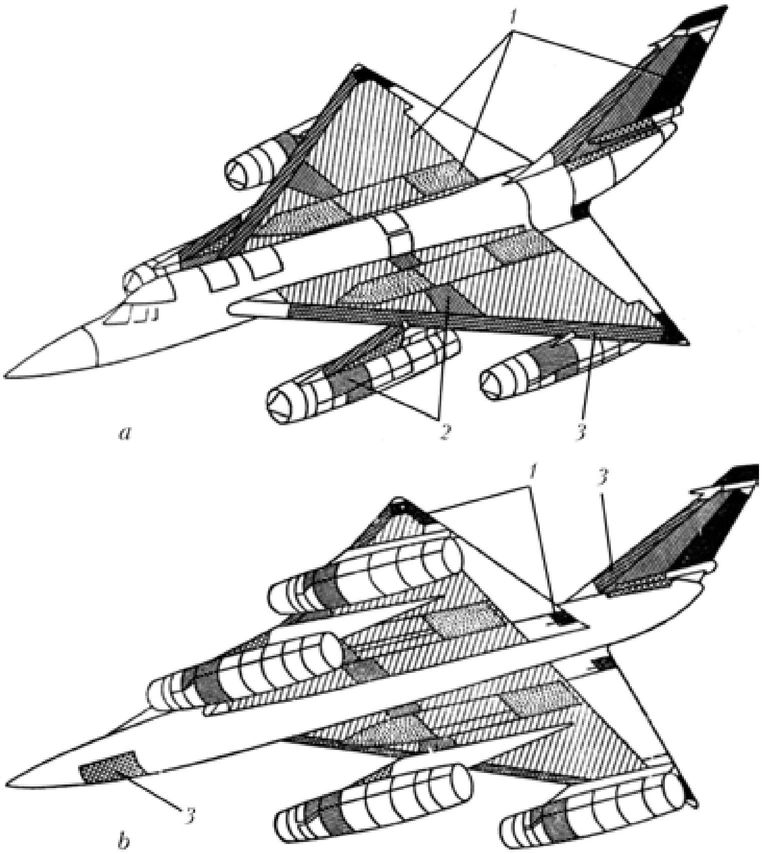

Figure 9. Application of honeycomb panels in the Hussper B-58 structures: *a*, *b* — top and bottom view, respectively; *1* — duralumin casings and honeycombs of glasscloth; *2* — duralumin casings and honeycombs; *3* — wing noses and rudder with duralumin honeycombs, fin noses and dismountable panels with honeycombs of glasscloth

The NASA Research Center in Langley developed for the Lockheed company (USA) a technology for production of center wing bearing frame of titanium alloys (Ti–6Al–4V) uniting welding and brazing. Z-shaped ribs 1.2 mm thick are welded to a panel 1.8 mm thick by resistance spot welding. Narrow strips of aluminium brazing alloy are placed into the clearance between the plate and the ribs (thickness of razor blade — up to 0.1 mm). Flux-free brazing is carried out in vacuum furnaces during 10 min at the temperature of 710±5 °C [37]. Brazing of structures of titanium and stainless alloys accounts for a considerable volume of operations in the Russian aircraft engineering. Brazing is mainly performed in stationary and assembling chambers in the inert gases with induction heating and self-fluxing brazing alloys. Ribbed panels of center wing of the fighter jet Su-30 is a typical specimen of the newest aviation structure [17]. Corporation IRKUT (RF) is one of the companies involved into large-scale works on improvement of existing and creation of new high effective technologies. Highly concentrated power sources (electron, laser, ionic beams), as well as high frequency current, radiation and ionizing radiation are employed by the Corporation for welding and brazing. Brazing is carried out in vacuum, in different shielding atmospheres, with self-fluxing brazes and others [17, 37].

A concept of advanced development of manufacturing technology should underlay creation of new competitive equipment. In compliance with this principle the following sequence may be optimal: creation of scientific and technical fundamentals, formation of a design-technological appearance of the article, development of particular technologies, preparation of manufacturing facilities and production of the article with predicted quality [38].

A problem of production of the whole-welded (brazed) aluminium aircraft has not yet been solved [39, 40]. Bearing structures of commercially produced aircrafts are riveted structures in the world civil aircraft engineering. Main efforts of specialists in different areas are focused on development of high strength and plastic aluminium alloys preserving their properties in welding and brazing. Specialists of NIAT, PWI, the N.E. Bauman MGTU, K.E. Tsialkovsky MATI and others are working jointly on creation of technologies and materials providing reliable operation of aluminium aircrafts. Ribbed panels and frames of new alloys of Al–Mg–Sc–Zr–Ti (type 1421) [40] are promising for whole-welded (brazed) fuselages and planes. Due to reliable joining technology it is possible to choose sizes of ribs and thickness of panels in every particular case in compliance with the designed parameters, which will make the aircrafts lighter. The specialists predict that in the nearest future aviation will switch to the liquid hydrogen fuel and cryogenic fuel tanks in the new generation of aircrafts are cylindrical containers made of wafer or ribbed panels with body thickness of 1.5–3.0 mm and thickness of butts in the welding zone of 2–10 mm [41]. In this case the use of brazed honeycomb structures may be economically efficient.

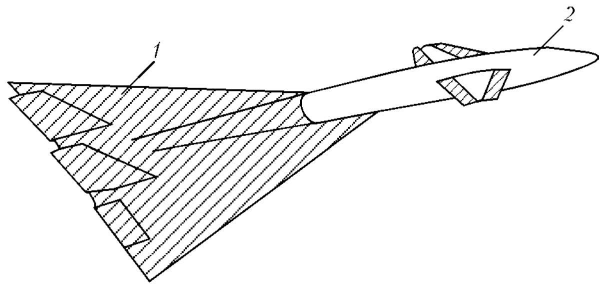

Figure 10. Application of brazed panels (*2*) with honeycomb filler (*1*) in the XB-70 «Valkyrie» design

CONCLUSIONS

1. Lattice and honeycomb structures were recognized in the early XX century as rational and effective components of the aircraft engineering being strong and relatively light. Scientific fundamentals for design of such structures were created by a number of scientists including N.E. Zhukovsky, S.A. Chaplygin, S.M. Belotserkovsky, A.I. Tyulenev and others. During the

first half of the XX century aviation lattice and honeycomb structures of different types were produced mostly by riveting and adhesives.

2. Appearance of supersonic aviation and use of high-strength steels, aluminium and titanium alloys as structural materials laid the foundation for using new technologies for their production (casting, forming, mechanical milling, electrochemical etching etc.). Limited use of welding is attributed to poor weldability of the most of aviation materials, complicated stress and strain control, complexity of structures.

3. Brazing is most promising technology for production of aviation structures with lattice and honeycomb elements. The E.O. Paton Electric Welding Institute, VIAM, NIAT, N.E. Bauman MGTU and others are developing brazing filler alloys and brazing technologies. Technology for brazing of structures of alloys on the basis of aluminium, magnesium, iron, titanium, nickel, beryllium, vanadium, tungsten, niobium, molybdenum, tantalum, chromium is created. It allows aviation designers to increase a range of the used materials, to assign parameters of the structure elements for every particular case and in compliance with calculations. The known tin and silver solders, as well as brazing filler alloys on the basis of Al–Cu–Si, Zr–Nb, Mn–Cr–Fe and other systems, are employed by a number of technologies.

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APPLICATION OF ARC SPOT WELDING IN FABRICATION OF CAR BODIES

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Application of arc spot welding for manufacture of side walls of car bodies for diesel trains, and, in particular, joining stiffeners to sheathing in the cars are considered. Optimum welding conditions for spot welds have been selected, quality of overlap welded joints has been assessed, and strength tests have been conducted.

Keywords: arc spot welding, programmer, body structures, diameter and penetration depth, breaking load, defects, gap, guaranteed penetration, optimum modes

Overlap joints made by arc welding through earlier bored-out holes in the upper element are widely used in welded structures of car bodies for electric and diesel trains. To reduce the labour consumption by eliminating the operations of marking out, drilling (piercing) holes, reducing the transportation operations and eventually reducing the amount of deposited metal, specialists of OJSC «HC Luganskteplovoz» and of the E.O. Paton Electric Welding Institute developed a technology and designed a specialized unit for gas-shielded arc spot welding (ASW) of Z-shaped stiffeners to sheathing of side walls of electric and diesel trains (Figure 1). A feature of ASW process is its programming, in particular, performance of welding cycle in the following three stages: «welding process excitation», «welding» (burning-through of the welded-on part and partial melting of the lower part), and «crater welding up in the formed spot weld». Each of the stages is performed in modes differing by the welding current, arc voltage, welding wire feed rate and welding time (Table 1).

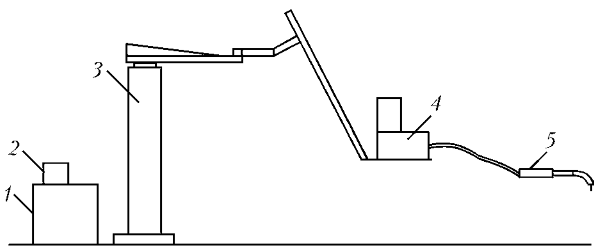

Figure 1. Schematic of unit for arc spot welding with upper element penetration: *1* — power source; *2* — power module of semi-automatic machine; *3* — rotating console; *4* — feed mechanism with electronic system of ASW programming and control; *5* — hose with holder

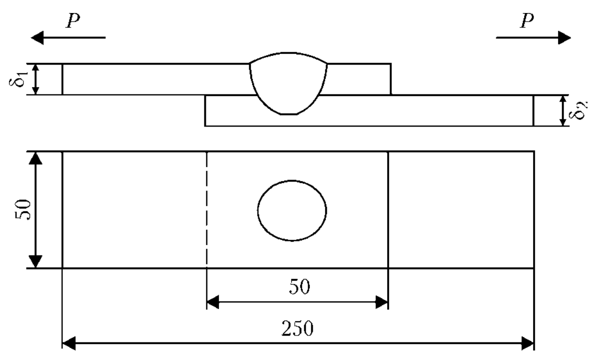

Figure 2. Schematic of test sample

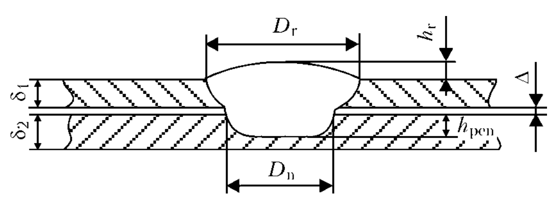

Figure 3. Schematic of measurements in a tested sample: δ_1, δ_2 — thickness of the upper and lower sheets, respectively; D_n — nugget diameter; D_r — reinforcement diameter; h_{pen} — penetration depth; h_r — reinforcement height; Δ — gap

One of the main issues related to application of ASW of overlap joints, is the compliance of the strength of such joints to the specified requirements, and producing spot welds with the required guaranteed dimensions at a possible gap between the parts being joined. Determination of the quality and dimensions of spot welds in overlap joints was conducted on samples, the dimensions of which are shown in Figures 2 and 3. Upper part from steel St3 (GOST 380–94) 2.5 mm thick simulated a welded-on side wall (stiffener), lower part — sheathing of a side wall from steel 10Kh13G18D (TU-14-1-4820–90) 1.5 mm thick. Prior to welding the samples were cleaned from oil and dirt in the joint locations. They were assembled so that the gap between the upper and lower plates did not exceed the minimum admissible dimensions (0.1, 0.3 and 0.5 mm). Used for this purpose were copper backing plates of 50×5 mm size of thicknesses equal to the gap size. ASW of overlap joints was performed with Sv-08Kh20N9G7T wire (GOST 2246–70) of 1.6 mm diameter in shielding gas (GOST 8050–85).

Selection of optimum modes of spot welding was conducted using a programmer by adjustment of arc voltage, setting optimum values of speed v and time of welding wire feed t. For this purpose the face panel of the programmer accommodates three pairs of buttons for welding mode control: v_1 and t_1 — process excitation; v_2 and t_2 — welding; v_3 and t_3 — crater welding up. Spot welding was performed at reverse polarity direct current in the downhand position on a copper backing. In order to select the optimum weld-

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Table 1. Modes of three stages of ASW of experimental samples

No. of sample group	Welding current, A	Arc voltage, V	Process excitation		Welding		Crater welding up	
			v_1, m / min	t_1, s	v_2, m / min	t_2, s	v_3, m / min	t_3, s
1	200–250	30–32	2.0–2.3	0.30–0.40	4.0–5.0	1.0–1.2	3.0–4.5	0.20--0.25
2	220–270		2.2–2.6	0.35–0.45	4.5–5.5	1.0–1.3	4.5–5.0	0.25--0.30
3	240–290		2.4–2.8	0.40–0.50	5.0–6.0	1.0–1.4	5.0–5.5	0.25--0.30
4	260–320		2.6–3.0	0.40–0.50	6.0–7.0	1.0–1.5	5.0–5.5	0.25--0.30
5	260–320		2.6–3.0	0.40–0.50	7.0–8.0	1.0–1.5	5.0–5.5	0.25--0.30

Table 2. Main defects in spot joints of the samples

No. of sample group	Detected defect
1	No defects
2	Same
3	Cavity (sample 5) and crack (sample 1) in weld reinforcement
4	No defects
5	Cavity (sample 5) in weld reinforcement

Table 3. Results of shear testing of samples

Gap between elements being welded, mm	Shear force, N	Type of sample fracture
0	2080–2240 / 2116	Pulling-out around cast nugget perimeter from lower plate
0.3	1820–2250 / 2070	
0.5	1720–2180 / 1923	Shear through the cast nugget

ing mode, five groups of samples, each of five samples, were welded, shielding gas flow being 6--7 l / min at all the stages (see Table 1). After welding, geometrical dimensions of spot weld section were determined (Figure 4). As is seen from Table 1, mode of sample group 4 is the most favourable welding mode.

Detection of defects (pores, cracks, etc.) in spot joints and nature of their distribution was conducted by metallographic examination (Table 2). Analysis of the obtained results (Figure 5) leads to the conclusion about absence of inadmissible defects in the welded

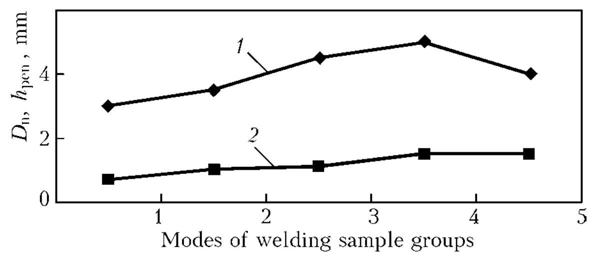

Figure 4. Influence of welding mode (see Table 1) on spot weld parameters D_n (*1*) and h_{pen} (*2*)

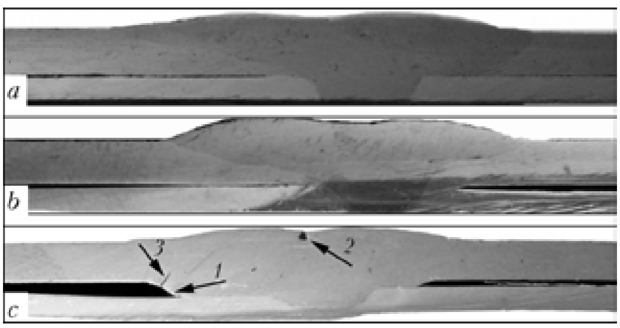

Figure 5. Macrosections of welded joints with gap of 0.1 (*a*), 0.3 (*b*) and 0.5 (*c*) mm: *1* — splashing out into gap; *2* — shrinkage cavity; *3* — crack

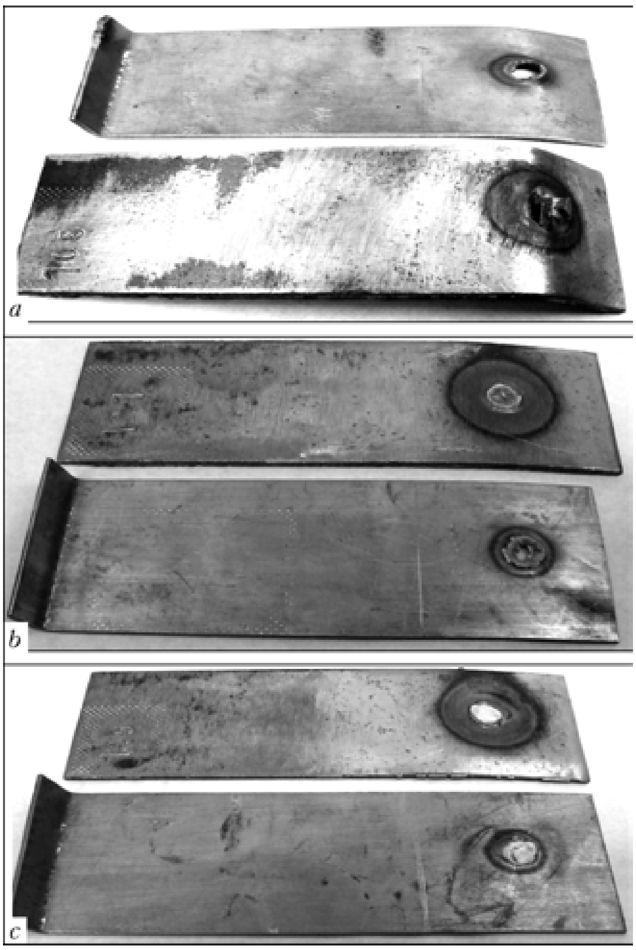

Figure 6. Appearance of samples with gap of 0.1 (*a*), 0.3 (*b*) and 0.5 (*c*) mm after testing

joints, thus confirming the correctness of selection of the spot welding modes.

When making the side walls of electric and diesel trains, the strength properties of such joints were checked on samples made in optimum mode 4 (see Table 1). Three groups of samples with a gap of 0.1, 0.3 and 0.5 mm were tested for shear in a tensile testing machine. As a result it was revealed that in most of the cases fracture runs with pulling-out around the fusion perimeter of the spot weld in the lower plate at shear force above 20,000 N (Figure 6, *a*, *b*). At smaller values fracture of the welded joint occurs without pulling-out of the base metal (Figure 6, *c*). In all the cases shear force of more than 20,000 N can be regarded as admissible for this joint type. Table 3 shows that the shear force of the welded joint somewhat decreases with increase of the gap. At more than 0.5 mm gap between the parts being welded, the molten metal can flow out into the gap. Presence of cavities on the spot weld surface is not a defect and does not influence its strength.

CONCLUSIONS

1. Developed ASW technology providing sound overlap welded joints, can be used in industry in fabrication of side walls of electric and diesel train bodies.

2. At more than 0.3 mm gap between the parts being welded, producing sound overlap joints is difficult, and a gap of more than 0.5 mm may lead to a defective welded joint because of metal splashing out.

3. At ASW of overlap joints the weld nugget diameter is equal to 5--6 mm, this being 20--30 % larger than at resistance spot welding (GOST 15878--79).

Editorial board and staff think it useful to introduce readers to the activity of Association «Electrode», which has been dealing with problems of development of electrode production in the CIS countries for 15 years by now. Below we publish a selection of articles based on papers presented at the 2nd Workshop «Arc Welding. Materials and Quality» held on 26–30 September 2005 in Magnitogorsk, Russia.

Editorial Board

15 YEARS OF ASSOCIATION «ELECTRODE» AND ANALYSIS OF STATE-OF-THE-ART IN PRODUCTION OF WELDING CONSUMABLES IN THE CIS COUNTRIES DURING 2000–2004

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Main areas of activity of Association «Electrode» in the CIS countries during the last 15 years are described. The rates of development of production of welding consumables and trends in improvement of quality and competitiveness are shown.

Keywords: arc welding, steel production, welding consumables, covered electrodes, quality problems, competitiveness

On 13–14 March 1990, a meeting of representatives of leading manufacturers of welding electrodes, developers and manufacturers of technological equipment, research and development institutions of the CIS countries took place at the Moscow Electrode Plant. The meeting concerned the address of 12 managers of leading enterprises to the Chairman of the USSR Soviet of Ministers N.I. Ryzhkov with a request to make corresponding ministries and departments ensure fulfilment of the tasks specified in the Resolution of the Soviet of Ministers as applied to development and manufacture of primary technological equipment. The existing equipment that had been in long-term operation at electrode workshops and bays was depreciated and became obsolete, which had a negative effect on the quality of produced electrodes. Despite a positive response of N.I. Ryzhkov to the above address, unfortunately, there was no follow up. In this connection, representatives of 31 enterprises and organisations, as well as of the USSR Gosplan, E.O. Paton Electric Welding Institute of the Ukr. SSR Academy of Sciences, Central R & D Institute «Prometej», Giprometiz, Production Association «Dneprometiz» and VNIIETO held an enterprising meeting in March

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1990, at which they decided that the interested manufacturers of welding electrodes would sponsor development of technological equipment, for which they suggested foundation of Association «Electrode». The Association undertook to develop production of electrodes at the modern level, provide it with raw materials, train staff, etc. Participants of the 10th All-Union Conference on Welding Consumables, which was held in September 1990 in Krasnodar, supported the idea of foundation of the Association. The first constituent assembly took place on 17–20 December 1990 in Moscow. It approved of the statute, elected the board, check-up committee, president and executive director. Necessity and timeliness of foundation of such an organisation became especially pronounced after disintegration of the USSR.

Soon after that, in February 1993, an expanded meeting, which was attended by 54 representatives of the Association and 40 invited persons, considered a number of specific proposals.

Encouraging was entry into the Association by such equipment developers as Limited Liability Company «Velma», Research and Production Company «Svapro», Open Joint Stock Company «Spetselektrod», Limited Liability Company «Roteks», Open Joint Stock Company «Tyazhpressmash», Open Joint Stock Company «NIImontazh», Limited Liability Company «Konsit», etc., which had made and were making significant contribution to building of technological equipment and development of advanced technological processes.

Despite continuing financial difficulties, the union of the leading manufacturers of welding consumables and developers of equipment allowed the problems concerning electrode production in the CIS countries to be addressed in a comprehensive way with a purpose to build equipment at a level of the leading foreign companies.

The following results were achieved during those years.

- Research and Production Company «Svapro» (now it is Limited Liability Company «Elikos») developed the electrode covering press PEG-5000, and Open Joint Stock Company «Tyazhpressmash» manufactured and delivered it to Open Joint Stock Companies OSPAZ and MEZ, Bijsk Oleum Factory, Limited Liability Company «Penza Elektrod», «Sevmash», Open Joint Stock Company «Mezhgosmetiz-Mtsensk» and Closed Joint Stock Company ELZ (St.-Petersburg).
- Company «Velma» developed dressing machines and a marker with a capacity of 1200 electrodes per minute, a number of production lines with a capacity of 500, 1000, 2000 and 2500 tons of electrodes per year (mixers, straightening-cutting machines, furnaces, screens and mills). Equipment for the press of a different capacity is optionally supplied at requests, and work is in progress on improvement of electrode manufacturing technologies. This equipment is supplied to different enterprises throughout the CIS countries.
- Company OSPAZ developed dressing machines, scrap-removing units, vacuum cleaners (bag filters) for dressing machines, semiautomatic packing lines, etc.
- Company «Roteks» developed and is manufacturing two modifications of production lines with an annual capacity of up to 3 thousand tons of electrodes.
- Open Joint Stock Company ChSPZ manufactured on its own a conveyer furnace. This made it possible to produce basic electrodes, while the production lines bought from «Velma» enabled manufacturing of small-diameter electrodes.
- Company «Spetselektrod» increased the general-purpose (along with special-purpose) basic and rutile electrode production by extending its production space. In addition, it arranged and mastered manufacturing of electric welding equipment and set up a metallurgical (melting) unit, where it produces a high-alloy wire for manufacturing of special-purpose electrodes. Equipping was done primarily due to in-house developments and partial procurements from Russia, Ukraine and abroad.
- Pilot Plant for Welding Consumables of the E.O. Paton Electric Welding Institute, using mostly in-house developments, accomplished technical re-equipment of the workshop for preparation of charge materials, lines for packing of welding electrodes into cardboard packs and polyethylene, assembled and set up the line for production of small-diameter flux-cored wire with row reeling.
- Through purchasing home-made and imported equipment, Limited Liability Company «Sychevsk Electrode Factory» fully reconstructed its electrode production.
- Closed Joint Stock Company «Electrode Plant», using its own forces, accomplished technical re-tooling of its production with the equipment built by the Association developers.

Therefore, during the time of existence of the Association, its members jointly achieved much success in technical re-equipment of their workshops and bays, development and manufacture of technological equipment, application of advanced processes and solving the problem of electrode packing. Developers continue working on making and upgrading of equipment to bring it to the level of leading foreign companies.

While considering the results of production of welding consumables in 2004, it should be noted that increase in their output depends upon the output of industrial and building products, as well as steel and rolled stock in Russia and Ukraine, which is evidenced by analysis of statistical data (Table 1).

For example, in 2004 Russian metallurgists produced 64.3 million tons of steel and 53.9 million tons of rolled stock. Compared with 2003, increase in steel production amounted to 4.7 % and that of rolled stock — to 4.8 %. Ukraine produced 38.738 million tons of steel and 33.38 million tons of rolled stock, the increase being 4.9 and 11 %, respectively.

Table 1. Production of steel / rolled stock in the CIS countries, million tons

Country	1999	2000	2001	2002	2003	2004
CIS	78.3 / 60.0	91.1 / 70.5	91.011 / 70.977	93.2 / 84.28	98.3 / 80.5	110.57 / 93.37
Russia	51.5 / 40.89	57.6 / 46.7	59.0 / 47.1	59.7 / 48.7	61.4 / 51.4	64.3 / 53.9
Ukraine	26.8 / 19.11	31.4 / 22.4	31.4 / 22.4	33.5 / 25.58	36.9 / 29.1	38.738 / 33.38
Kazakhstan	No data	No data	No data	No data	No data	5.4 / 4.0
Other countries	Same	2.1 / 1.4	1.611 / 1.477	Same	Same	2.136 / 2.096

The total output of covered welding electrodes in 2004 in the CIS countries was 290,751 tons, among them the Russian Federation enterprises produced 77 %, Ukraine produced 18 % and the rest of the CIS countries — 5 %. Compared with 2003, the total output grew by 6.3 %, including in Russia by 5.4 % and in Ukraine — by 9.3 %. The output of rutile-ilmenite electrodes was 187,291 tons, the output of basic electrodes — 87,343 tons, and that of special-purpose electrodes for welding high-alloy steels and non-ferrous metals — 16,117 tons (27.7 % increase).

The Russian Federation produced 223,743 tons of electrodes, including 130,603 tons of ritule-ilmenite electrodes, 77,538 tons of lime fluorspar electrodes and 15,602 tons of special electrodes. Ukraine produced 52,032 tons of electrodes, including 43,213 tons of rutile-ilmenite electrodes, 8,309 tons of lime fluorspar electrodes and 510 tons of special electrodes.

The positive trend now is towards increase in production of small- and medium-diameter electrodes (from 2 to 4 mm). Their total output amounted to 257,668 tons (88 % of total quantity). Increase in production compared with 2003 is 8 %. The output of 5 and 6 mm diameter electrodes was 32,810 and 272 tons, respectively.

The total output of alloyed welding wire up to 2 mm in diameter for mechanised gas-shielded welding was 48,695 tons, including 22,980 tons of wire with a diameter of 0.8–1.4 mm. The Russian Federation produced 32,635 tons of wire, including 17,108 tons of wire with a diameter of 0.8–1.4 mm, and Ukraine — 16,060 tons, including 9,020 tons of wire with a diameter of 0.8–1.4 mm. Compared with 2003, the total output of wire increased by 26 %, while in Russia it increased by 30 % and in Ukraine — by 18 %. Commercial manufacture of copper-clad welding wire has been started. This wire is supplied by orders of customers in spools and reels with a weight of 5 to 15 kg. The primary suppliers of this wire are the Association member companies, such as «Mezhgosmetiz-Mtsensk» and MMMZ (the latter is now called Open Joint Stock Company «MMK-Metiz»), ChSPZ and OSPZ — part of the Open Joint Stock Company «Severstal-Metiz». In 2004, the output of the copper-clad wire amounted to 5,780 tons, which was 48 % larger than in 2003.

The output of welding and surfacing wire in 2004 was 4,426 tons (23 % more than in 2003), including 2,549 tons of welding wire and 1,877 tons of surfacing wire. The volume of production of flux-cored wire in Russia was 3,458 tons, including 2,212 tons of welding wire and 1,246 tons of surfacing wire. Ukraine produced 968 tons of flux-cored wire, including 337 tons of welding wire and 631 tons of surfacing wire.

The output of welding fluxes in 2004 was 36,886 tons, including 10,585 tons in Russia and 26,301 tons in Ukraine. The volume of production of welding fluxes in Russia increased by 75 % and in Ukraine — by 5 %, compared with 2003.

In 2004, the total output of welding consumables was 380,758 tons, including 80,751 tons for mechanised welding. Welding consumables for mechanised welding constitute 21 % of the total output.

It can be seen from the above data that the major part of welding operations in the CIS countries is still performed using covered electrodes. Despite a low level of application of mechanised welding, the situation is changing for the better now. For example, whereas production of welding electrodes in 1990 and 1999 was 690 and 213.6 thousand tons, respectively (3.2 times decrease), that of alloyed welding wire was 23 and 2.3 thousand tons (10 times decrease), and welding flux — 146.5 and 21.9 thousand tons (6.7 times decrease), the situation with production of welding consumables, especially for mechanised welding, substantially improved in 2000–2004 (Table 2).

Now the CIS countries have enough capacities for production of welding consumables for both manual and mechanised welding. However, because of a slow rate of growth of industrial products, existing capacities are underutilised. As a result, Open Joint Stock Company «Balashejsky Production Works», a large workshop at the Open Joint Stock Company «Sulinsky Metallurgical Plant» (capacity of 40 thousand tons), a workshop at «Atommash» (Volgodonsk), and Open Joint Stock Company DEIZSM (Dnepropetrovsk) were closed. The electrode workshop with a capacity of 35 thousand tons at the Open Joint Stock Company «Stalekanatny» (former «Odessa Steel-Rolling Factory»), etc. nearly stopped working.

Despite financial difficulties and unstable sales of products, the Association member enterprises pay much attention to reconstruction and technical re-equipment of their electrode workshops, as well as to replacement of obsolete and depreciated equipment by the new one. These are such enterprises as Closed Joint Stock Company ELZ (St.-Petersburg), Limited Liability Company «Sychevsky Electrode Factory»,

Table 2. Output of welding consumables in the CIS countries in 1999--2004

Consumables (type of covering, diameter)	1999	2000	2001	2002	2003	2004
WELDING ELECTRODES (CIS)						
Total	213657	277407	252321	245978	273542	290751
Including:						
Rutile-ilmenite	164807	199446	179231	159419	178481	187291
Lime fluorspar	40339	62873	76489	82438	87438	87343
Special	8511	9969	10217	10070	12623	16117
Diameter, mm:						
3.0	60370	83384	76706	75476	79283	89080
4.0	127380	154855	142455	140161	159943	168589
5.0	23296	38790	32329	28994	32820	32810
6.0	2611	378	831	1347	1496	272
RUSSIA						
Total	167900	224559	211745	189403	212194	223743
Including:						
Rutile-ilmenite	126140	156575	143916	110721	128536	130603
Lime fluorspar	33560	58184	58045	69178	71599	77538
Special	8200	9800	9784	9504	12059	15602
Diameter, mm:						
3.0	49983	48694	62876	56218	65730	68524
4.0	162811	141203	120799	109365	119524	128653
5.0	12600	34384	27390	23000	25519	26387
6.0	2546	278	680	820	1421	193
UKRAINE						
Total	34758	35833	34807	44276	47624	52032
Including:						
Rutile-ilmenite	27668	30067	29646	36399	37636	43213
Lime fluorspar	6779	5280	4728	7311	9428	8309
Special	311	486	433	566	560	510
Diameter, mm:						
3.0	10427	9968	9737	11175	14675	16207
4.0	17179	20247	20512	27874	27274	30798
5.0	6594	5400	4407	5168	5601	4948
6.0	558	168	151	59	74	79
REST OF CIS						
Total	10999	6720	5769	12072	13724	14976
Including:						
Rutile-ilmenite	10999	6720	5769	12072	12310	13475
Lime fluorspar	--	--	--	--	1411	1496
Special	--	--	--	--	3	5
Diameter, mm:						
3.0	--	1690	1656	3808	1734	4346
4.0	7200	4415	3581	7130	9609	9134
5.0	3799	615	530	1922	2383	1495
ALLOYED WELDING WIRE (CIS)						
Totally, up to 2 mm diameter	26503	33227	31648	36577	38723	48695
Including 0.8--1.4 mm diameter	12756	13647	9925	16610	17108	22980

Table 2 (cont.)

Consumables (type of covering, diameter)	1999	2000	2001	2002	2003	2004
RUSSIA						
Totally, up to 2 mm diameter	6298.8	23161	22290	23615	25123	32635
Including 0.8--1.4 mm diameter	3940	9118	6076	9328	9708	13980
UKRAINE						
Totally, up to 2 mm diameter	20204.2	10066	9358	12962	13600	16060
Including 0.8--1.4 mm diameter	8816	4529	3849	7282	7400	9020
FLUX-CORED WIRE (CIS)						
Total	2274	2836	3073	2865	3585	4426
Including:						
Welding	1395	1590	1610	1763	1948	2549
Surfacing	878.7	1246	1463	1102	1637	1877
RUSSIA						
Total	1756	2253	2336	2076	2535	3458
Including:						
Welding	1180	1414	1398	1485	1579	2212
Surfacing	890	839	938	591	956	1246
UKRAINE						
Total	518.5	583	737	789	1050	968
Including:						
Welding	215.8	176	212	278	271	337
Surfacing	302.7	407	525	511	779	631
WELDING FLUXES (CIS)						
Total	21955	30215	28746	28066	31106	36886
Including:						
Russia	6650	7650	8715	8732	6051	10585
Ukraine	15305	22565	20031	19334	25055	26301

Pilot Plant for Welding Consumables of the E.O. Paton Electric Welding Institute, Open Joint Stock Companies MMMZ, «Mezhgosmetiz-Mtsensk», ShEZ, «AO Spetselektrod», Closed Joint Stock Companies «Artemmash Vistek» and SEZ SIBES, Open Joint Stock Company «OSP Velkom», etc., equipment developers «Velma», Closed Joint Stock Company «Arktos», Open Joint Stock Company «Tyazhpressmash», Limited Liability Company «Elikos», etc.

Priority activities of the Association include sourcing of new deposits of raw materials, assistance in deliveries of quality raw stuff components to electrode manufacturers, etc.

Considering the price policy, the Association sees establishing mutually beneficial relations between manufacturers and customers of welding consumables, and raw stuff suppliers to be its top priority activity. This concerns, first of all, deliveries of the required quality of ferrotitanium and potash for production of sodium-potassium and potassium-sodium silicate lumps.

TECHNOLOGY AS AN OBJECT AND TOOL OF QUALITY MANAGEMENT IN WELDING ELECTRODE PRODUCTION

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Quality and price are the key components of market competitiveness of electrode products. Technology of welding electrode manufacturing is a complex multi-operation process, having a multitude of potential disturbance sources that should be suppressed to achieve the required quality of products at an affordable price. The article analyses traditional engineering-technical approaches, which should be applied in combination with management approaches used by our electrode manufacturers in practice in keeping with recommendations of ISO 9000:2000.

Keywords: welding electrodes, manufacturing technology, competitiveness of products, quality management

The negative trends have become evident lately in production of welding electrodes in the CIS countries. For example, the output of electrodes has reduced by a factor of 3.5–4, resulting in decrease of industrial load on active production lines of traditional electrode manufacturers. Many lines were put out of operation, while the remaining ones are run in irregular modes. There appeared many small-scale electrode manufacturers that are geographically close to customers, which is accompanied by decrease in the concentration of production and an associated deterioration of technical and economic indices. Almost all research in the field of electrode manufacturing technology has been closed, and results of the research that still goes on are inaccessible for a wide range of manufacturers.

Sources of initial raw materials have increased in number, as many electrode manufacturing companies started using raw materials from the nearby regions, while these materials are most often little-studied. This led to deterioration of processing characteristics of the used raw materials, and their shipments substantially decreased in volume, as it makes no sense to tie up money for purchase of large batches of raw materials that will remain unclaimed for a long time.

The rhythm of production has been broken, which also added to deterioration of the quality of products. The load on analytical services has grown at operating enterprises, while the equipment they have lags behind the demands of the time, and many new enterprises have no analytical services. The shortage of qualified personnel is acute.

The only positive point is decrease in average weighted diameter of the electrodes manufactured, which, on the one hand, solved a number of technological issues arising in line production of large-diameter electrodes, but, on the other hand, aggravated problems associated with accuracy of electrode manufacturing.

It can be concluded that the existing situation added many new technological problems to the previous ones, which are little-studied, little-analysed and hard to handle.

Technology as a method of electrode manufacturing. In a literal sense, the word «technology» (from Greek — «technē» — art, facility, skill, and «logos» — learning) can be referred to any activity of a human, in the course of which he creates material, social or cultural values. Being a product of scientific research, technology provides a human with the methods to create these values.

The task of technology as a science is to reveal physical, chemical, mechanical and other mechanisms for development and practical application of the most efficient and cost-effective production processes, i.e. methods for affecting the raw stuff, materials or semi-finished products by appropriate production instruments [1].

In the material sphere, technology is an area of knowledge that includes scientific concepts, methodology, methods and required means to realise them in order to achieve a practical result.

In sociology, technology is a set of commercial processes or methods for affecting by labour the objects of labour in manufacture of commercial products.

Technology as a method for realisation of a manufacturing process is a set of methods intended for treatment, manufacture, transformation of state, properties and form of a raw stuff, material or semi-finished product, implemented in the process of manufacturing of products [1].

As defined by Khint [2], technology is a science of using achievements of natural sciences to develop methods for manufacturing the raw stuff and further processing it into production means and consumer goods. Electrodes are one of the types of industrial raw materials used for welding fabrication, and this definition applies to them in full extent.

The electrode manufacturing technology as an area of knowledge was formed and developed in the 20^{th} century on the basis of scientific results of physical (including colloidal) and organic chemistry, rheology, as well as practical achievements of the technology of such large-scale production areas, developed in parallel, as chemical, metallurgical, silicate, hardware, production of polymers, building materials, etc. Manage-

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ment theorists predict that in the 21st century the mutual penetration of technologies into all spheres of human activity will become more radical [3]. It should be expected that further development of the electrode technology will be affected to a much higher degree by the outsourced knowledge, generated using fundamental and related sciences, of which the electrode specialists have no idea so far. The main challenge will be to persistently master the knowledge, extend and intensify it, first of all, with a purpose of improving the electrode technology as a science (area of knowledge) and employing it to effectively and efficiently address the technological problems of welding electrode manufacturing, so that the technology, on the one hand, could be always ready to adequately respond to the electrode manufacturing needs and, on the other hand, could occupy a deserving place in manufacturing of welding consumables, such as the technology of metals in machine building, technology of forming in foundry, and technology of welding — in fabrication of welded structures.

Transition to the market economy resulted in changes of priorities in problems to be addressed by technological means. If before production was targeted at achievement of a high productivity of labour to maximise the output, now the focus is on manufacture of such products, which have to entirely comply with customer's requirements in their characteristics and quality, and be marketable.

Technology as a means of ensuring competitiveness of products. The purpose of business activity of any enterprise manufacturing welding electrodes is to achieve productive efficiency by manufacturing and marketing their products.

Under the market economy conditions, products to be sold should be competitive.

Competitiveness is a characteristic (or combination of characteristics) of products that determines the degree of consumer preference compared with other similar products [4].

In the world practice, competitiveness is determined by the following requirements:

- conformance of quality of products to market and specific customer requirements;
- value of aggregate costs incurred by a customer for purchase, delivery and operation of products;
- ability of a manufacturer to deliver products in time required by a customer;
- market reputation of a manufacturer, availability of objective evidence to prove reliability of a supplier as a partner, and capability of submitting such evidence at the first request of a customer [5].

All of the above goals are typically taken into account by leading companies in their competitiveness improvement programs.

In practice, however, many of them pay attention primarily to the goals, the achievement of which could help optimise the product quality to price ratio.

Quality, according to DSTU ISO 9000:2001, is an extent to which the combination of inherent characteristics (distinctive features) of products conforms to requirements, i.e. their formulated demands or expectations, either commonly accepted or mandatory.

Price is formed on the basis of costs incurred by a company to manufacture quality products. Moreover, price should be affordable for customers and, at the same time, acceptable for a manufacturer, i.e. it should be higher to an extent that the profit is sufficient for funding all needed to support and improve the quality of products and their manufacturing [6].

Price competition, which has dominated until recently in relations between our electrode manufacturers, is the most devastating and very undesirable form of fighting for a customer. Only powerful companies can afford to apply the price competition without prejudice to themselves, and only temporarily, until they achieve ousting of small competitors from the market. In addition, selling of products at a price that is too low is a waste of natural resources, which are not infinite. It is immoral in itself, as it is done by those who have nothing to do with production of these resources and whom they do not belong to [7].

Raising the price of products even within the limits of market price differences hardly benefits a company. The higher the price, the lower the profit, as in this case the volume of sales falls. Besides, by raising the price of products to provide their market competitiveness, not weighting it with its financial capabilities, a company can become bankrupt, losing its own competitiveness.

So, the above-said allows the following conclusion: quality and competitiveness are the interrelated categories, but they are far from being coincident. Competitiveness of products can decrease with improvement of quality, and vice versa. «Therefore, improvement of quality and competitiveness of products, as thought by some people, is an absurd ... and the main task of the national economy in the 21st century is growth of competitiveness due to the growth of quality» [7]. This statement is fully valid for welding electrodes.

Considering competitiveness of national electrode manufacturers, it should be emphasised that they are functioning under conditions of globalisation of the world economy and investment famine. Therefore, they need to be ready sooner or later to compete in the home market with the leading world electrode manufacturers, independently of whether they wish this competition or not, having an appreciably limited possibility to invest money into improvement of their own technologies and products. The competition is anticipated to be severe. The national electrode manufacturers will have to compete not just with the leading companies, but with companies that became leaders under conditions of the really severe competition, and came out of it victorious, having shared the world spheres of influence and being ready to actively intrude into our market. Upon joining the World Trade Organisation, the world market will come to us, even

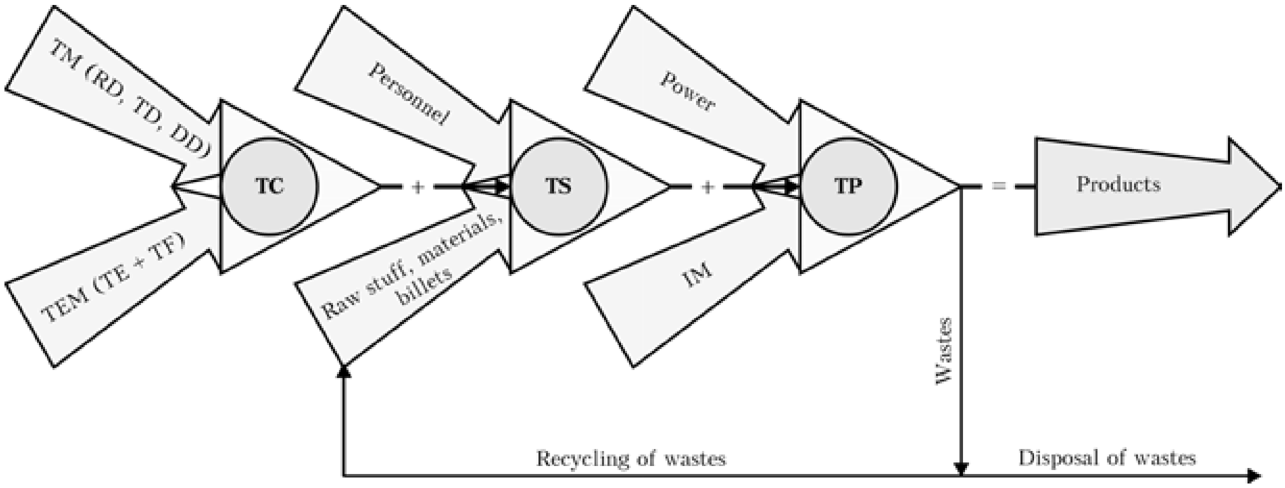

Figure 1. Key components of electrode manufacturing process (see designations in the text)

if we are reluctant to enter it, and any electrode manufacturer will hardly manage to sit out in a retreat.

It should be noted that commodity producers of the countries that were called tigers after they achieved outstanding success in business were once in a similar situation. The national electrode manufacturers should learn their experience and, where possible, use it in their practical activity.

Therefore, ensuring competitiveness of products is the immediate priority task of national electrode manufacturers, and it should be addressed through assuring a competitive quality of products by companies that expand their business on the basis of self-financing. At this end, they have to orient themselves mostly to an existing technology, as the majority of national companies will hardly have any funds in the foreseeable future for radical changes. In this case, to achieve a positive result, it will be right to choose a response strategy based on continuous upgrading of components of the existing technology by minimising the explicit costs. What is also important is to decide where at a given time moment it is most efficient to direct efforts and funds to.

Technology as a means of upgrading the electrode manufacturing process. As seen from Figure 1, technology consists of several components. Technological method (TM) is the basis of a technological complex making up the core of the technological system, which is part of the technological process, while totally they form the industrial process with its structure, control, information and financial flows.

TM is a set of rules that determine the content and sequence of actions in processing, handling of the materials treated, technical monitoring and tests in the course of manufacturing or repair of products, established irrespective of a given type of products, its designation, standard size or modification. TM is a separate area of fundamental research.

Technological complex (TC) incorporates regulatory (RD), technological (TD) and design documents (DD), as well as technological equipment means (TEM) consisting of technological equipment (TE) and technological fixture (TF). TC is formed at the stage of development of the specific type of product and implemented through design, building and completing with technological equipment of the production base intended for manufacture of the product. This provides the possibility of materialising TM using the production means selected by a designer in the course of practical implementation of the specific production process.

Technological system (TS) allows implementation of potential capabilities of TC by including performers (skilled personnel) into it and by affixing it to the quality, available, durably and reliably functioning raw materials base, as well as the well-established logistics.

TS is put into use and its reliable operation is provided in the form of technological process (TP) using the types of energy, methods of inspection and testing of products, and monitoring of processes with the required instrumentation means (IM), which are specified by project.

To make production of electrodes effective and efficient, i.e. consistently providing competitive products, all of the above-mentioned components should function perfectly.

Given that structures welded by covered electrodes are of a highly critical nature and should meet special requirements for their reliability, new types and grades of electrodes, as well as documents on them are traditionally developed by competent and well-equipped research organisations. Besides, they develop also the primary technical documents for manufacture of electrodes. The former serve as an information model for electrode products (formulations, specifications), while the latter are used as a technological model for manufacturing them (technological regulations, baseline technological processes, technological instructions).

The major task of electrode developers is to set a new technical level to a new development (using the market language, ensure technical competitiveness of products), based on investigation of development forecasts for industries where welding is applied as TP, analysis of the data of catalogues, promotional book-

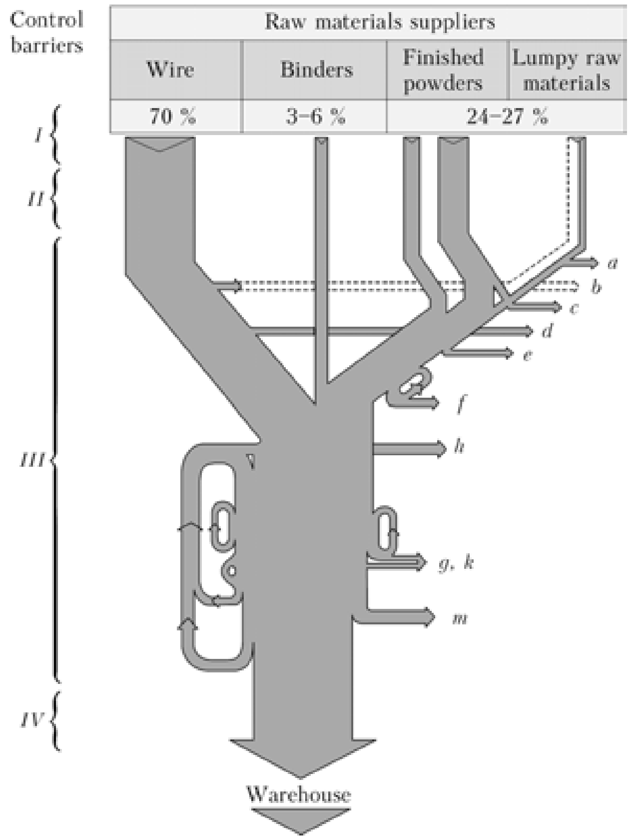

Figure 2. Flow diagram and balance of materials in technological process of electrode manufacturing: *a, c, e* — material losses in refining, screening and dry mixing; *b, d* — same in preparation of rods; *f* — same in dry mixing; *h* — wire and covering losses in cleaning and washing of rods; *g, k* — covering losses in extrusion and cleaning of electrode tips; *m* — moisture losses in heat treatment of electrodes

lets, national and international standards, patents and publications referring to electrodes. The required technical level is incorporated into technical documents in the form of the so-called specified indicators of electrodes.

Few electrode manufacturers develop RD on their own. Most of them buy RD from developers under licence. The task of buyer of a licence is to choose a subject and seller of the licence, realisation of which will provide him with expected market benefits. It will be better for a developer and potential manufacturer of electrodes if the specified indicators are chosen on the basis of results of joint investigation and analysis of the market, as well as allowing for actual technical capabilities of a manufacturer, or potential improvement of the indicators.

Production of electrodes is designed and relies on the basis of the technological model of electrode products as a first stage of technological embodiment of development (TED).

The purpose of the second stage of TED is to provide conditions for reproduction of specified characteristics in the form of the so-called object indicators of electrodes. In other words, this secures an unconditional achievement of electrode indicators specified by RD, owing to the fact that they are made from the required raw stuff, using specified technological process parameters, at a required accuracy and with participation of personnel of a required competence and responsibility level.

The final element block of TED should ensure consistency and reproducibility of electrode manufacturing processes and indicators, which are usually characterised by the level of defectiveness of products. The higher the quality of manufacturing, the lower the level of defectiveness of electrodes.

Electrode manufacturing technology is a multi-operation process (Figure 2). Technological operations performed in a required sequence provide the specified degree of transformation of material and desired quality of semi-finished products. Step-by-step inspection should show perfection of each operation, otherwise the errors formed and non-revealed at a stage of preceding operations will multiply at subsequent stages of manufacturing. For example, inadequacy of products may be caused by the following factors: supply of poor raw materials, imperfect arrangement of deliveries, violation of technological conditions, abnormal arrangement of workplaces, irregular power supply, untrained personnel, unskilled performers, etc. As a result, the designed level of technical competitiveness of products and quality of manufacturing will not be achieved.

In the course of TP, performers have to continually address the mutually contradictory problem. On the one hand, it is required to use the methods providing prompt detection of deviations and prevention of their formation in order to maintain the specified indicators of products and processes (adaptive control by varying technological parameters with variations in external conditions), and, on the other hand, it is necessary to continuously improve the indicators of products and processes to make them meeting the growing market requirements. Considering the application and peculiarities of manufacturing of electrode products, adaptive control of production and improvement of products and processes should be accomplished using the statistical management methods.

At the same time, it is necessary to address the problem of recycling and disposal of wastes to protect environment.

Technology as a quality management object. In terms of continuous improvement of competitiveness of products, the electrode manufacturing technology by all means should rely not only on technological regulations, but also on control principles. It is necessary to strictly regulate division of powers and responsibilities between managing, performing and supervisory personnel. This principle should cover all the elements providing functioning of a technology (technical methods, techniques and instrumentation means, objects of labour, personnel, power supply and information). Therefore, technology should be regarded not only as a tool, but also as an object of quality management.

Modern quality management is based on provisions of international standards ISO 9000:2000 (having corresponding national versions in the CIS countries: DSTU ISO 9000:2001 in Ukraine, and GOST R ISO 9000:2001 in Russia).

Provisions of ISO 9000:2000 cover almost all spheres of activity of an organisation. Independently of an application object, this activity is accomplished on the basis of a process model, even if it is not specified in the process form in a standard (compare resources, infrastructure with such items as procurement, planning, output of products). Flow diagram of the processes specified in ISO 9000:2000 can be represented in the form shown in Figure 3. It comprises management processes, including arrangement of functioning of the processes and information exchange, executive processes (documentation and supply of resources), output of products (product life cycle — PLC), measurement processes and management response based on their results. As seen, blocks of the processes are based on the PDCA (plan–do–check–act) cycle. They are joined by the quality management system (QMS), the development and adjustment of which are an independent process, the responsibility for which rests with the top managers of an organisation, as it allows the rest of the processes to be implemented to the best advantage.

As seen, structure of the QMS, according to ISO 9000:2000, covers in fact all types of the activity required for normal functioning and continuous im-

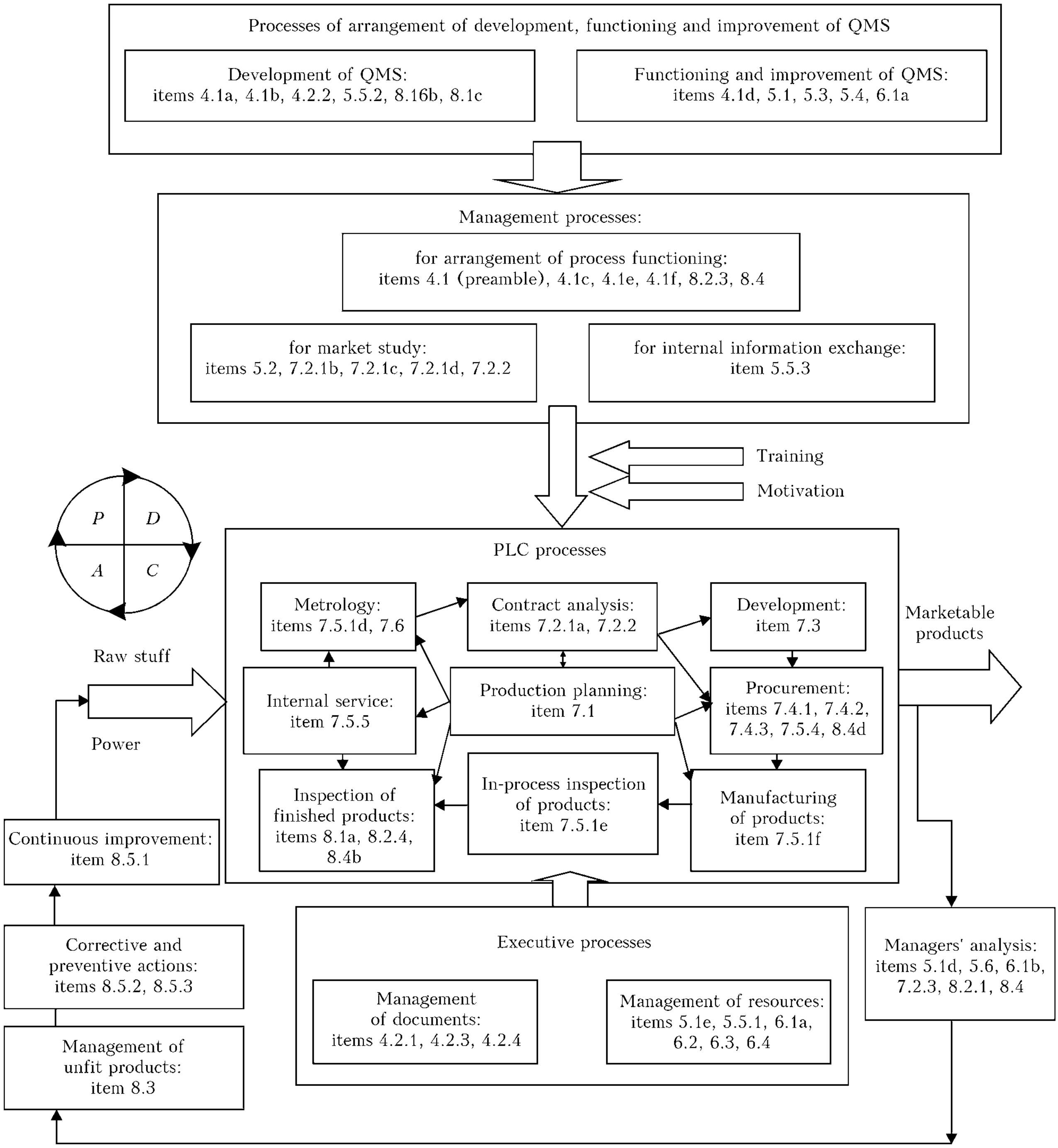

Figure 3. Flow diagram of quality management processes according to DSTU ISO 9001:2001

provement of the electrode manufacturing technology. Orientation of the technological model toward the above structure transforms it into a dynamic system targeted not so much to a primitive digestion of resources as to accumulation of potentialities of an organisation and achievement of excellent technical and economic results, and, therefore, competitive benefits [8].

Technology can be an object of an independent special estimation. For the majority of production companies, technology is certified under certification of their production [9]. In Ukraine, certification is performed in compliance with DSTU 3414--96 [10]. The welding production technology implemented primarily in the form of special processes, the quality of products of which cannot be confirmed by direct measurement, is a subject of an independent certification in Ukraine (DSTU 3951--2000). The best way to estimate the electrode manufacturing technology is to do it under certification of QMS of a company, as it comprises not so many special processes, but expenditures for development and application of QMS are almost the same as for development of documents required for certification of production. At the same time, technical and economic effects due to functioning of QMS are as a rule much more appreciable compared with the effects due to certification of production. Reported are QMS systems of electrode manufacturing enterprises, which were certified on the basis of technological documents (instructions).

Methodology of improvement of the electrode manufacturing technology within QMS is based on the results of statistical estimation of products and processes, which is an integral part of quality management according to ISO 9000:2000. It uses simple statistical estimation methods oriented toward application of existing IM, which are available and comprehensible for the production staff that took a short training course in the area [11, 12]. They include a plot, control chart, Pareto chart, histogram, scattering graph, cause and effect relationship diagram (fishbone diagram), and data stratification chart. Every time when it is necessary to have a new turn of improvement, the use is made of the PDCA cycle. The sequence of actions can be illustrated by a diagram shown in Figure 4 [13]. They are repeated until a desired result is achieved.

Statistical data are used to estimate accuracy and reproducibility of technological processes, indicators of the quality of preparedness of personnel, estimation of suppliers, etc.

In parallel, the economic indicators are estimated with a set periodicity, among which by all means should be the quality costs. For this, it is possible to use somewhat transformed results of book-keeping and management accounts. They are broken down, in compliance with requirements of ISO 9004:2000 (and, accordingly, DSTU ISO 9004:2001 or GOST R ISO 9004:2001), into four categories (Figure 5): inspection costs, preventive measures costs, internal losses due to reject, and external losses due to reject. At this point, it is important to meet the following requirements:

• cost categories should be constant and not duplicating;

• to ensure comparability, total costs should be reduced to certain bases (e.g. to volume of products sold, value added, labour intensity or production cost), and each time the base should be one and the same;

• it is necessary to make sure that the numerator and denominator used in rationing correspond to the same time period [14, 15].

Analysis of the quality costs allows location of the sources of losses, the elimination of which will increase competitiveness of products and a company.

Emergence of the Taguchi's concept [15] opened up wide prospects for product competitiveness management based on quality. According to this approach, improvement of quality should be accompanied by reduction of its cost. Quality is related to cost by a characteristic called the loss-of-quality function. It is a known fact that at the beginning of the 20th century F. Taylor introduced the concepts of rating and tolerance, and proved that being within the tolerance limits at a required rating is sufficient to assure quality. Later on, to increase the quality assurance, e.g. in motor industry, it became necessary to narrow scattering of a controlled parameter within the tolerance limits to such an extent that they could accommodate six root mean square deviations characterising statistic scattering of an indicator. In this case, the accepted products can contain not more than three defective pieces per million [12]. According to the Taguchi's concept, losses caused by quality deviations can be equal to zero only in the case if the value of a parameter coincides with rating. They grow for customers and society in squared relationship as the quality indicator deviates from the rating.

The most important point at the stage of development of a product (equipment, process) is to specify such technical solutions, at which characteristics of the products are least scattered under the effect of imperfection of a technology. Of course, only an experienced developer, well equipped technically, can manage to solve this problem.

The indicator, which is inverse to the variation coefficient known in statistics, was suggested for use as a criterion of robustness, i.e. insensitivity to the technology effects.

On this basis, electrode covering compounds based on liquid glasses, which, as to their composition, are in the initial part of the concentration--viscosity curve, must be characterised by the highest robustness. And the longer this part, the better. According to our observations, statistical yield of defective electrodes as to differences in thickness of an electrode covering is really minimal at a certain mean viscosity of a liquid glass. And it grows almost in squared relationship with deviation of viscosity to a larger or smaller side from the said optimal value.

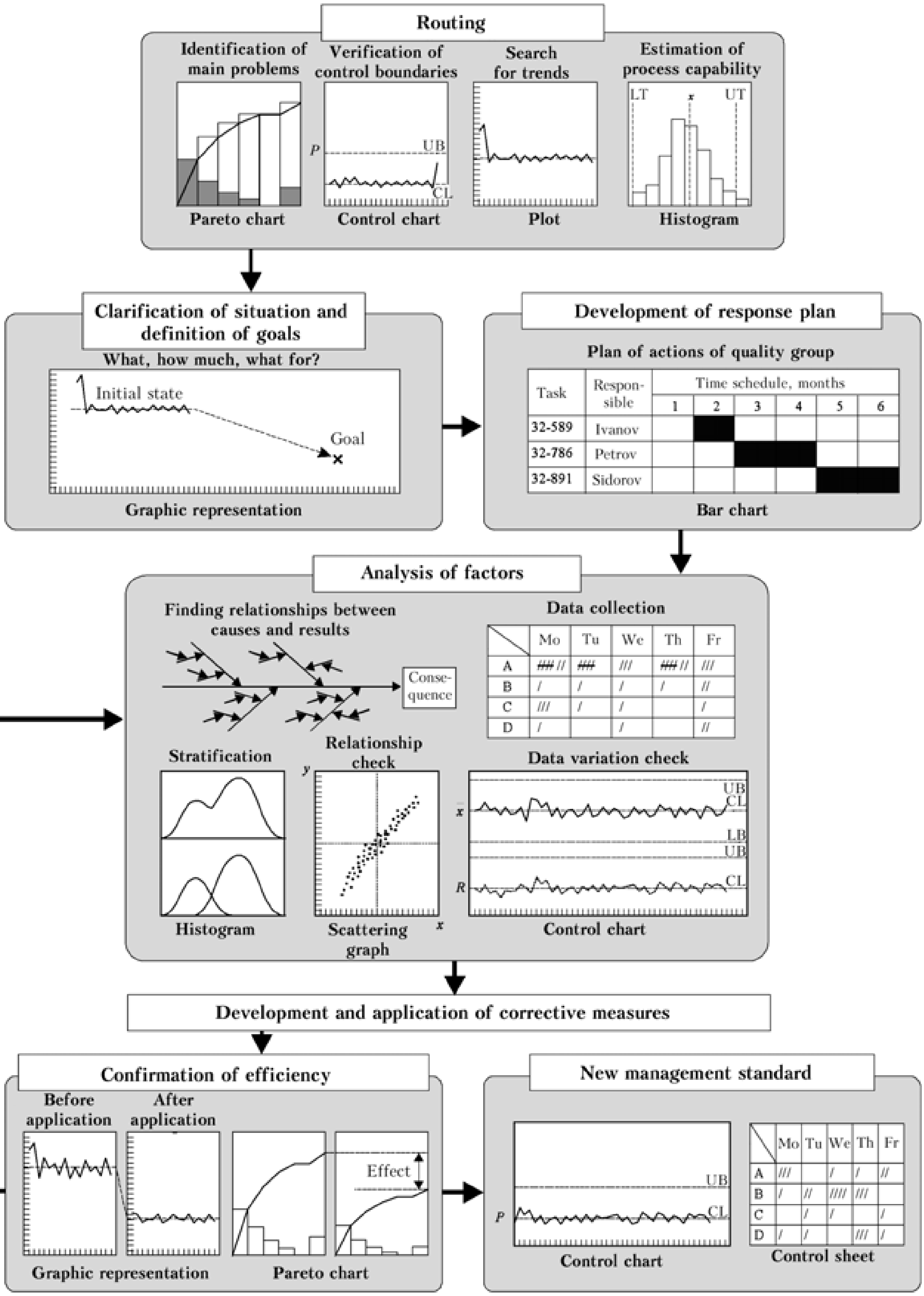

Figure 4. Cyclogram of application of statistical methods for continuous improvement of processes: UB — upper bound; CL — central line; LT — lower tolerance; UT — upper tolerance; LB — lower bound

Similar recommendations can be offered for regulation of grain compositions of powders of electrode covering materials to ensure plasticity of the covering compounds. As experimentally proved, from this standpoint the optimal grain compositions of powders are such compositions that provide the closest packing of the charge grains. In some cases, where a grain composition of the charge is regulated by changing

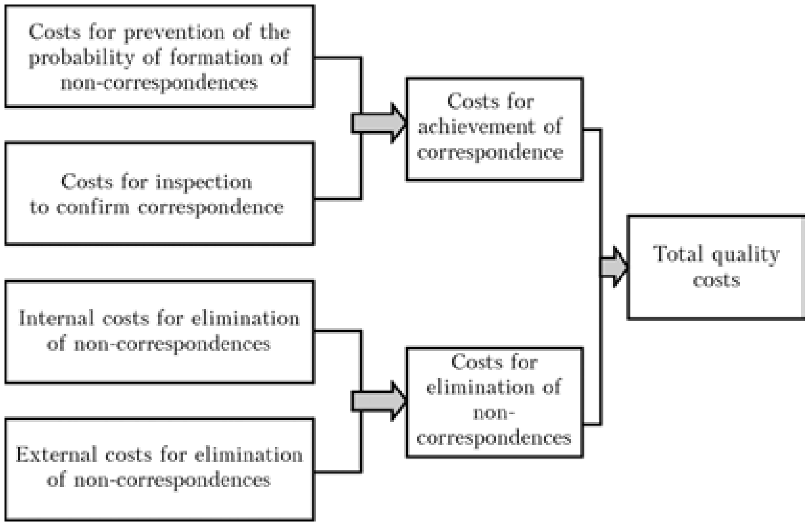

Figure 5. Components of quality costs

grain characteristics of each separate material of a covering, grain compositions of the rest of the components being kept unchanged, it is possible to achieve the unique technological effect, which can show up as a very high plasticity of the covering compound. What is distressing, however, is a too large quantity of optimal grain compositions of the charge, if it is regulated by the above method, on the one hand, and a dramatic deterioration of plasticity caused by the slightest deviation of grain composition of the charge from the optimum, on the other hand. In terms of production, this process is very difficult to control, particularly if changes in grain composition of powders occur for the reasons beyond the control of an operator. At the same time, a change of grain characteristics similar for all components of an electrode covering is better for production conditions owing to more acceptable characteristics of the process robustness, although it does not lead to a unique technological effect.

It is impossible to control technology by the quality management methods, according to ISO 9000:2000, following some uniform recipes for all enterprises and all types of electrode products. The above standards offer what should be done, but it is up to a user of standards to choose approaches to be used for problems he has to solve. The author described general approaches, including those based on his own experience, in recommendations given in [16].

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DEVELOPMENT OF ELECTRODES WITH HIGH WELDING-TECHNOLOGICAL PROPERTIES FOR SURFACING

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Data are given on development of a series of new generation electrodes designed for surfacing the sealing surfaces of fittings, working surfaces of bearings, cutting edges, parts exposed to highly aggressive media in operation.

Keywords: arc surfacing, coated electrodes, wear resistance, welding-technological properties, testing

In addition to widening the product range, CJSC «Elektrodny zavod» is continuously working on improvement of welding-technological properties of welding and surfacing electrodes. Over the recent years four grades of surfacing electrodes of the new generation have been developed, namely ELZ-N2, ELZ-N3 (for surfacing carbon steels), ELZ-NV-1, ELZ-NV-4 (for surfacing carbon and high-alloyed steels).

Electrodes of ELZ-NV-1 and ELZ-NV-4 grades with rutile-basic type of coating are designed for surfacing the sealing surfaces of fittings, working surfaces of friction and plain bearings of electrical engineering equipment, cutting edges of heavy-duty hot stamping dies, edges of cutters of the equipment for chips grinding in wood-pulp, paper and waterproof insulation production, as well as other parts operating in highly aggressive media at temperatures of up to 600 °C. Surfacing is performed at reverse polarity direct current. These electrodes offer the following essential technological advantages:

- possibility of performance of part surfacing without preheating or concurrent heating with a guaranteed absence of cold or hot cracks or other defects in the deposited metal;
- stable arcing in a broad range of welding current;
- excellent formation of deposited beads;
- easy separation of the slag crust from the surface of deposited beads;
- easy re-striking of the arc after its extinction without removing the surface-melted coating from the electrode tip;
- possibility of subsequent bead deposition without removing slag from the previous beads.

On the other hand, these electrodes meet all the requirements made of the metal for surfacing the sealing surfaces of fittings operating in various aggressive media, namely concentrated acids, acid and alkali solutions, NPP heat carriers, etc. In addition, they completely lack the drawbacks, characteristic of electrodes of TsN-2, TsN-12M grades, as well as stellites of various compositions.

Electrodes guarantee the following physico-mechanical properties of the deposited metal: deposited metal hardness in the initial condition — *HRC* 20–38, and after the respective heat treatment (tempering at specified temperature, soaking and cooling in air) — *HRC* 40–55 for ELZ-NV-1 electrodes and more than *HRC* 56 for ELZ-NV-4 electrodes. Surfacing electrodes of ELZ-N2 grade with the basic coating type were developed to replace the known electrodes of T-590 grade, widely applied in different industries.

The need to develop new electrodes is due to the fact that electrodes of T-590 grade have a number of disadvantages, namely low wear resistance of the deposited metal in operation under the conditions of intensive shock-abrasive impact; impossibility to produce a multilayer deposit of a great thickness; high susceptibility of the deposited metal to brittle fracture and spallation from the base metal during operation; poor formation of the deposited beads, etc. In addition, production of electrodes of T-590 grade continuously runs into problems related to producing sound coatings on electrode rods.

Conducted package of R&D and comprehensive industrial testing of electrode of ELZ-N2 grade showed the following:

- at operation under severe shock-abrasive impact conditions (crushing and milling of ferrochromium, ferrovanadium, ferrotungsten, etc.), the absolute wear resistance of the metal, deposited with new ELZ-N2 electrodes, is 3 to 4 times higher than that of the metal deposited with electrode of T-590 grade;
- deposited metal hardness in as-surfaced condition is *HRC* 58–60;
- possibility of performing surfacing in several layers of the total thickness of up to 15–20 mm;
- high resistance of the deposited metal to hot and cold cracking;
- good formation of the deposited beads with good separability of the slag crust from their surface;
- high adaptability of the coating to fabrication in batch-production of electrodes in the extruding machines.

In 2003–2004 the company developed new electrodes of ELZ-N3 grade for surfacing the worn working

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surfaces of hot stamping dies. Metal (of 4Kh3V2M2F type) deposited with these electrodes, has the hardness of *HRC* 45–48 in the initial condition. Presence of 10–15 % of residual austenite in the deposited metal results in its higher hot cracking resistance, this allowing surfacing of rather large surfaces in 3 to 5 layers of the total thickness of 8–12 mm. After tempering hardness rises to *HRC* 51–52 as a result of residual austenite decomposition.

Metal deposited with ELZ-N3 electrodes has hot hardness, and high wear resistance at the temperature of up to 650 °C. Hot hardness at the temperature of 600–650 °C is in the range of *HRC* 32–35, this providing wear resistance of the surfaced area of the dies during hot stamping.

Pilot production trials of electrodes of ELZ-N3 grade in KAMAZ Car-Making Factory confirmed the above data.

IMPROVEMENT OF TECHNOLOGIES FOR WELDING ELECTRODE MANUFACTURE

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Experience of using mineral alloys in electrode coatings, containing aluminium in the form of alumina, kaolin or nepheline is described. It is shown that additions of mineral alloys decrease the reactivity of powder components of electrode coatings.

Keywords: arc welding, coated electrodes, production, coating mixture, liquid glass, mineral alloys

Plants manufacturing welding electrodes are interested in establishing conditions, ensuring the required level of feasibility of extrusion, main quality indices of the coating, welding-technological properties of electrodes and mechanical properties of the deposited metal of welds.

In extrusion of electrodes with calcium-fluoride coating, coating mixture solidification quite often takes place (right up to its solidification in the press cylinder), as well as change of coating thickness. Coating mixture solidification was found at addition of aluminuim and magnesium powders, pigmented grades of titania, including TSM grade, limestone from Uglovsk field, mable of stripping grades, sodium fluosilicate, and in some cases soda ash into the coating.

Deterioration of the quality of ferrotitanium raises the problem of porosity prevention in the deposited metal of welds. Porosity develops in the weld metal at addition of such components as alumina, kaolin, nepheline, feldspar, i.e. containing aluminium oxide, to the coating.

The above-said may lead to the conclusion on development of the processes of formation of crystalline hydrated compounds and colloid new compounds forming at cement solidification, in the coating mixture and electrode coating.

It was established that similar to the case of agglomerated welding fluxes, water is not completely removed from welding electrode coatings at their baking at the temperature of 360–400 °C; a considerable amount of it is preserved right up to 650–800 °C. This is not caused by the presence of dry residue of liquid glass. As shown by differential thermal analysis of three samples of liquid sodium and sodium-potassium glass, made by Prof. S.I. Pechenyuk (IKhTREMS KNTs of RAS), water from the dry residue is not removed completely at heating up to 400 °C.

Analysis of published sources, for instance [1, 2], which present the problem of producing adsorbents based on the use of alkali solutions, leads to the following conclusions:

- water-soluble silicates are substances, from which silica colloids and gels are produced;
- liquid glasses — water solutions of alkali silicates (ash) — form silica hydrogel at drying. Gel formation starts at room temperature, the process being accelerated with temperature increase;
- the longer does the liquid glass stay at room temperature, the greater is the quantity of forming silica gel nuclei, and the smaller is their size, which results in greater chemical activity of the gel;
- commercial grades of liquid glass with not less than module 4, form gel particles of 30 to 100 nm size;
- particles of gel formed at drying consist of silica $Si(OH)_4$ and $HSiO_3$ ions, which are in equilibrium with it;
- when alumosilicates are produced in the form of zeolite (adsorbents), aluminuim hydroxide is required for reaction with silica monomer.

If aluminium powder or its oxide are present in the mixture, they are hydrolyzed completely during a short time interval.

Reaction of monomer silica with Al^{3+} ions proceeds with formation of $Al_{12}Si_2O_5(OH)_8$ halloysite, releasing water at 650 °C (more seldom at 800 °C).

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Results of trials of test batches of 4 mm electrodes of UONI-13 / 55 type (with Minal)

Company	Marking of electrode batch (test date)	Deposited metal composition, %					Mechanical characteristics of deposited metal					
		C	Si	Mn	S	P	σ_t, MPa	σ_y, MPa	δ, %	ψ, %	Impact energy, *KV*, J / m^2, at Ò, ¹Ñ	
											–40	–60
SEVMASh	Sv-08AA (02.12.2004)	0.07	0.45	1.43	0.013	0.014	559–569	461–466	33	75	80–124	68–102
INSTREL	Sv-08A (10.06.2004)	0.07	0.44	1.23	0.019	0.012	570–580	450–485	27–31	76–78	64–124	42–71

Zeolites most often form at the temperature of 90 °C in the case of soaking (ageing) of hydrogel at room temperature [3].

The above short essay of special publications on sol-gel technology certainly does not touch upon many practical aspects. It, however, can be the basis for assessing the presence of similar processes in coating mixtures and electrode coatings, if they include aluminium or aluminium oxide in the form of alumina and other compounds (kaolin, nepheline, cyanite). These processes result in water containment in the form of hydroxyl groups, surrounding the cations of metals (silicon and aluminuim) by layers with different bond strength and separating from the cations at heating up to the temperature of 400 to 800 °C. Similar phenomena can be observed in coating mixtures containing oxides of titanium, manganese, calcium, magnesium and other metals.

Therefore, to avoid the above reactions of silica hydrogel, the powders of electrode coating components should be made low-active. Use of mineral alloys, similar to fused welding fluxes, is one of the practical solutions of this problem. Their composition should meet somewhat different requirements, taking into account the electrode coating composition.

The defined problems have been partially solved in Federal State Unitary Enterprise «Central R&D Institute of Structural Materials PROMETEJ».

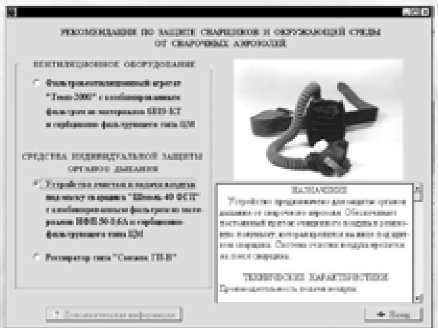
In 2003 the work on development of the electrode coating based on a calcium-magnesium-titanium composition and the respective mineral alloy (conditionally called Minal) was finished.

Development of welding electrodes of UONI-13 series based on this composition is being completed now. The Table gives the results of trials of test batches of the electrodes.

1. Ayler, R. (1982) *Chemistry of silica*. Moscow: Mir.
2. Korneev, V.I., Danilov, V.V. (1991) *Manufacturing and application of soluble glass*. Leningrad: Strojizdat.
3. Zhdanov, S.P. (1987) General principles and peculiarities of kinetics of zeolite crystallization. In: *Adsorption and Adsorbents*. Proc. of 6th All-Union Conf. on Theoretical Problems of Adsorption. Moscow: Nauka.

COMPUTATION-INFORMATION SYSTEM FOR HYGIENIC CHARACTERISATION OF WELDING FUMES

The computer system allows obtaining information on quantitative characteristics of particulate and gaseous components of welding fumes in simple and comprehensible form for a wide range of welding parameters and consumables, as well as computation of the required productivity of ventilation of a welder's work place and selection of the appropriate ventilation equipment or individual means for protection of welder's respiration organs. The system has a built-in editor, making it possible to update the databases.



Application. The system can be used at machine building enterprises (chief welder and labour protection services) for hygienic evaluation of the welding process and design of the welder and environment protection systems from a harmful effect of welding fumes.

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RENOVATION SURFACING OF METALLURGICAL AND MINING EQUIPMENT USING FLUX-CORED WIRES

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The paper gives information on flux-cored wires produced by TM.VELTEK, Ltd. and experience of their application in renovation of the parts and mechanisms in metallurgical and mining industries.

Keywords: arc surfacing, flux-cored wires, renovation of parts and machines, rolls, crane wheels, metallurgical equipment, casting defects

Electric arc surfacing, using flux-cored wires, occupies strong positions in renovating parts of machines and mechanisms in various branches of industry. A flux-cored wire is chosen taking into account operation conditions of a part to be renovated, its design peculiarities, type of protection, and available equipment.

Rolls of machines for continuous casting of ingots (MCCI). About 80 % of the whole steel produced in developed countries is treated using energy-conservation technology of continuous steel casting, which has a number of other advantages as well. Efficiency of using MCCI is determined to a great degree by durability of its rolls, which operate under conditions of long cyclic and thermal-mechanical loads in corrosive atmosphere. Rollers of supporting and unbending assemblies operate under extreme temperature conditions: maximum temperature of roller surface may achieve 670–750 °C, and they are subjected to ferrostatic bulging and unbending actions of an ingot. In straight sections rollers are mainly subjected to abrasive wear. Destruction of their working surface is manifested by the surface layer wear and formation of fair cracks. The most efficient manufacturing and renovation surfacing of rollers is achieved when flux-cored wires are used as a surfacing material. Surfacing efficiency is determined by the cost of a flux-cored wire, productivity of the process, thickness of a deposited layer, power consumption at all technological stages, cost of installation works, and shut-down period of the equipment. For renovation surfacing of MCCI rollers, solid and flux-cored wires 12Kh13 and 20Kh17 in combination with fluxes AN-20S and AN-26P are traditionally used in national metallurgy. This ensures production of a chromous deposited metal with martensite-ferrite structure (Figure 1), for which formation of big (more than 15 %) areas of δ-ferrite is characteristic, which is the reason of increased wear and fair crack formation.

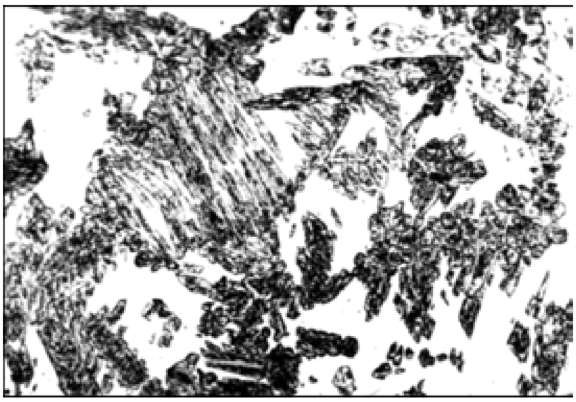

Figure 1. Microstructure of metal deposited with wire Np-20Kh17 (×500)

In addition, the surfacing process is accompanied by difficult separation of the slag crust, which is the reason of origination of the defects in the form of elongated slag impurities. The service capacity of rollers, renovated according to this technology, is 300–400 ths t of ingots, which does not meet state-of-the-art requirements.

At the enterprise of TM.VELTEK, Ltd. flux-cored wires VELTEK-N470 and VELTEK-N470S (TUU 19369185.018–97) in combination with fluxes AN-20 and AN-26 are used for this purpose. Complex alloying of chromous metal with Ni, Mo, V, Nb and rare-earth metals is used for improving structure of the deposited metal. Optimum content and ratio of alloying elements, technological parameters, and surfacing techniques, which allow stable producing deposited metal with martensite structure (Figure 2) and insignificant volume share (3.5–5.0 %) of δ-ferrite having hardness HRC_e 40–44, were determined and implemented. This ensures high resistance of the deposited metal to wear and fairing.

Application of proposed technology ensures spontaneous separation of slag crust and absence of pores and cracks in the deposited metal. Comparative tests of flux-cored wires VELTEK-N470 and VELTEK-N470S showed that their working parameters are similar to those of the wires produced by leading foreign companies — OK15.73 (ESAB), 4142MM-SLC, 414MM-S (WELDCLAD). Wire VELTEK-N470 was successfully used at Novo-Kramatorsk Machine-Building Works for fulfillment of export orders. Within the last eight years at the Iliich Mariupol Metallur-

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gical Works the wire of this grade was also used for renovation of MCCI rollers. Service capacity of surfaced rollers is minimum 1.5 mln t of ingots. At present wires of new modification are produced at the enterprise TM.VELTEK, Ltd., which increase service capacity of the rollers up to 2.5–3.0 mln t.

Rollers are the main technological tools in the rolling process. Productivity of rolling mills, technical-economic performance of rolling workshops, quality of ready rolled stock, and production cost mainly depend upon reliability and wear resistance of working surface of rollers, and their term of service between repairs. In the process of operation surface of rollers is subjected to cyclic, mechanical, and thermal action, to their working surface sticks metal, the surfaces are non-uniformly worn, and fair cracks form on them. Renovation surfacing with application of solid or flux-cored wires is used for maintaining necessary stock of the rollers. For surfacing of hot rolling rollers surfacing materials Np-30KhGSA, NP-35V9Kh3SF, Np-25Kh5FMS, and Np-30Kh4V2M2FS in combination with fluxes AN-348, AN-60, AN-20, and AN-26 are traditionally used.

Companies TM.VELTEK and REMMASh jointly with metallurgical works «Krivorozhstal», «Zaporozhstal», Dzerzhinsk Metallurgical Works, carried out complex of works directed at improvement of surfacing materials, technology, and equipment for surfacing rollers. Proceeding from the assortment of items produced by the metallurgical works, which participated in the work, main attention was paid to surfacing materials and technology of surfacing hot rolling rollers of billet, section, and partly sheet mills. Analysis of literature data, in which serviceability of surfaced rollers is discussed, showed that possibilities of the alloying systems C–Si–Mn–Cr–Mo–V and C–Si–Mn–Cr–W–V are not completely implemented. On the basis of standard flux-cored wires of the grades PP-Np-35V9Kh3SF and PP-Np-25Kh5FMS systems for alloying flux-cored wires of new grades were improved taking into account operation conditions of rollers.

Improvement of serviceability of the rollers was achieved due to changing structure of a deposited metal. Structure of the metal, which was deposited using wire PP-Np-35V9Kh3SF, has the following form: over the boundaries of a primary austenite grain open areas of δ-ferrite are located, in which elongated eutectic precipitates in the form of a mixture of austenite and carbides are present. In crystallization cells martensite and single fine carbides are formed, and at the boundaries of cells δ-ferrite is formed. Size of a primary austenite grain is 6 points. In overlap zone of beads change of the structure and microhardness from *HV* 6500 to 4500 MPa (Figure 3) is observed. Metal, deposited by the wire VELTEK-N500, has the following structure: boundaries of austenite primary grain are clearly pronounced and interrupted precipitates of δ-ferrite and fine carbides are observed in them. Inside crystallization cells disperse martensite and carbides are formed. In structure of the metal, deposited by wire VELTEK-N505, over boundaries of austenite grains, which have size 17–20 μm, also form very small precipitates of δ-ferrite and carbide, similar to eutectic ones. In crystallization cells form fine-acicular martensite and disperse carbides. In structure of the metal, deposited with wire VELTEK-N550, over primary austenite boundaries precipitates of δ-ferrite and disperse carbides are present, and in the cells carbides, similar to eutectic ones, and fine-acicular martensite are formed. In the overlap places of beads change of structure does not take place.

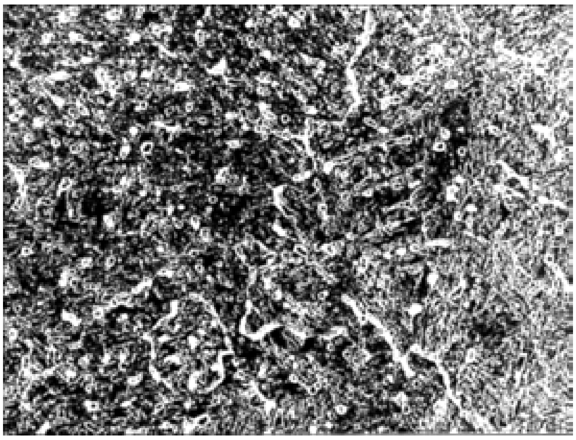

Figure 2. Microstructure of metal deposited with flux-cored wire VELTEK-N470 (×1000)

In the process of a roller operation coagulation and enlargement of carbides over boundaries of grains with their subsequent spalling and development of fair cracks under action of high temperatures are observed. Inhibition of these processes is achieved by change of structural state of grain boundaries due to optimizing the ratio of carbon to carbide-forming elements. The results obtained were implemented in the systems for alloying new flux-cored wires. Structure of the metal, deposited by the flux-cored wire VELTEK-N500RM, represents an acicular fine troostite with insignificant volume share of martensite, and over boundaries of grains formation of individual δ-ferrite impurities is observed. Insignificant amounts of carbide eutectic impurities are formed at the grain boundaries.

Mentioned flux-cored wires demonstrated their efficiency in surfacing rollers. Average parameters of relative wear resistance were determined by wear and relative resistance against formation of cracks, and amount, opening, and penetration of the latter in the rollers. Below examples of applying new flux-cored wires are given.

Surfacing of edger stand rollers at «Zaporozhstal». Lateral reduction and alignment of side edges of a rolled sheet are performed by means of vertical rollers of an edger stand on continuous thin-sheet hot-rolling mill of «Zaporozhstal» (rolling mill 1680). In the process of operation cylindrical surface of rollers in the place of their contact with a hot sheet end is subjected to intensive abrasive wear and significant specific pressure of compression forces. As a result on the surface of rollers circumferential galling of up to

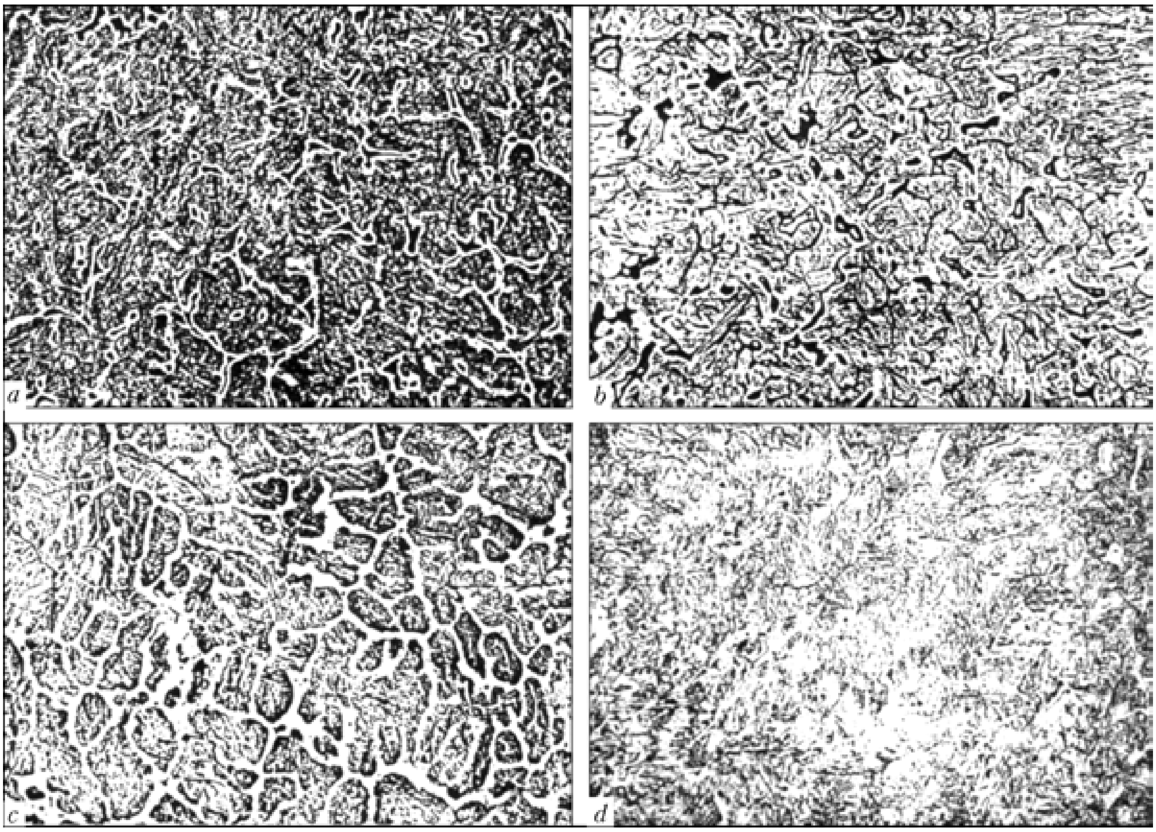

Figure 3. Microstructure of metal produced using flux-cored wires VELTEK-N505 (*a*), Np-35V9Kh3SF (*b*), VELTEK-N550 (*c*) and VELTEK-N500 (*d*) (×500)

100 mm width and up to 5 mm depth is formed over generatrix near flange. It causes the need for replacing the rollers, because their further operation may cause non-uniformity of reduction and rolling speed, which negatively effects quality of the rolled metal. Study of the character and dynamics of the wear showed that it takes place as a result of oxidation and detachment of the oxidized metal particles from surface of the rollers by ends of the hot sheet, which has surface temperature 1100–900 °C and is partially coated with a thin layer of scale, the surface of rollers in the place of their contact with a rolled sheet being heated up to 400–500 °C. Term of service of the rollers, hardened by surfacing with flux-cored wires PP-Np-35V9Kh3SF or PP-Np-25Kh5FMS, is maximum 3–4 months, which does not meet requirements of the production. Application of the flux-cored wire VELTEK-N550RM for surfacing allowed increasing wear resistance and service life of the rollers 3 times.

Surfacing of hot-rolling mill rollers. At the Dneprovsky Metallurgical Works one set of rollers is renovated 5–10 times. For a long time renovation of rollers of the rolling mills 900 and 500 of the iron rolling workshop was performed using surfacing with solid wire Np-30KhGSA in combination with piercing or re-piercing of passes down to a smaller diameter. Use of this technology didn't ensure required «hot hardness» and wear resistance of surfaced working layer of passes. As showed technical-economic analysis, application of standard surfacing materials PP-Np-35V9Kh3SF, PP-Np-25Kh5FMS, and PP-Np-30Kh4V2M2FS in this production turned out to be inexpedient because of complexity and capital expenses connected with renovation of the rollers. For hardening renovation of the stand rollers of the rolling mill 500 of the iron rolling workshop flux-cored wire VELTEK-N500RM was used. Tests of the renovated rollers of the rolling mill 500 of the iron rolling workshop showed that their service life increased more than 2 times after hardening.

Surfacing of vertical walls of passes of the stand 900 rollers, for the purpose of their hardening, wire of the grade VELTEK-N370RM was used. Technology of surfacing of these rollers is similar to the one used for surfacing rollers of the stand 500 of the iron rolling workshop (except preheating). Volume of metal rolled on one pair of rollers within the time between their repairs increased from 18–20 to 45–50 ths t.

Hot-rolling rollers of the rolling mill NZS-730 of the workshop «Blooming-1» of Metallurgical Works «Krivorozhstal», manufactured from steel 50, were traditionally repaired using standard flux-cored wire PP-Np-35V9Kh3SF. In operation of renovated rollers a number of shortcomings were detected. So, in the process of rolling on the surface of a roller formation of «tongues» of up to 2 mm height is observed as a result of a rolled metal sticking. Presence of «tongues» causes the need to stop rolling process and use laborious process of fettling the passes, otherwise rollers with «tongues» will apply defective pattern on the surface of a rolled metal. After 50–60 ths t of metal were rolled, on the surface of passes galling of 2–3 mm depth was formed that caused need to replace the rollers. Depth of penetration of certain cracks, after 50–60 ths t of metal were rolled, achieved 30–40 mm. This caused increased repair expenses and frequently premature rejection of rollers. Surfacing technology with application of flux-cored wire VELTEK-N505RM was used for removing mentioned shortcomings. This technology is similar to that used for surfacing with application of the wire PP-Np-35V9Kh3SF. Due to mentioned technology formation of «tongues» and cracks reduced 2–3 times. This allowed performing repair of 80–90 % rollers using shortened technology and essential reducing all kinds of expenses, and increasing operation time between repairs of the mill by 20 %.

Parts of metallurgical equipment. Self-shielded flux-cored wire VELTEK-N250RM of 1.6–3.0 mm diameter is successfully used for renovating rolling stand pads and scissors, spindles and couplings of roller drives, sprocket wheels, bushings, shafts, hubs, etc. Characteristics of this wire are not inferior to those of the known flux-cored wire DÜR 250-FD (Böhler).

Cores of crab cranes and jaws of the ingot stripper were surfaced, which are subjected in the process of their operation to shock and compression loads under high temperature conditions. Cores contact with metal heated up to 800–1250 °C and operate under thermocycling conditions because of their periodic cooling in water tanks. For this purpose self-shielded flux-cored wire VELTEK-N480S of 2 mm diameter was used with the alloying system C–Cr–W–Mo–V–Ti, which ensures after surfacing HRC_e 50–54, hot hardness HRC_e 40–44 at 600 °C, and high resistance against formation of cracks (100 thermo-cycles before origination of the first crack). Application of mechanized surfacing using wire VELTEK-N480S instead of electrodes T-590 and T-620 allowed increasing service life of cores 4–5 times and reducing expenses for repair. The task of renovation of cores was solved as a common «equipment–material–technology» complex.

In surfacing of parts that were subjected to shock-abrasive wear, using flux-cored wire PP-AN170, increased propensity to crack and spalling formation is observed, and surfacing thickness makes up one-two layers, which limits use of this wire in certain cases. For solution of this task self-shielded flux-cored wires VELTEK-N600 (C–Cr–Mo–V–Nb–Ti–B) and VELTEK-N620 (C–Cr–Mo–V–Ti–B) were used, which ensured hardness of deposited metal HRC_e 55–63. Wear resistance of deposited metal increases by 30–50 % in comparison with wire PP-AN170 and there is possibility to apply four-five layers. Mentioned wires have diameter from 2 to 5 mm. Surface of big bell of the blast furnace was renovated using mechanized and automated surfacing with flux-cored wire VELTEK-N600 of 3 mm diameter. As a result significant increase of wear resistance of the deposited metal was achieved (in comparison with electrode T-590) and the time of repair was reduced 2-fold. In automatic surfacing of a small bell with flux-cored wire VELTEK-N620 of 4 mm diameter higher wear resistance was achieved in comparison with tape PL-AN-101. These wires were successfully used in surfacing excavator bucket teeth, bulldozer blades, and clamshell jaws for the purpose of their hardening.

Surfacing of fire bars and sprocket wheels of a single-roll crusher of sinter was performed using self-shielded flux-cored wires. One set of the crusher comprises 16 fire bars, each having the mass 270 kg, and 15 sprocket wheels, each having the mass 85 kg, manufactured from steel of the grades 35L or 45L. Before new technology was introduced, the fire bars were not hardened, but replaced for new ones. Flux-cored wire VELTEK-N600 with alloying system C–Cr–Mo–B–V–Ti ensures multilayer deposit of fire grades, which is resistant to shock-abrasive loads at increased temperature. Multilayer surfacing was performed with wire of 2.6 mm diameter at DCRP under the following conditions: I_s = 280–300 A, U_a = 26–28 V. Hardness of deposited metal was HRC_e 59–62. In comparison with the metal, which was deposited using wire PP-AN1-70, propensity to cracking and spalling significantly reduced. Taking into account non-uniformity of wear, number of layers and thickness of surfacing varied depending upon degree of wear of each fire bar and sprocket wheel from 3 to 12 mm.

Periodic inspection of the experimental set showed the following dynamics of wear of fire bars and sprocket wheels in various zones of the crusher (Figure 4): in 2 months — from 3 % at the periphery to 6 % in the center; in 4 months — from 5 % at the periphery to 12 % in the center; in 6 months — from 8 % at the periphery to 25 % in the center, whereby the period between repairs of the crusher increased 3 times, quality of sinter improved, and repair expenses reduced.

Crane wheels. Wear of crane wheels, produced from steel grades 45L, 40L, 60L and 55L, occurs because of friction of metal against metal at high alternating loads both over the wheel tread and over the flange, the wear over the wheel tread being on average 6–10 mm per a diameter, and over the flange — 15–

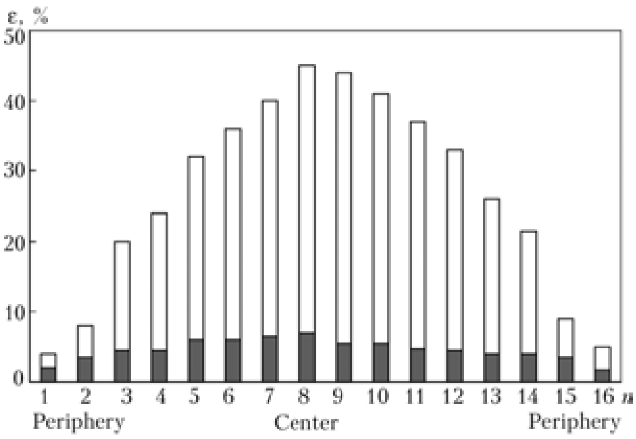

Figure 4. Wear ε of hardened and non-hardened (hatched area) fire bars of sinter crusher after 2 months of crusher operation: n — order of arrangement of fire bars in sinter crusher

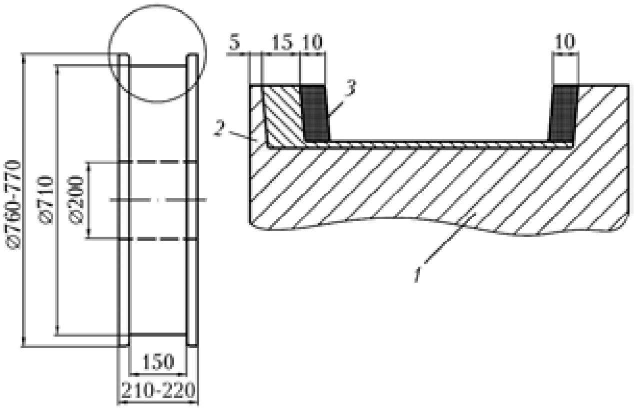

Figure 5. Scheme of crane wheel surfacing: *1* — base metal; *2, 3* — deposited metal produced using wires VELTEK-N300RM and VELTEK-N280RM, respectively

25 mm per a flange, which causes the need of replacing a wheel each 1–3 months.

Flux-cored wires VELTEK-N300 and VELTEK-N350 of 1.6–4.0 mm diameter were used in combination with fluxes AN-348 and AN-60 for surfacing crane wheels in CO_2 atmosphere. In recent years wire VELTEK-N300RM is successfully used instead of solid wire Np-30KhGSA. For surfacing wheels of heavily loaded cranes technological option was developed, at which the most intensively worn flanges were surfaced using flux-cored wire VELTEK-N285RM of 3 mm diameter in combination with flux AN-348. Cr–Mn deposited metal, having structure of metastable austenite, ensures high wear resistance due to development of self-reinforcement under action of work hardening, which is manifested in hardness increase from HRC_e 28–32 to 42–45. Less worn wheel treads were surfaced using flux-cored wire VELTEK-N300RM in combination with flux AN-348, hardness of deposited metal being HRC_e 300–350 (Figure 5).

This technology allowed increasing service life of wheels 2 times, while material consumption increased only by 70 %, and labor input into machining increased by 35 %.

Parts of mining machines and crushing-grinding equipment. At present CJSC «Krivorozhie Mining Equipment Plant» is an advanced enterprise in Ukraine, which produces and repairs mining equipment. High share of welding and renovation operations are performed at this plant using arc welding and surfacing. The plant uses wide nomenclature of welding and surfacing consumables due to the need of welding low-carbon low-alloy, low-alloy high-strength, and high-manganous and heat-resistant steels; welding of dissimilar steels, cast steels, and correction of casting defects. In majority of cases these are large-size items, that's why special requirements are established to welding materials, technology, and technique of welding and surfacing. Because of this reason improvement of quality of the works and reduction of material, power, and labor consumption are actual tasks. Flux-cored wires completely meet these requirements. Within the last five years the Krivorozhie Mining Equipment Plant jointly with TM.VELTEK increases volumes of arc welding and surfacing operations using flux-cored wires. As a result a range of flux-cored wires of various designations were developed and introduced. The share of flux-cored wires in general volume of the consumables used for welding and surfacing increased from 15 to 85 %. Efficiency of welding and surfacing increased in comparison with coated electrodes due to higher productivity and quality of work, and reduction of volume of works connected with a repeated quality control. Traditional mistrust to flux-cored wires in regard to their application for producing quality welded joints and reinforcement coatings significantly reduced. Below several examples of flux-cored wire application at the enterprise of TM.VELTEK, Ltd. are given.

Figure 6. Welding of mill bowl

Bowl of cone crusher KKD-1500 was welded. The bowl of 50 t mass, manufactured from steel 35L, was made of two parts — lower and upper ones, which were welded together. Horizontal field joint of 2980 mm diameter was produced using double-sided bowl-like beveling, the metal thickness being 180 mm. CO_2 welding (at DCRP) was performed using flux-cored wire PPs-TMV29 of 1.6 mm diameter (Figure 6).

Welding of parts and units of agglomeration and enrichment equipment and mining machinery (including units of excavators from steel grades St3ps, 09G2S), and welding up of cast parts from steel grades 20L and 35L, are performed at mentioned enterprise using gas-shielded flux-cored wires PPs-TMV5, PP-AN8, PPs-TMV8, PPs-TMV29, and units, produced from low-alloy high-strength steels 12Kh2NMSA and 12Kh2NVSA, are welded using wire PP-AN-57. The most efficient for welding-up casting defects in steels 20L and 35L is flux-cored wire PPs-TMV5. Due to low content of slag (4–5 %) there is no need in its removal in the process of welding-up deep grooves. High wire utilization factor $K = 1.08$ and resistance against formation of pores and cracks prove advantage of this wire over other welding consumables.

For welding parts of heat-resistant Cr–Mo steels 15KhM, 12KhM, 20KhML and 35KhML, and welding-up casting defects gas-shielded flux-cored wire PPs-TMV14 of 1.6–2.0 mm diameter with the core of carbonate-fluorite type is used.

Welding-up of high-manganous steel 110G13L casting defects is performed by self-shielded flux-cored wire VELTEK-N220 of 2 mm diameter.

Surfacing of reinforcement layers on locking bars of bottoms, cutting edges and bodies of excavator buckets, edges of inlet devices of ball mills, bodies of sludge pumps, pumps of suction-tube dredgers, road grader and bulldozer blades is performed using self-shielded flux-cored wires VELTEK-N580, VELTEK-N600, VELTEK-N605, and VELTEK-N620 of 2--3 mm diameter (instead of electrodes T-590 and T-620) and flux-cored wires PP-AN-125, PP-AN-170, Linocore 60-O, Linocore 60-S, Linocore 65-0, DÜR 600-FD, DÜR 650, DÜR 650MP, OK Tubrodur 14.70, and OK Tubrodur 15.52.

For renovation surfacing of hydraulic press plungers and protection bushings of suction dredges, designed for pumping slurry, flux-cored wire VELTEK-N410 of 2.4--3.6 mm diameter is used in combination with fluxes AN-20 and AN-26, and for open-arc surfacing wire VELTEK-N420 of 1.4--3.0 mm diameter is used. For surfacing parts of mining hydraulic equipment flux-cored wire VELTEK-N425 of 2 mm diameter is used in combination with fluxes AN-20 and AN-26, surfacing process being characterized by high stability, good formation of metal, and spontaneous separation of slag crust. Deposited metal, produced according to this process, has high corrosion resistance and is fit for operation in mine faces.

ADVANCED WELDING CONSUMABLES FOR FABRICATION OF STRUCTURES FROM COLD-RESISTANT STEELS IN DIFFERENT INDUSTRIES

V.V. GEZHA, R.V. BISHOKOV, S.I. SHEKIN and **P.V. MELNIKOV**
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The paper gives the characteristics of new electrodes, ceramic flux and flux-cored wire for welding cold-resistant steels of different strength levels.

Keywords: arc welding, coated electrodes, agglomerated fluxes, flux-cored wires, welding-technological properties, deoxidizers

Federal State Unitary Enterprise «Central R&D Institute of Structural Materials PROMETEJ» developed a series of welding consumables for welding structures from cold-resistant steels of different strength levels, which have become widely accepted in local and foreign companies in construction of critical structures. However, changes in the raw materials sources, requirements to welding consumables and range of manufactured structures require a continuous improvement of welding consumables.

In view of the absence of enterprises in Russia, manufacturing quality ferrotitanium, as well as a continuous increase of its cost, the issue of development and introduction of welding consumables, not containing ferrotitanium in their composition became urgent. The developed welding consumables should satisfy the requirement of ensuring welding-technological and service properties of welds on a level not lower than that provided by the currently available consumables of a similar composition, containing ferrotitanium.

The following slag systems were studied at electrode development: $CaO–CaF_2–SiO_2–TiO_2$ and $CaO–MgO–SiO_2–TiO_2$, as well as three systems of weld metal deoxidation: Si–Mn, Si–Mn–Al and Si–Mn–Mg. Welding electrodes have been developed, providing a set of high welding-technological and service properties. Mechanical characteristics and composition of weld metal, obtained at testing the best variants of the electrodes, are given in Table 1. Electrodes with the slag system of $CaO–CaF_2–SiO_2–TiO_2$ and Si–Mn system of weld metal deoxidation have the highest service and welding-technological properties. These electrodes are currently being put into production.

With the start of production of large-diameter thick-walled pipes for the needs of the gas and oil industries, and in connection with pipe production transfer from fused to agglomerated fluxes the issue of development and introduction of the latter for multi-arc high-speed welding became urgent. During their development the agglomerated flux of 48AF-51 grade earlier developed by PROMETEJ was used as a basis. As multi-arc high-speed welding has a number of different features compared to single-arc automatic welding, in order to improve the adaptability to fabrication of the process of multi-arc welding, the flux composition was corrected to lower its basicity. Systems of deoxidation and alloying were corrected to provide the required cold resistance of weld metal.

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Table 1. Mechanical characteristics and composition of weld metal made with test electrodes

Slag system and system of weld metal deoxidation	Wire grade	Average values of mechanical characteristics of weld metal						Weld metal composition, wt.%					
		σ_t, MPa	σ_y, MPa	δ, %	ψ, %	*KV*, J / m^2, at temperature, °C		C	Si	Mn	Ni	S	P
						–40	–60						
$CaO–CaF_2–SiO_2–TiO_2$, Si–Mn	Sv-08A	524	427	31	74	95	80	0.05	0.25	0.88	--	0.019	0.029
$CaO–CaF_2–SiO_2–TiO_2$, Si–Mn	Sv-10GA	545	460	30	75	110	70	0.06	0.17	0.82	0.98	0.005	0.010
$CaO–MgO–SiO_2–TiO_2$, Si–Mn–Al	Sv-10GNA	575	500	23	71	60	40	0.05	0.33	1.17	1.10	0.003	0.014
$CaO–MgO–SiO_2–TiO_2$, Si–Mn–Mg	Sv-10GNA	565	480	23	72	90	65	0.05	0.16	0.79	1.10	0.003	0.015

Table 2. Mechanical characteristics of welded joints on steel X65 made by automatic submerged multi-arc welding

Sample No.	Welding wire of 4 mm dia. + flux	Average values of mechanical properties of weld metal				Relative humidity of flux, %		Impact toughness of metal in weld center on Charpy samples *KV*, J / m^2, at different temperature, °C			
		σ_t, MPa	σ_y, MPa	δ, %	ψ, %	After baking	72 h after baking	–30	–40	–50	–60
1	Sv-10GNA + 48AF-55	664	585	25.3	0.88	0.002	0.024	166	136	--	120
2	Sv-10GNA + 48AF-55	644	561	29.0	0.87			160	153	149	131
3	Sv-10GNM + 48AF-55	691	608	22.5	0.88			99	92	85	58
4	Sv-10GNM + OK Flux 10.74	725	649	22.0	0.90	0.003	0.040	115	95	--	49
Requirements to weld metal			> 450		< 0.9						> 45

Flux of 48AF-55 grade developed by PROMETEJ and tested under production conditions in the mill of Vyksunsky Metallurgical Works, demonstrated a high level of welding-technological and service properties of weld metal. Mechanical characteristics of weld metal, made with flux of 48AF-55 grade, are given in Table 2. A feature of the developed flux is its low hygroscopicity, compared to foreign analogs, this greatly simplifying the technological process of its application. The flux currently is at the stage of introduction at the Vyksunsky Pipe Plant.

In addition, PROMETEJ developed flux-cored wire designed for making the root (assembly) welds, as well as for welding in site (weld metal composition, wt.%: 0.05C, 0.26Si, 1.1Mn, 1.25Ni, 0.02S, 0.007P). The wire was named 48PP-10T. Wire manufacture and testing were conducted at Cherepovets Steel-Rolling Plant. The wire features high welding-technological properties in welding in all the positions. Mechanical characteristics of weld metal made with this wire at 20 °C are as follows: σ_t = 585 MPa; σ_y = 498 MPa; δ = 27 %; ψ = 70 %; impact toughness *KV* = 90 (at –40 °C) and 64 J / m^2 (at –60 °C).

APPLICATION OF THE TECHNOLOGY OF MECHANIZED UNDERWATER WELDING IN CONSTRUCTION OF OFF-SHORE ICE-RESISTANT PLATFORM «PRIRAZLOMNAYA»

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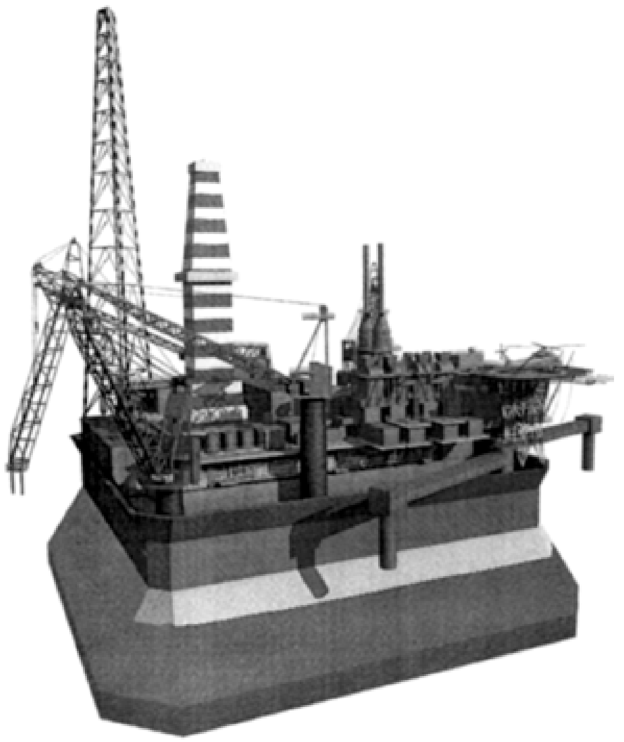
Specifics of mechanized underwater welding of butt sealing devices for off-shore ice-resistant stationary platform using flux-cored wire PPS-EK1 is described.

Keywords: mechanized underwater welding, flux-cored wire, off-shore platform

On September 7, 2005 underwater welding operations were completed, which were performed starting from November, 2004 in Severodvinsk Federal Srate Unitary Enterprise «PA Sevmashpredpriyatie» by divers of INTERAKVA company registered in Russia. This work allowed joining the last (third) butt sealing device in the lower part of the off-shore ice-resistant platform «Prirazlomnaya». The metal structure weight is approximately 70,000 t with overall dimensions of $126 \times 126 \times 24.5$ m (Figure). No welding operations of similar scale or complexity have been earlier conducted underwater in the territory of CIS countries. In the world practice such metal structures are joined with application of special heavy-load pontoons, which are ordered 3–4 years before the moment of work performance. At smaller volumes of work flexible kessons can be used.

The work was performed with the supervision of the Russian Sea Register. In 55 working days, including preparatory-finishing time, 1800 m of single-pass welds were made at down to 8 m depths in the overhead and vertical positions. Preparatory-finishing operations include cramp mounting, butt clamping, surface scraping before welding, making tack welds, cramp dismantling, cleaning the tack weld surface before welding, scraping of each layer and layer-by-layer visual inspection for inadmissible visible defects with application of underwater TV unit. Connecting weld of the butt sealing device was formed in three passes. Average speed of welding a single-pass weld in the overhead position was equal to 6.0–6.5 m / h. Welding operations were performed using the technology of mechanized underwater welding by shielding flux-cored wires. PSP-3 semi-automatic machine for underwater welding made in Russia, as well as flux-cored wire 003-97 of PPS-EK1 grade (TU-14288312103–97) of 1.6 mm diameter, developed and supplied by EKO-TEKHNOLOGIYA (Ukraine) were used. After drying of the three butt sealing devices no water in-leakage through the underwater welds was detected. This was followed by welding the superassembly sections by standard technologies accepted by the company. Thickness of the joined metal on the bottom and sides was up to 36 mm.



Off-shore ice-resistant platform «Prirazlomnaya»

The next stage of work performance is cutting up the butt sealing devices into segments, using the technologies of underwater oxy-arc and exothermal cutting and removal of segments from under the kesson bottom, which are scheduled to be completed in December, 2005.

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APPLICATION OF A COMBINED ELECTRODE IN ELECTROSLAG WELDING OF THIN MATERIALS

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It is suggested that joints of a small length and thickness should be made by electroslag welding using a combination of consumable and nonconsumable electrodes. Technological peculiarities of the above welding process are described, and results of investigation of weld metal produced in welding of KhN38VT alloy are given. Advantages of the new welding technology are shown.

Keywords: electroslag welding, combined electrode, high-temperature alloy, mechanical properties

Circular billets from refractory alloys of thickness δ = = 10–30 mm are becoming widely accepted in several general and special engineering industries. It is recommended to apply single-pass electroslag welding (ESW) in fabrication of such products. ESW of short welds at a comparatively small thickness of parts being welded is performed using a wire electrode. The welded joints often have lacks-of-penetration and undercuts of the edges being welded.

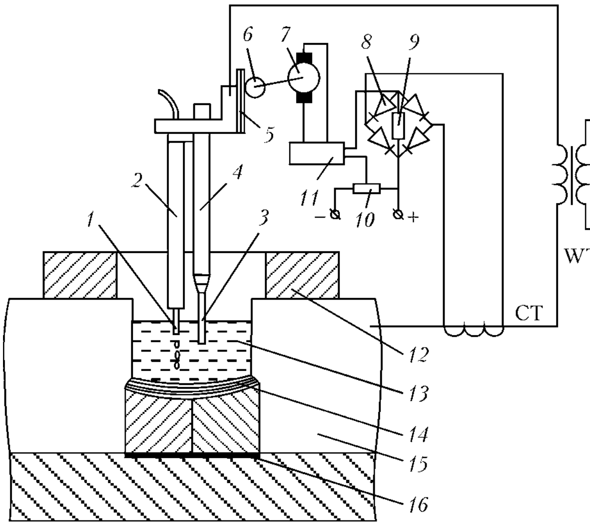

Figure 1. Schematic of combined electrode welding (for explanations see the text)

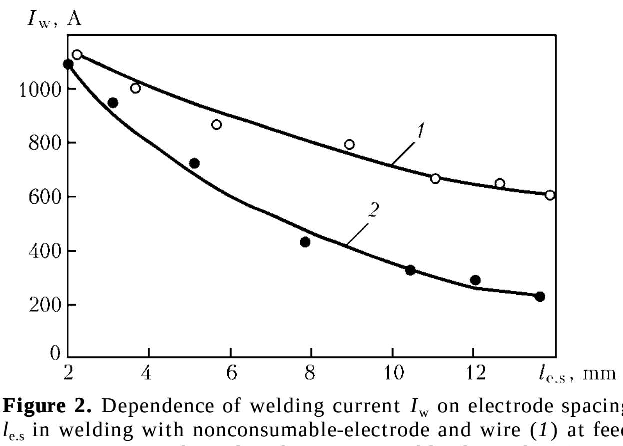

Figure 2. Dependence of welding current I_w on electrode spacing $l_{e.s}$ in welding with nonconsumable-electrode and wire (*1*) at feed rate $v_{w.f}$ = 190 m / h, and with nonconsumable electrode (*2*)

To eliminate the above drawbacks, ESW with a «split» combined electrode (Figure 1) was used, which is conducted by simultaneous immersion of the nonconsumable and consumable electrode into the slag pool. A nozzle of a special design, simultaneously acting as electrode holder *4* with nonconsumable electrode *3* and guide *2* for wire *1*, is introduced into the gap formed by the edges being welded *15* and weld-forming coverplates *12* of the copper water-cooled device.

As in operation with non-cooled nozzle the slag process stability is disturbed due to increase of contact resistance of the wire slip surface in the guide channel, a water-cooled electrode holder was used in the device. Cooling allows up to 1500 A current flowing through the current supply and increasing the «dry» electrode extension up to 20–30 mm. In order to prevent short-circuiting at small gaps, the nozzle is insulated by a layer of aluminium oxide deposited on its surface. To create the slag pool, the nonconsumable electrode is shorted to the device bottom through seed-substrate *16* from the metal being welded with δ = 1.5–2.0 mm, which is followed by flux pouring. Slag pool *13* is induced by flux melting by the heat evolved during the electric current passage in the nonconsumable electrode–device bottom circuit. Wire electrode feed is switched on after surface melting of the edges being welded. From this moment the welding current runs both through the nonconsumable and the consumable electrodes through a common current supply. Heat evolved in the slag pool, melts the edges being welded and the filler material, and metal pool *14* is induced. At the end of welding, electrode wire feed is interrupted, and the possibility of shrinkage cavity development is eliminated due to metal pool heating by the nonconsumable electrode with its gradual withdrawal from the slag pool.

However, stability of such a welding process is not high. This is caused by disturbance of the self-regulation

Table 1. Optimum parameters of ESW of EI-703 alloy with a combined electrode

δ, mm	$d_{n.e}$	I_w, A	U_a, V	v_w, m / h	$v_{w.f}$, m / h
16	8	800–1000	18--19	5.4--6.0	160–180
18	8	900–1100	19--20	4.9--5.6	180–200
20	10	1000–1200	20--21	4.5--5.5	190–220

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Table 2. Mechanical properties of weld metal produced in ESW of EI-703 alloy

Electrode type	σ_t, MPa	σ_y, MPa	δ, %	ψ, %	KCU_{+20}, MJ / m^2
Combined	526–561 / 541	271–306 / 285	29.3–32.5 / 30.4	43.2–48.7 / 45.8	1.35–1.59 / 1.47
Wire	483–516 / 498	242–261 / 251	24.1–28.6 / 26.1	31.7–42.6 / 36.9	1.10–1.26 / 1.16

process at addition of a nonconsumable electrode to the slag pool, this leading to considerable fluctuations of welding current and, as a result, to slagging. This is confirmed by experimental dependencies of current on electrode spacing $l_{e.s}$, obtained in welding with a nonconsumable tungsten electrode of diameter $d_{n.e}$ = = 8 mm with application of EP-533 electrode wire of 3 mm diameter and ANF-21 flux (Figure 2).

As is seen from the Figure, in the range of maximum working currents (800--1100 A) the nonconsumable electrode current has a dominant role. Therefore, its stabilization is required to produce sound welds. An automatic machine has been developed for current stabilization during welding by changing the distance between the metal pool and nonconsumable electrode by its displacement in the slag pool (see Figure 1). At connection of TShS-3000 welding transformer (WT), current flows through the circuit of WT--electrodes *1* (consumable) and *3* (nonconsumable)--slag pool *13*--metal pool *14*--welded workpiece *15*--WT second pole. On the other hand, variable voltage proportional to welding current, is induced in the winding of the current transformer (CT). This voltage is rectified using bridge *8* and is transferred to resistance *9*. Required value of welding current is assigned by potentiometer *10* in the form of DC voltage. Setting voltage and voltage proportional to the actual current in the welding circuit, are equalized at the input of amplifier *11* and generate the input signal. Amplified voltage of the respective value and polarity appears at the amplifier output, which rotates servomotor *7*, engaging gear wheel *6* and rack *5*, on which the nonconsumable electrode is rigidly fixed. In case of lowering of current value in the welding circuit, compared to the required (set) value, the motor will move the rack downwards, reducing the distance between the nonconsumable electrode and metal pool. This will lead to increase of welding current, as the conductivity of the nonconsumable electrode--metal pool section is increased. With current increase in the welding circuit above the required value, the motor rotation is reversed. As a result, the rack, and, therefore, also the nonconsumable electrode, move upwards, thus lowering the current. Thus, the required value of welding current is maintained automatically with certain accuracy. Testing of the developed device showed that the minimum welding current amplitude $I_w = \pm 10$ A, its maximum frequency being $f = 2$ Hz.

Retrofitting of the technology of ESW by a combined electrode was conducted on samples of alloy EI-703 (KhN38VT) of thickness δ = 10–30 mm, using the above welding consumables.

As a result of the conducted experiments, optimum modes of ESW by a combined electrode have been established (Table 1). In such modes, the welds form without lacks-of-fusions, undercuts or slagging (Figure 3).

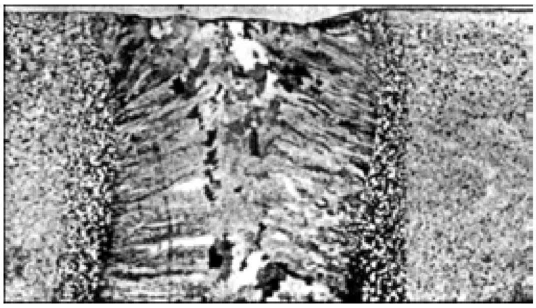

Figure 3. Macrostructure of weld produced in ESW of EI-703 alloy by a combined electrode (×2.5)

Results of mechanical testing showed that the properties of the weld metal, obtained using a combined electrode, are higher than in the case of a wire electrode (Table 2).

Evaluation of weld metal composition by the main alloying elements, conducted in an optical-emission analyzer ARG-MET-930P, showed that titanium losses in welding with a combined electrode are equal to 2--15 %, while in welding with the wire they are up to 20--26 %. This is attributable to lower heating of the consumable electrode in its extension at its feeding into the slag pool simultaneously with the nonconsumable electrode at their powering through one current supply. In addition, tungsten concentration even increased in the first case, while in the second case its loss is up to 5--7 %. This, apparently, results from electrolytical alloying of weld metal due to partial dissolution of the nonconsumable electrode. As shown by experiments, tungsten electrode consumption in welding at a symmetrical alternating current is equal to 0.2 to 0.8 g / min, depending on the mode parameters. It is obvious that increased concentration of the main alloying elements in combined electrode welding, leads to higher mechanical properties of the weld metal than in the case of a wire electrode.

Obtained results showed the rationality of application of ESW by a combined electrode in production of thin items from high-temperature alloys.

CONCLUSIONS

1. Application of a combination of a consumable and nonconsumable electrodes in ESW of thin high-temperature alloys allows eliminating formation of lacks-of-fusion, undercuts and slagging.

2. Improvement of mechanical properties of the weld metal in ESW of refractory alloys by a combined electrode is due to its electrochemical alloying as a result of partial dissolution of the nonconsumable electrode.

THESIS FOR SCIENTIFIC DEGREE

E.O. Paton Electric Welding Institute of the NAS of Ukraine

M.Yu. Kharlamov (V. Dal East-Ukrainian National University) defended on October 12, 2005 his thesis for a candidate of technical sciences degree on subject «Improvement of Efficiency of Technological Processes of Detonation Coating Spraying on the Basis of Comprehensive Mathematical Model». Thesis is devoted to developing mathematical models of the processes of detonation coating spraying (DCS), studying on their basis regularities of behavior of powder particles in spraying, and developing methods for selection of rational technological conditions and reduction of costs for development of technological processes (TP) of DCS.

Results of theoretical studies of physical processes, which proceed in DCS, are generalized, and structural scheme of their comprehensive mathematical modeling is developed, whereby input and output parameters of models of main DCS stages are singled out and their interaction is established.

Model of pulse jet generation for gas detonation products is proposed. Mathematical model is developed, which allows determining spatial-time characteristics of a flow of spraying particles both inside the detonation unit barrel and in external environment, including variable section barrels. Respective software is developed.

Numeric studies of behavior of powder particles in detonation spraying are carried out. It is established that acceleration and heating of particles in detonation spraying occur in two stages: behind the detonation wave and in the vacuum wave. It is shown that in the process of bi-phase flow efflux from the detonation unit barrel powder cloud is stretched in radial and axial directions, the particles being deviated from straight-line trajectory of movement. By means of reduction of the density of material of particles and their diameter, degree of their radial deviation increases. The degree of radial displacement of particles in the process of their movement depends also upon their initial position relative the barrel axis. Radial displacement of powder particles, located near the barrel axis, is negligent and significantly increases when particles are located near the barrel walls. Possibility is substantiated of controlling speed and temperature of spraying particles by means of a set of technological parameters of detonation spraying: shape and size of the barrel; combustible mixture composition and degree of the barrel filling; volume of a powder dose and its spatial distribution; shape and size of powder particles; and distance of spraying.

Principles of developing system for decision-making support (SDMS) are developed for designing DCS TP. The system consists of a block of independent modules. Information retrieval system, which contains information on developed thermal spray coatings and facilitates their selection by industrial engineers, and automated system for retrieval of rational spraying conditions, which ensure necessary for obtaining assigned properties of the coatings speed and temperature of powder particles, are structural elements of SDMS. Method based on genetic algorithm and software for its use are developed for rational selection of technological conditions. Application of this method significantly reduces time for development of detonation spraying technologies.

Control algorithm and recommendations on construction of a comprehensive system of the DCS process automated control are proposed. Basis of the control system is SDMS, the results of operation of which are used for direct control of the technological complex equipment for DCS.

THESIS FOR SCIENTIFIC DEGREE

E.O. Paton Electric Welding Institute of the NAS of Ukraine

C.V. Alekseenko (Chernigov State Technical University) defended on the 12th of October 2005 his thesis for a candidate of technical sciences degree on subject «Solid-State Joining of Single-Crystal Silicon to Borosilicate Glass». The thesis is focused on development of the method for determination of the optimal time of electrostatic-field solid-state joining of single-crystal silicon to borosilicate glass, as well as improvement of the technology for joining multi-layer assemblies of the silicon--glass–silicon type.

The extent of formation of a joint was found to depend upon the value of the joining current density at the initial moment of application of joining voltage, i.e. the peak value of the joining current density. It is shown that the peak value of the joining current density is determined by the area of an actual contact between the mating surfaces and value of the ratio of the rated contact area between the parts to the total perimeter of the side surfaces of a tubular glass part. At a constant joining voltage, the peak value of the joining current density and rate of formation of a joint decrease with increase in the above ratio.

As found by measuring the rate of approach of the surfaces during joining, formation of a physical contact takes place at the initial moment of application of the joining voltage. The value of the electrostatic compression forces was established to depend upon the intensity of the electric field in an air gap between the mating surfaces, which in turn is determined by the ratio of the joining voltage drop at contact resistance to the air gap size.

It was revealed that the time of joining silicon to glass depends upon the volume of micro voids formed in the contact zone of the materials under the effect of the electrostatic compression forces, as well as upon the initial value of the joining current density at the moment of application of the joining voltage. In a general case, with increase in roughness of the surfaces from 14 (R_z = 0.025 μm) to 13 (R_z = 0.1 μm) class of surface finish, the required strength of the joints is achieved by holding a joint under voltage for a longer time.

A new method was developed for determination of the joining time directly during the joining process. The method allows a reasoned holding of an assembly under voltage.

Decrease in strength properties of glass in the assemblies after joining takes place because of formation of a layer in the sub-surface area in contact with silicon, which is characterised by structural changes caused by migration of sodium ions to a cathode during the joining process. Strength properties of this layer decrease with increase in its thickness, which, at an established joining time needed for the joint to be formed over the entire contact plane, grows with increase of the ratio of the rated contact area between the parts to the total perimeter of the side surfaces of a tubular glass part, or with increase in roughness of the mating surfaces. Decrease in thickness of the sub-surface glass layer characterised by structural changes occurs in the case of using the maximum possible level of the joining voltage during the joining process, limited by a stress in the glass lap area.

It was found that the absence of lacks of penetration and burns-through in the contact zone, which might be caused by development of the electric-discharge processes in the air gap, and strength of glass in a joint in uniaxial tension tests at a level of not lower than 12 MPa are provided at specific joining current densities of 10 to 50 μA / mm^2.

Analysis of the stressed state of the joints and mechanical tests of the glass-silicon assemblies used in semiconductor pressure sensors show that the silicon membrane becomes more resistant to the external mechanical impact with decrease in the ratio of the rated contact area between the parts to the total perimeter of the side surfaces of a tubular glass part. Therefore, it is proved that the glass-silicon assemblies should be designed so that the above ratio has a minimal value.

The research results were used as a basis for the development of the technology for electrostatic-field solid-state joining of multi-layer assemblies of semiconductor sensors of the silicon–glass–silicon type in one joining cycle.

70th BIRTHDAY OF PROF. K.A. YUSHCHENKO

Konstantin A. Yushchenko, a noted scientist in the field of welding technology and materials science, doctor of technical sciences, professor, honoured worker of science and technology of Ukraine, laureate of the state prizes of the USSR and USSR Soviet of Ministers, Paton Prize winner, academician of the National Academy of Sciences of Ukraine, and Deputy Director on science at the E.O. Paton Electric Welding Institute, is seventy this birthday on the 8th of December.

After graduating from the Kiev Polytechnic Institute in 1958, K.A. Yushchenko started his labour activity at the E.O. Paton Electric Welding Institute, where he has risen from an engineer-experimenter to deputy director.

Here he defended his theses for candidate (1965) and doctor of technical sciences (1982) degrees and acquired the title of professor (1987). He was elected a corresponding member (1990) and then academician (2003) of the National Academy of Sciences of Ukraine. From 1970 he was the head of laboratory, and later (since 1978) he became the head of department for metallurgy and technology of welding high-alloy steels and alloys.

The baseline direction of his scientific activity is development of new metallic materials, processes for their production, and welding and surface engineering technologies. The range of research covers development of weldable steels and alloys and elaboration of the theory of their welding for the manufacture of parts intended, in particular, for operation under extreme conditions of aggressive environments, cryogenic and high temperatures, radiation and strong magnetic fields.

In 1962–1965, K.A. Yushchenko completed a package of investigations on the theory of welding steels of the ferritic-austenitic grade. The principles of variations of physical-mechanical and corrosion properties of metal of a welded joint with a multi-component phase composition were defined. Selective character of electrochemical dissolution of phases depending upon alloying and linear sizes was studied. This served as a basis for the development of new ingenious systems of steels and welds sparsely alloyed with nickel, welding consumables and processes ensuring their wide application in chemical engineering.

From 1965, K.A. Yushchenko was managing investigations at the Ukr. SSR Academy of Sciences to develop new weldable steels and alloys for cryogenic engineering. The integrated studies were carried out in close collaboration with VNIIKriogenmash, I.P. Bardin TsNIIChermet (Moscow), Chelyabinsk Metallurgical Works, Uralkhimmash (Sverdlovsk), Spetstekhmontazh (Bajkonur), Dneprospetsstal, Novo-Kramatorsk Machine-Building Works, Izhorsky Heavy Engineering Plant and other organisations of the former Soviet Union.

The efforts resulted in finding solution to the problem of optimisation of steel and weld metal compositions proceeding from requirements for high specific strength and embrittlement resistance under different loading conditions at 4.2–293 K, including in strong magnetic fields, under radiation and thermal impact. The investigations performed, along with the theoretical studies, allowed development of fundamentally new well-weldable steels for cryogenic engineering, welding consumables and joining processes.

The pioneering process for the world and USSR practice, consisting in production of cold-resistant stainless steels with super low carbon content in 100 t arc furnaces, was applied at the Chelyabinsk Metallurgical Works. This initiated a new scientific area — cryogenic welding materials science, which was approved both in the CIS countries and abroad. The cycle of the work was completed on assessment of structural strength of welded joints at cryogenic temperatures.

Theoretical investigations served as a basis for the elaboration of codes and methods, accepted in Ukraine, Russia and other countries, for design of a new type of cryogenic structures, involving the method of low-temperature metal hardening.

More than 50 patented grades of steels, welding wires, electrodes and fluxes developed under the supervision and with participation of K.A. Yushchenko are used in cryogenic engineering. They were applied in such major projects as «Buran» (launching system), «Tokamak-7», «Tokamak-15» (power superconducting MHD generator complex), large space imitator, life support system, airborne engines of space systems, and a new generation of gas turbine engines. New steels and materials, as well as technological processes, developed by K.A. Yushchenko are included as candidates for building of the international fusion reactor ITER and stellators.

In 1985, K.A. Yushchenko elaborated new principles applicable for the processes causing formation of solidification and reheating cracks in welds. The role of dislocation and segregation processes for the upper and lower brittle ranges and cracking was substantiated theoretically and confirmed experimentally.

In 1975–2005, K.A. Yushchenko performed a cycle of investigations to study weldability of materials. The new theory of weldability and classification of methods for joining materials depending upon the aggregate state of the matter was elaborated. The new weldability criterion to evaluate the degree of material degradation in terms of energy widens technical capabilities for producing permanent joints of any structural metals and non-metals.

The team of scientists form the E.O. Paton Electric Welding Institute headed by K.A. Yushchenko, in collaboration with the Physico-Technical Institute of Metals and Alloys of the NAS of Ukraine, suggested, on the basis of investigations of embrittlement of high-chromium steels with bcc structure of the Fe–20Cr system, controlling the segregation phenomena occurring in recrystallisation of metal through controlling dispersion of impurities in the bulk of grain. These investigations opened up a new promising area in development of general-application well-weldable nickel-free corrosion-resistant high-chromium ferritic steels.

One of the scientific achievements is the development of the theory of welding high-alloy steels with super equilibrium nitrogen content, made by K.A. Yushchenko and his associates. The cycle of the performed work resulted in substantiation of the principles of producing sound joints in a new class of metals alloyed with super equilibrium amounts of gases. Investigations on the kinetics of denitriding allowed identification of conditions required for existence of quasi-equilibrium states in boundary zones of the solidifying metal and role of phase changes in metal of the «liquid–gas» system. Materials and processes permitting welding the metal with super-equilibrium nitrogen content of up to 1 % were developed for the first time in the world practice.

In 1986–2005, K.A. Yushchenko has actively participated in the efforts on development of new consumables and processes for surface engineering and coating. He conducted research on the development and application of special flux-cored wires for wear- and corrosion-resistant cladding, new types of wires and powders based on refractory materials, and compositions of alloys with amorphous structure. The consumables and processes developed found commercial application. They include such processes as vanadium carbide deposition, plasma detonation treatment, discharge-pulse treatment and microplasma spraying. Many of them are ingenious, covered by patents, and won international recognition.

K.A. Yushchenko is the author of over 650 publications and inventions, among which are 7 monographs. More than 35 theses for a candidate of technical sciences degree and 7 theses for a doctor’s degree were prepared under the supervision of K.A. Yushchenko. He is very active in the field of science organisation. In 1989, he was elected a vice-president of the International Institute of Welding. From 1986 till 1992, he was a deputy chairman of the National Welding Committee of the USSR. Since 1993, he has been the chairman of the National Welding Committee of Ukraine, and since 1990 — manager of the «Permanent Joints and Coatings» and «New Substances and Materials» programs. K.A. Yushchenko is the head of the coating session at the Inter-State Science and Technology Council of the CIS countries, and since 1983 — member of the board of the Department for Physical-Technical Problems in Materials Science of the NAS of Ukraine, member of the Specialised Board for defence of theses at the E.O. Paton Electric Welding Institute, member of the editorial boards of the «Avtomaticheskaya Svarka» (Automatic Welding) and «Svarshchik» (Welder) journals, member of the Technical Committee and chairman of the Select Committee of the International Institute of Welding for joining and coating of advanced materials for aircraft engineering. Since 1984, he has been a member of the top executive boards of international organisations on cryogenic engineering and cryogenic materials.

K.A. Yushchenko was awarded the diplomas of the Ukr. SSR Supreme Council, the Order of the Friendship of Peoples and medals. In 1994, he was elected a full member of the International Electrotechnical Academy (Moscow).

PLASMA CUTTING OF METALS UNDER WATER

Plasma cutting of metals under the water is one of the often applied and rather labour-consuming kinds of underwater-engineering operations, requiring high qualifications of the divers and considerable expenses. In practice underwater cutting is used at emergency-rescue underwater-engineering operations in the open sea or in shippable rivers (for instance, at repair of the underwater part of a ship without placing it into a dock). The need to perform underwater cutting often arises in fabrication or repair of coastal hydraulic engineering facilities, and (in considerable volumes) at severing of sunk ships, salvaging of which as one piece is difficult. Such operations have to be performed, when it is necessary to clean the coastal sea areas, port warfs, river water areas, etc., from the sunk ships. In most of the cases, severing of sunk ships is justified by ecological requirements, and the expenses are partially compensated by sale of metal scrap, produced when severing the salvaged ship parts on the shore.

Currently available methods of underwater cutting of metals are low-efficient and involve considerable expenses for equipment or materials. For instance, with the most widely accepted traditional method of oxy-arc cutting of steels 15 mm thick at 7–10 m depth, the average cutting speed is 2 m / h, and up to 1 m^3 of oxygen and 12 tubular electrodes with a special coating are consumed in cutting 2 m of steel. It is also necessary to take into account the time, spent by the diver for electrode replacement and metal scraping along the entire length of the cut. Semi-automatic underwater cutting is related to consumption of deficit flux-cored wire and increased consumption of power.

Explosive cutting methods do not meet the ecological requirements to underwater operations, and abrasive-jet cutting requires expensive high-pressure equipment (of several thousand atmospheres) and high consumption of the abrasive.

The method of underwater air-plasma cutting (UAPC) proposed by us differs from the currently available ones by a high efficiency and cost-effectiveness. It essentially consists in through-thickness penetration and metal blowing out of the cut cavity by a high-temperature (16,000–20,000 °C) air-plasma jet, formed by compressed air fed into the electric-arc chamber of the plasma cutter. Ingenious circuit of plasma cutter water cooling in combination with a system of plasma jet formation ensures a small weight and overall dimensions of the cutter, and improves the effectiveness of metal severing.

The unit called Delfin-1 consists of a DC power source and plasma cutter, connected to the source by a cable-hose assembly. Power is supplied to the source from an on-board system or diesel-generator set (380 V). Consumed power of the unit, including power of the compressor (up to 10 kg / cm^2 pressure, up to 6 m^3 / h air flow rate) and the pump (up to 4 kg / cm^2 pressure, up to 0.5 m^3 / h water consumption) is equal to 50–80 kW, depending on the depth of work performance. Reliable insulation of cutter current-carrying elements and cable-hose assembly, as well as automatic system of voltage supply from the source to the cutter during arc striking and its instantaneous switching off at arc extinction provide complete safety of the diver against electrocuting. Length of the cable-hose assembly of the plasma cutter is 30 m, considering operation at down to 20 m depth. Quality cutting of steel and aluminium structures of up to 25 mm thickness is guaranteed down to such a depth.

Thus, at UAPC using Delfin-1 installation, compressed air is the only cutting tool, and calculation of the cost of one running meter of the cut is performed taking into account the consumption of power (or diesel fuel at independent power supply), cost of replaceable parts and diver descents. For comparison, at 7–10 m depth the average speed of cutting 15 mm thick steels by UAPC method is 20 m / h, i.e. it is by an order of magnitude higher than that of oxy-arc cutting, this being quite important, considering the limited time of the diver staying under the water. Replacement of the cathode and nozzle of the plasma cutter is performed approximately after 1 h, and the need to scrape the metal along the cut line is eliminated.

UAPC method was checked more than once in the shop at down to 30 m depth. Cutting technique is quite simple, and does not require the diver-cutter to have high level of skills. Air-plasma cutter is resting through a special attachment on the metal to be cut, plasma arc is struck by a light pressing, and then the cutter, resting on the metal, easily moves along the cut line. There is no need for the diver to maintain the arc length «by eye» (as is required in oxy-arc cutting for a stable arcing). Plasma arc hidden by the attachment, does not blind the diver, and metal cutting through is controlled by the cutting flame, visible through the cut. Automatic switching on of the arc by a light pressing on the cutter, and its switching off by moving the cutter back up to the arc extinction, simplify the diver operation.

An important advantage of Delfin-1 unit is the possibility of using it on land for severing the salvaged parts of the ship for scrap.

As regards the diver protection means, the unit meets the requirements of GOST 12.2.035–78 SSBT: Diver Outfit and Supporting Means for Diver Descents and Operations.

PLAZMOTRON Company supplies units of Delfin-1 type, performs setting up and adjustment operations and training of divers-cutters in the customer facility, guarantees reliable operation of the unit, prompt supply of plasmatron replacement parts and spare parts.

For unit purchasing please contact:
NPMGP «Plazmotron»,
9a, E. Potier st., Kiev-57,
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ELECTRON BEAM MELTING OF TITANIUM SPONGE BLOCKS


Appearance of electron beam unit UE 185 for ingot surface melting

In order to lower the cost of the initial charge materials, the E.O. Paton Electric Welding Institute suggested performing remelting of uncrushed titanium sponge blocks (Figure 1) in a specialized EB unit with an intermediate crucible (Figure 2). In this case cleaning of the block surface to remove the films or contamination is performed directly in EB unit at the preheating stage.


Technological fixtures for surface melting of round ingots

During melting the bloom is continuously fed into the working space, where the block bulk heating and its preliminary degassing occur under the impact of the electron beams. The process runs in a stable and steady manner (Figure 3). Comparison of EBMIC metal yields shows that the titanium losses for evaporation are practically the same in melting of the bloom and lumpy wastes, and are by 30 to 40 % less than in melting of crushed sponge of 12 to 70 mm fraction.


Titanium ingots of 110–600 mm diameter after surface melting

Distribution of impurity elements is uniform along the ingot length (Figure 4), and their content is in the range of standard requirements. Ultrasonic testing of the ingots and template studies showed that the metal structure is dense, uniform and without defects.

Proposed technology of EBMIC of titanium sponge blocks provides 20 % improvement of the technical and economic characteristics, compared to EBMIC of sponge titanium of 12–70 mm particle size.

Application. The technology is applied to produce sound titanium ingots directly from uncrushed blocks of titanium sponge.


Titanium slabs of 165×950×2000 mm size after surface melting

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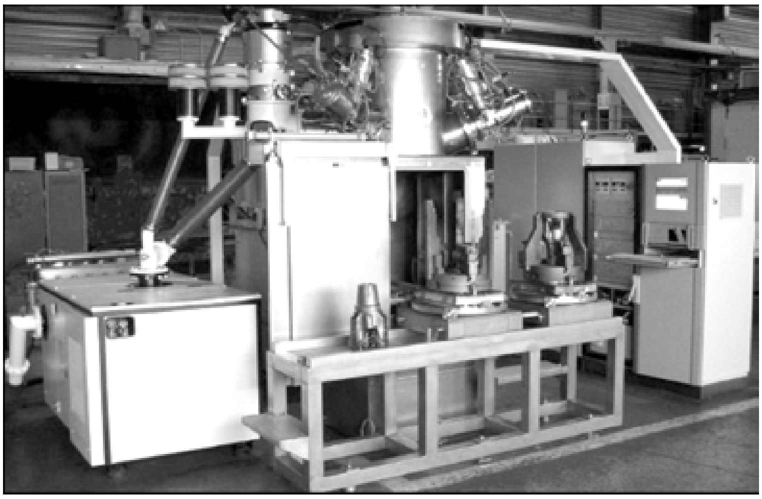
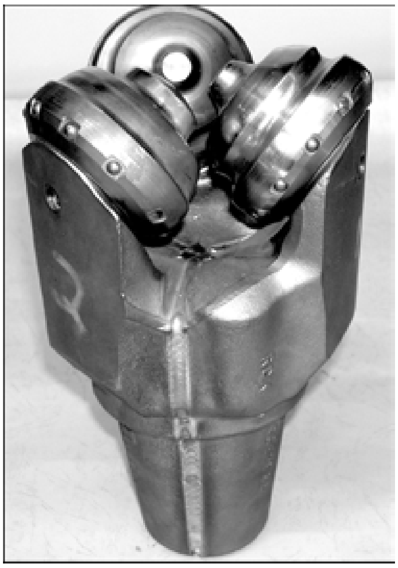
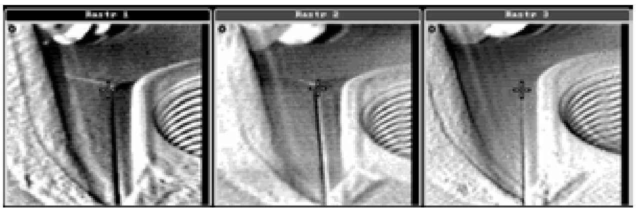
3-GUN MACHINE KL-117
FOR ELECTRON BEAM WELDING OF DRILL BITS





✔ Machine is intended for electron beam welding of drill bits up to 17.5" diameter with simultaneous performance of three welds, thus increasing both accuracy of drill bits dimensions and welding output.



✔ Application of a powerful control electronic tube in the accelerating voltage source prevents the arc processes in the welding gun by a short interruption of accelerating voltage, which does not lead to weld formation defects.

✔ The RASTR system, functioning on the principles of raster electron microscope, enables following the welding process and automatic coquidance of each of three electron beams to the butts of groove faces in the real time. The clear picture of the welding process is displayed on the monitor screen and is not exposed to the welded metal vapors, which is characteristic for traditional optical observing systems.

✔ Machine is provided with the electron beam diagnostic system allowing an operator:

- to define the beam focusing plane position prior to welding;
- to periodically evaluate changes in space and energy beam parameters in order to define the necessity of the welding gun cathode replacement.

✔ Lanthanum hexaboride cathode as a tablet has service life of not less than 40 h in the welding mode at beam power of 20 kW, and the beam axis position does not change at changes in beam focusing.

✔ Control of all equipment subsystems by means of CNC + PLC.

✔ The computer system of electron beam scanning stabilizes the molten pool state and improves the quality of face and root surfaces formation of the weld.

E.O. Paton Electric Welding Institute of NASU
11, Bozhenko Str., 03680, Kiev, Ukraine; Tel. / fax: (38044) 525 4319
E-mail: nazarenko@technobeam.com.ua www.nas.gov.ua / pwj / beam / index.html

ADVANCE BOOK INFORMATION

FORTHCOMING BOOK INFORMATION

Vladimir I. Makhnenko, Viktor E. Pochynok. STRENGTH CALCULATION OF WELDED JOINTS WITH CRACK-LIKE IMPERFECTIONS.
Approx. 300 pp., 165×235 mm, hardback. November 2005. US$ 90

In this manuscript, the idea of the fitness-for-purpose concept is used to improve strength calculations of welded joints with crack-like imperfections caused by structural or technological factors. These include welded joints with fillet, spot, slot and butt welds having sharp fissures brought by geometry of the elements welded and limited sizes of the weld sections. Such joints are widely encountered in modern general-purpose welded structures used in civil building, shipbuilding, automobile industries, etc.

The welded joints just mentioned do not usually cause problems for structures of relatively ductile materials with small-to-medium thicknesses of component sections, and operating under predominantly static loading. However, the use of new structural materials, especially high-strength steels and aluminum alloys, etc., large cross sections of structural elements, and loading with alternate loads, requires a certain caution to be taken. Nonetheless, the technological advantages that these joints produce attract an interest in their use, of course, when it does not cause any harm to the structure safety and its residual service life.

Performing strength calculations based on the fitness-for-purpose criterion for the joints encountered in general-purpose structures, allows ensuring the requirements concerning the service life-time. However, there is a difficulty of implementing such calculations in wide engineering practice. As shown by the authors, a successful implementation of the mentioned concept for general-purpose welded joints and for wide range of users is possible only when it is based on the use of corresponding computer systems with friendly user interface, which do not require a user to have a special knowledge in fracture mechanics, deformation mechanics, numerical methods, etc. Such systems are to be portable and efficient, i.e. calculations of appropriate section sizes or verification of strength of specific joints should be done promptly. In turn, it requires development of numerical procedures and creation of specialized databases that simplify and accelerate calculations.

Viktor Ya. Kononenko. TECHNOLOGIES OF UNDERWATER WET WELDING AND CUTTING.
Approx. 140 pp., 140×200 mm, softback. December 2005. US$ 40

The book deals with the features of arcing, metal transfer and joint formation in consumable-electrode wet underwater welding. Principles of development of coated electrodes and self-shielded flux-cored wires for underwater welding and cutting are established. Characteristics of welding consumables and mechanical properties of weld metal are given. Some types of joints, procedure of preparation and fit-up for welding, possible defects of the joints and methods to prevent their formation are described.

Information on characteristic damage to the underwater metal structures is generalized, and technological solutions are given, which have been implemented during restoration of their performance, using wet processes of underwater welding and cutting. The book gives the characteristics of the equipment for implementation of underwater arc welding process.

The main processes of thermal underwater cutting are presented, and characteristics of consumable materials and equipment for its implementation are described. Examples of work performance using underwater cutting are given.

The book is designed for scientific and engineering-technical personnel, qualified welders-divers involved in design, fabrication and repair of underwater constructions.

The book is written by a specialist, who is developing electrode materials and technologies and has a vast experience of practical work under the water.

ADVANCE BOOK INFONATION

TITANIUM: Titanium and its alloys. Technologies. Equipment. Production. Electrometallurgy. Welding

Approx. 180 pp., 200×290 mm, softback. December 2005. US$ 50

The collection presents papers on electrometallurgy and welding of titanium and its alloys published between 2002 and 2005 in «Advances in Electrometallurgy» and «The Paton Welding Journal» journals. The authors of the papers are scientists and specialists in the field of titanium and its production, known in Ukraine and abroad. The collection is designed for a broad range of readers dealing with the problems of production, processing and use of titanium.

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INDEX OF ARTICLES FOR TPWJ'2005, Nos. 1–12

Hybrid technologies

Impact strength

Information technologies

Joinability

Modelling

News **5, 6, 7, 8, 9, 10, 11, 12**

Phase transformation

Pipelines

Welding abroad

Welding arc

LIST OF AUTHORS

Alaluss K. No.7
Alekseev G.M. No.5
Alimov A.N. No.4
Antonyuk D.A. No.4
Arsenyuk V.V. No.3
Arsyukov D.V. No.12
Averianov A.A. No.3

Baranov A.V. No.12
Bazhukov A.V. No.10
Belov Yu.M. No.12
Berestovoj A.M. No.3
Bernadsky V.N. No.1, 6
Bernatsky A.V. No.8, 10
Bilinets A.V. No.6
Bishokov R.V. No.12
Blashchuk V.E. No.2, 7, 9
Boeva G.E. No.2
Bondarev A.A. No.3
Borisov Yu.S. No.6, 7, 8
Brodovoj A.V. No.10
Brodovoj V.A. No.10
Brusnitsyn Yu.D. No.12
Bugaets V.P. No.3
Bugaj A.I. No.3, 12
Bunchuk S.G. No.10
Bursky G.V. No.4
Buryak V.G. No.3
Bushma A.I. No.12
Butenko Yu.V. No.5
Byvalkevich A.I. No.10

Chervyakova L.V. No.5, 6
Chigarev V.V. No.10
Chizhskaya T.G. No.10

David S. No.6
Denikin E.I. No.1
Derlomenko V.V. No.1, 8
Dilman V.L. No.11
Dilthey U. No.4, 5
Dmitrik V.V. No.3, 7
Dobrushin L.D. No.2, 7, 8
Dolinenko V.V. No.2
Dumchev E.A. No.1

Eryomin E.N. No.9, 12

Fadeenko Yu.I. No.7
Fedorchuk V.E. No.9
Fefelov V.I. No.12

Garf E.F. No.11
Gavrik A.R. No.5, 11
Gavrish V.S. No.4
Gerasimenko A.M. No.10
Gezha V.V. No.12
Giyuk S.P. No.6
Gnatenko M.F. No.7
Golovko V.V. No.2
Golyakevich A.A. No.6, 12
Grabin V.F. No.2
Grigorenko G.M. No.1, 2, 3, 10, 11
Grigoriants A.G. No.5
Gumenyuk A.V. No.5
Gushcha O.I. No.2, 10
Guzej V.I. No.2

Ignatchenko P.V. No.3, 12
Ignatenko V.Yu. No.8
Illarionov S.Yu. No.2, 7, 8
Ilyushenko R.V. No.8
Ilyushenko V.M. No.7
Ishchenko A.Ya. No.1, 10, 11
Ivakhnenko A.G. No.3
Ivakhnenko G.A. No.3
Ivanov N.A. No.10

Kachinsky V.S. No.8
Kalina P.P. No.4
Karasevskaya O.P. No.9
Kasatkin O.G. No.1, 5
Kasatkin S.B. No.3
Kashchenko D.A. No.12
Kashirsky Yu.V. No.5
Kharlamov M.Yu. No.2
Khaskin V.Yu. No.2, 8, 10
Khorunov V.F. No.5, 8, 10
Kiselevsky F.N. No.2, 4, 5, 10
Kislitsa A.N. No.8
Kislitsyn V.M. No.5
Kiyanets I.V. No.8
Kolyada V.A. No.4, 5
Kononenko V.Ya. No.9, 12
Konyk A.I. No.7
Kornetsky O.Yu. No.4
Kornienko A.N. No.3, 12
Korotynsky A.E. No.3
Korzh V.N. No.9
Kostin V.A. No.2, 10, 11
Kostylyov V.I. No.10
Kot A.N. No.4
Kotelchuk A.S. No.6
Kotenko S.S. No.9
Kovalchuk V.S. No.2
Kovtunenko V.A. No.10
Kozhukhar V.A. No.11
Krivtsun I.V. No.6, 7, 8, 12
Kucherova M.I. No.12
Kuchuk-Yatsenko S.I. No.1, 8
Kulik V.M. No.4
Kunkin D.D. No.3
Kuskov Yu.M. No.10
Kuzmenko A.Z. No.2
Kuzmenko V.G. No.2
Kuzmin S.V. No.5
Kuznetsov A.I. No.12
Kuznetsov V.D. No.6

Labur T.M. No.10, 11
Lapandin V.D. No.3
Lavrenyuk A.V. No.6
Lazebnov P.P. No.5
Lebedev V.A. No.5, 9, 10
Leontiev L.I. No.3
Lesnoj A.B. No.5, 9
Levchenko O.G. No.10
Lisin V.L. No.3
Lobanov L.M. No.8, 11
Loginov V.P. No.11
Loginova Yu.V. No.11
Lokshin V.E. No.1
Lopota V.A. No.5
Lozovskaya A.V. No.3, 6
Lukashenko A.G. No.2

Makhlin N.M. No.3
Makhnenko V.I. No.8, 11
Makovetskaya O.K. No.1
Maksimov S.Yu. No.2, 11
Maksymova S.V. No.10
Maloshenko A.I. No.12
Maly A.B. No.5
Manchenko A.N. No.1
Marchenko A.E. No.3, 12
Margolin B.Z. No.10
Markashova L.I. No.1, 3
Mashin V.S. No.1, 2, 9
Masychev V.I. No.5
Matthes K.-J. No.7
Matveev V.V. No.6, 11
Mazurovsky V.L. No.3
Melnik E.S. No.10
Melnikov P.V. No.12
Mikitenko A.M. No.4
Mikitin Ya.I. No.1
Miroshnichenko A.P. No.10
Mishenkov V.A. No.7
Misyurov A.I. No.5
Mokrov O. No.4
Moravetsky S.I. No.6, 11
Motry A.V. No.9

Nabok T.N. No.8, 10
Naumejko S.M. No.4, 6
Nazarenko O.K. No.1, 8
Nedej T.N. No.8