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RISK OF COLD CRACKING IN WELDING OF STRUCTURAL HIGH-STRENGTH STEELS

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Mathematical model of the risk of cold cracking in welding of structural high-strength steels is considered. The model is based on distributed data on the state of microstructure, content of diffusible hydrogen and stressed state in elementary volumes within the welded joint zone. It is shown that the model makes it possible to more precisely evaluate the local conditions of cold cracking on the basis of the above parameters.

Keywords: *arc welding, low-alloy high-strength steels, brittle fracture, cold cracks, diffusible hydrogen, microstructure, stressed state, probability model*

It is a known fact that the presence of quench structures, diffusible hydrogen and tensile stresses [1] are conditions that induce cold (hydrogen) cracks in welding of structural steels. As to the quantitative characteristics of the specified conditions, at present it is possible just to approximately evaluate critical values of the corresponding characteristics, allowing for locality of cold cracking processes, presence of a significant gradient of changes of these characteristics in a zone of welding heating, their strong mutual effect and other factors, by limiting their extreme demonstrations with almost no account for their mutual effects. Meanwhile, development of the methods (experimental and calculation) for determination of distributed parameters of the above characteristics in welding of different joints on structural steels, as well as the trends to optimization of the techniques to prevent cold cracks require development of more precise criteria of the risk of their formation.

It can be shown that many recent approaches [1] based on such integral characteristics as carbon equivalent in the HAZ [1], content of hydrogen in filler metal, degree of restraint and thicknesses being welded, used as the quantitative conditions for microstructure, diffusible hydrogen and effective stresses are of a very general character. They are far from providing an ambiguous determination of the quantitative characteristics of the conditions causing cold cracking at certain parameters of welding heating. It has been proved in recent decades, due to the development of the «Sysweld» and other types of computer systems, which help to obtain the calculation information on the distributed characteristics in the weld and HAZ metals regarding the cold cracking conditions, that zones of potential cold cracks do not always have the most extreme combinations of volumes of quench microstructures, content of diffusible hydrogen and level of tensile stresses. Often the zones with a maximum volume of martensite and content of diffusible hydrogen are within the compressive zones, or the zones with high tensile stresses have a purely bainitic microstructure and low level of diffusible hydrogen, i.e. they are not potential centers of cold cracks. In other words, the proper, physically substantiated criteria that quantitatively connect, on the level of the distributed parameters, the necessary conditions for cold cracking to occur in welding heating of structural steels under consideration, are required.

An approach for development of such criteria, based on the following factors, is given below:

• probability assessment of the risk of cold cracking is performed in a specified area of a welded joint (certain region of the fusion zone or HAZ);

• initiation and propagation of cold cracks take place by the brittle fracture mechanism, i.e. determined by correspondent normal stresses $\sigma_{jj}(x, y, z)$ at a point with coordinates x, y, z, acting in an area with normal j and corresponding characteristic of resistance of a material, $A_j(x, y, z)$, to brittle fracture formation.

A_j is a function of microstructural state and content of diffusion hydrogen for a given steel.

The probability of brittle fracture in specific volume V, in compliance with the Weibull theory, is determined by dependence

$$P_j(V) = 1 - \exp\left[-\int_V \left(\frac{\sigma_{jj} - A_j}{B_j}\right)^{\eta} dV/V_0\right], \quad (\sigma_{jj} > A_j). \quad (1)$$

In (1), integration is carried out only with respect to elementary volumes dV, where $\sigma_{jj} > A_j$, and A_j, η and $B_j V_0^{1/\eta}$ are the Weibull distribution parameters. As a rule, $\eta = 4.0$, and A_j and $\overline{B}_j = B_j V_0^{1/\eta}$ are determined experimentally.

The values of $\overline{B}_j$ depend on the size of the volume V along the section with normal j (Figure 1). If stresses σ_{jj} and material resistance A_j in length l_j of this volume change but slightly, then a change of $dV = l_j dF$ can be made in integral of expression (1), where F is the cross-section area of volume V.

Accordingly, the following will be obtained instead of (1):

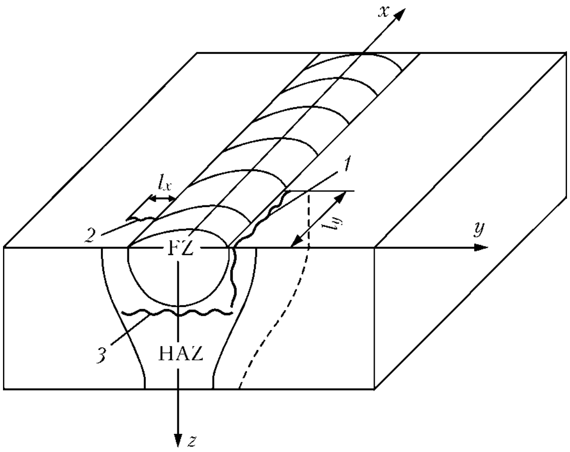


Figure 1. Schematic of cold cracking in fusion zone (FZ) and heat-affected zone (HAZ): *1* --- longitudinal crack with normal y; *2*--- transverse crack with normal x; *3* --- underbead crack with normal z (longitudinal)

$$P_j = 1 - \exp\left[-\int_F \left(\frac{\sigma_{jj} - A_j}{B_j \ / l_j^{1/\eta}}\right)^{\eta} dF\right]. \qquad (2)$$

From which

$$P_j(l_j) = 1 - [1 - P_j(l_0)] \left(\frac{l_0}{l_j}\right)^{1/\eta}, \qquad (3)$$

where $P_j(l_0)$ is the probability of cold cracking in plane with normal j in length l_0 of volume V. In a particular case, where normal j is directed across the weld, then l_j and l_0 are the lengths of volume V along the weld, and longitudinal cracks A take place. If j is directed along the weld, then l_j and l_0 are the lengths of potential volume V directed across the weld, and transverse cold cracks form. It can be seen from (2) and (3) that if the sensitivity of material to longitudinal and transverse cold cracking differs insignificantly, i.e. the values of parameters A, B and h for longitudinal and transverse cracks are approximately identical, the probability of longitudinal or transverse cold cracking depends not only on the level of transverse and longitudinal normal stresses, but also on the values of l_j in potential volume V in a corresponding direction. Therefore, it is quite natural that the longitudinal cold cracks form in HAZ at the transverse stresses that are much lower than those in the longitudinal direction.

It follows from the above-said that the probability of cold cracking in different sections with normal j can be calculated from equation (2) at the known values of parameters A, B and η, which depend mainly only on the microstructure and concentration of diffusible hydrogen, as well as on the distribution of stresses in the joining zone.

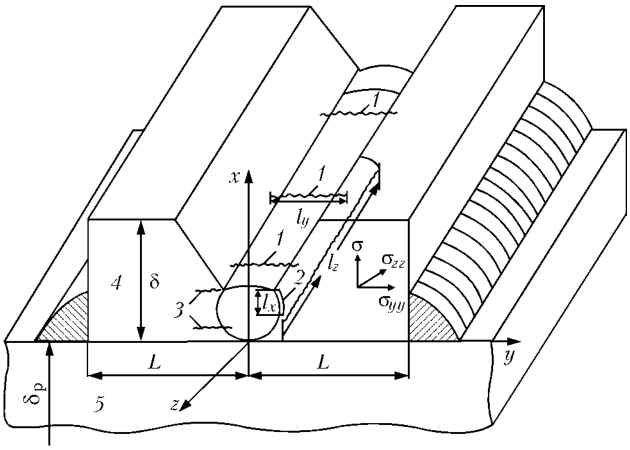


Figure 2. Schematic of root weld with longitudinal (*1*) and transverse (*2, 3*) cracks in welding sample (*4*) δ thick and $2L$ wide, fixed with side fillet welds to plate (5) $\delta_p >> \delta$ thick

Application of the described approach for description of cold cracking conditions in welding of the butt weld root pass in a typical welding sample of steel 14KhG2SAFD with thickness δ = 18 mm thick is shown below (Figure 2). The CCT diagram is also given below (Figure 3). Arc welding with ANP-10 electrodes was used for that. Chemical composition of the base and filler metals is given in Table 1.

In Figure 2, initial heating temperature T_0, hydrogen content H_{filler} in filler metal and restraining base L were variable conditions for welding of the butt weld sample. Arc welding of the root pass was carried out under the following conditions: I = 140–150 A, U_a = 24 V, and v_w = 7.2--7.5 m/h. Values of variable parameters T_0, H_{filler} and L for different variants of butt welding are given in Table 2.

Welding of ten samples was performed for each variant. The probability of cold cracks of the type shown in Figure 4 was determined on the results of their examination. Further examinations related to determination of temperature fields in welding, microstructural changes, hydrogen diffusion and stresses in FZ and HAZ were carried out by using numerical methods based on the corresponding mathematical models developed by the E.O. Paton Electric Welding Institute [2]. These models are based on the principle of sequential tracing of evolution of temperature fields, microstructural changes, stresses and strains, as well as diffusion of hydrogen from a correspondent initial distribution in the filler and base metals, allowing for changes in solubility and diffusion coefficients depending on the temperature, as well as microstructure changes [2].

Not dwelling on peculiarities of such modeling for the steel under consideration, the thermal-physical and mechanical properties of which are well known

Table 1. Chemical composition (wt.%) of base metal and metal deposited by electrodes

Material	C	Si	Mn	Cr	Cu	V	Al	P	S
14KhG2SAFD steel	0.13	0.57	1.42	0.44	0.39	0.08	0.08	0.019	0.015
ANP-10 electrode	0.09	0.43	1.90	Traces	Traces	0.01	--	0.020	0.020

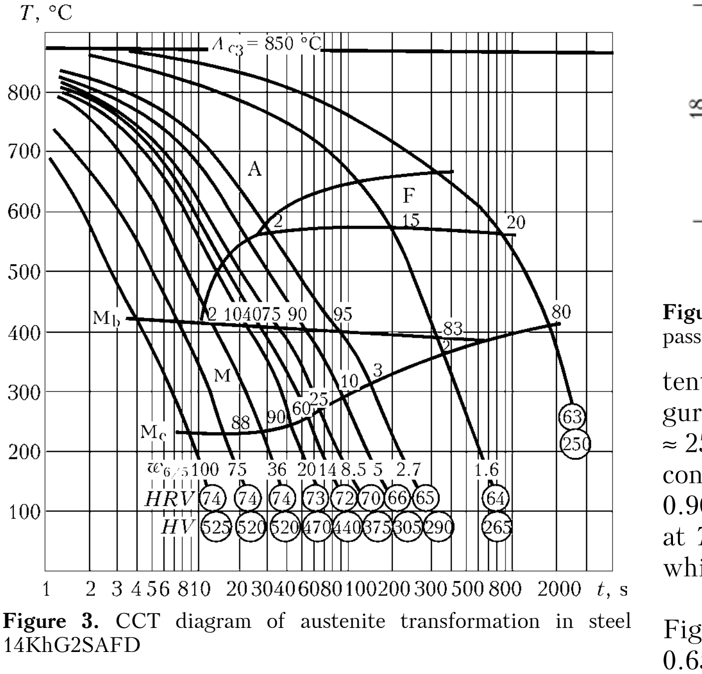


Figure 3. CCT diagram of austenite transformation in steel 14KhG2SAFD

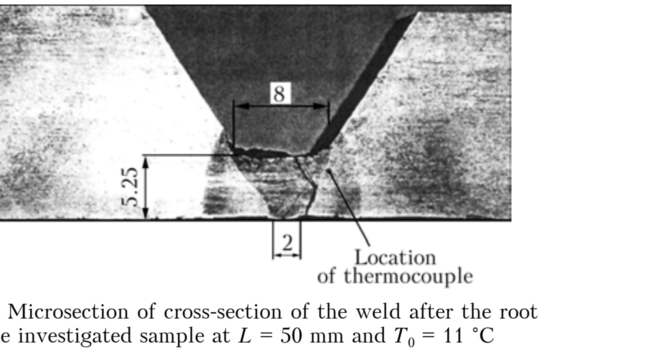


Figure 4. Microsection of cross-section of the weld after the root pass in the investigated sample at L = 50 mm and T_0 = 11 °C

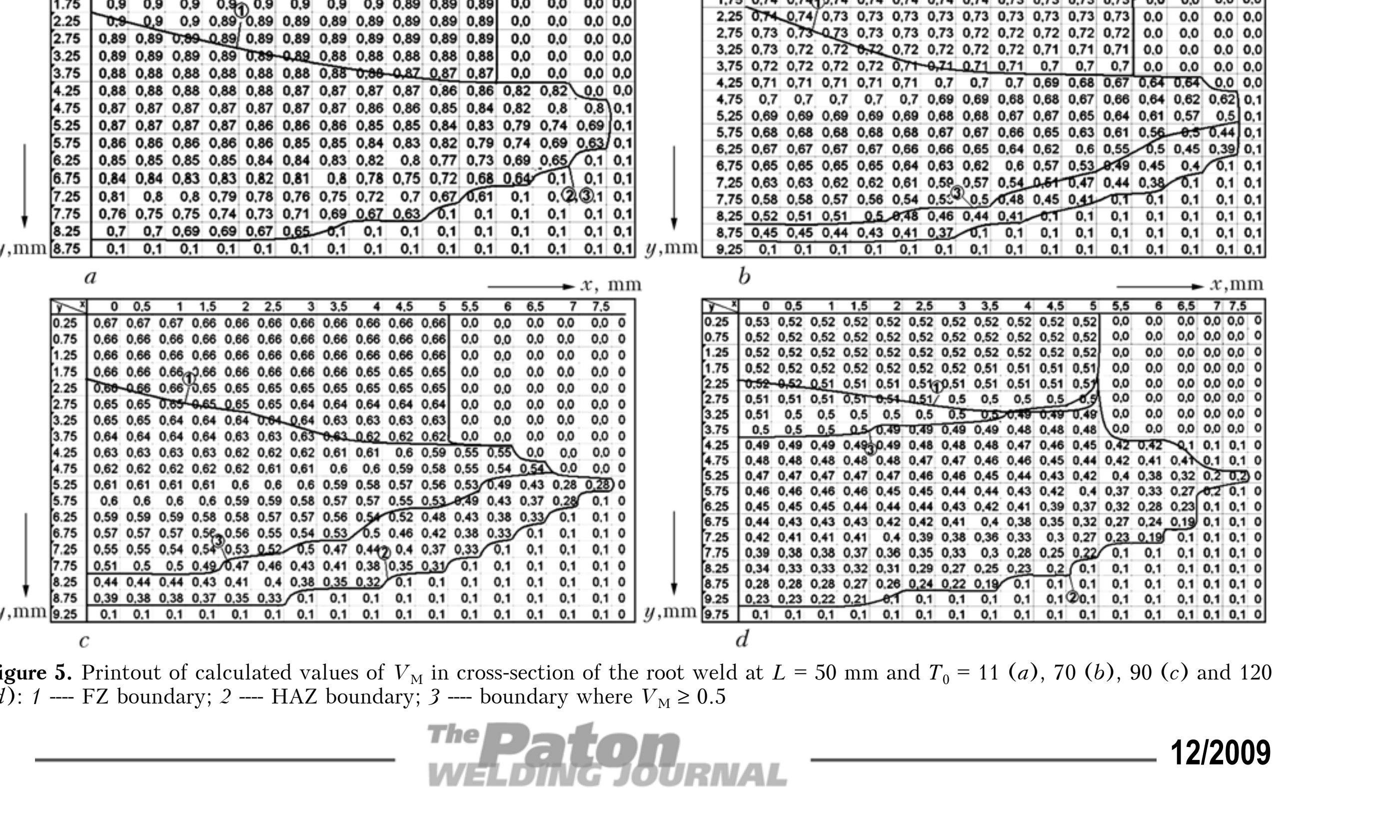
[3], below we give the main calculation results used to determine parameters of the cold cracking model (2) in welding heating of the considered steel.

The data on distribution of martensite in cross-section of the root weld (at distance from its beginning and end) during welding are given in Figure 5. Since the martensitic-bainitic structure (see Figure 3) is generally formed at a cooling rate ranging from 600 to 500 °C, $w_{6/5}$ > 7.8 °C/s, the data shown in Figure 5 provide sufficiently comprehensive characterization of microstructure of the volume (see Figure 4) where a cold crack is formed, depending on the hydrogen content and stresses. In particular, as follows from Figure 5, at T_0 = 11 °C, which corresponds to $w_{6/5} \approx$ ≈ 25–35 °C/s in the CCT diagram (see Figure 3), the content of martensite in the HAZ metal is V_M = 0.70–0.90; V_M = 0.70--0.40 at T_0 = 70 °C; V_M = 0.65–0.35 at T_0 = 90 °C, and V_M = 0.50--0.20 at T_0 = 120 °C, which corresponds to $w_{6/5} \approx 10$ °C/s.

As to the zone of potential cracking proper (see Figure 4), the martensite content is V_M = 0.89, 0.72, 0.65 and 0.50, according to the data of Figure 5. This corresponds to classical conditions of cold cracking, other necessary conditions on hydrogen and stresses being in place.

Figure 6 gives an idea of diffusible hydrogen distribution up to a time moment ($t \approx 200$ s) when temperature conditions for cold cracking are created. These data were obtained for initial hydrogen content H_{filler} = 10 cm^3/100 g in filler metal.

It can be seen that the real diffusible hydrogen content in a crack region (see Figure 4) is not higher than (3.5 ± 0.5) cm^3/100 g. i.e. 35 % H_{filler}, by the moment of crack formation, and that it hardly depends



a (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7
0.25	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,0	0,0	0,0	0,0
0.75	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,0	0,0	0,0	0,0
1.25	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,0	0,0	0,0	0,0
1.75	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,9	0,89	0,89	0,89	0,0	0,0	0,0	0,0
2.25	0,9	0,9	0,9	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,0	0,0	0,0	0,0
2.75	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,89	0,0	0,0	0,0	0,0
3.25	0,89	0,89	0,89	0,89	0,89	0,89	0,88	0,88	0,88	0,88	0,88	0,0	0,0	0,0	0,0
3.75	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,88	0,87	0,87	0,87	0,0	0,0	0,0	0,0
4.25	0,88	0,88	0,88	0,88	0,88	0,87	0,87	0,87	0,87	0,86	0,86	0,82	0,82	0,0	0,0
4.75	0,87	0,87	0,87	0,87	0,87	0,87	0,87	0,86	0,86	0,85	0,84	0,82	0,8	0,8	0,1
5.25	0,87	0,87	0,87	0,87	0,86	0,86	0,86	0,85	0,85	0,84	0,83	0,79	0,74	0,69	0,1
5.75	0,86	0,86	0,86	0,86	0,86	0,85	0,85	0,84	0,83	0,82	0,79	0,74	0,69	0,63	0,1
6.25	0,85	0,85	0,85	0,85	0,84	0,84	0,83	0,82	0,8	0,77	0,73	0,69	0,65	0,1	0,1
6.75	0,84	0,84	0,83	0,83	0,82	0,81	0,8	0,78	0,75	0,72	0,68	0,64	0,1	0,1	0,1
7.25	0,81	0,8	0,8	0,79	0,78	0,76	0,75	0,72	0,7	0,67	0,61	0,1	0,1	0,1	0,1
7.75	0,76	0,75	0,75	0,74	0,73	0,71	0,69	0,67	0,63	0,1	0,1	0,1	0,1	0,1	0,1
8.25	0,7	0,7	0,69	0,69	0,67	0,65	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
8.75	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

b (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7
0,25	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,0	0,0	0,0	0,0
0,75	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,0	0,0	0,0	0,0
1,25	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,0	0,0	0,0	0,0
1,75	0,74	0,74	0,74	0,74	0,74	0,74	0,74	0,73	0,73	0,73	0,73	0,0	0,0	0,0	0,0
2,25	0,74	0,74	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,73	0,0	0,0	0,0	0,0
2,75	0,73	0,73	0,73	0,73	0,73	0,73	0,72	0,72	0,72	0,72	0,72	0,0	0,0	0,0	0,0
3,25	0,73	0,72	0,72	0,72	0,72	0,72	0,72	0,72	0,71	0,71	0,71	0,0	0,0	0,0	0,0
3,75	0,72	0,72	0,72	0,72	0,71	0,71	0,71	0,71	0,7	0,7	0,7	0,0	0,0	0,0	0,0
4,25	0,71	0,71	0,71	0,71	0,71	0,7	0,7	0,7	0,69	0,68	0,67	0,64	0,64	0,0	0,0
4,75	0,7	0,7	0,7	0,7	0,7	0,69	0,69	0,68	0,68	0,67	0,66	0,64	0,62	0,62	0,1
5,25	0,69	0,69	0,69	0,69	0,69	0,68	0,68	0,67	0,67	0,65	0,64	0,61	0,57	0,5	0,1
5,75	0,68	0,68	0,68	0,68	0,68	0,67	0,67	0,66	0,65	0,63	0,61	0,56	0,5	0,44	0,1
6,25	0,67	0,67	0,67	0,67	0,66	0,66	0,65	0,64	0,62	0,6	0,55	0,5	0,45	0,39	0,1
6,75	0,65	0,65	0,65	0,65	0,64	0,63	0,62	0,6	0,57	0,53	0,49	0,45	0,4	0,1	0,1
7,25	0,63	0,63	0,62	0,62	0,61	0,59	0,57	0,54	0,51	0,47	0,44	0,38	0,1	0,1	0,1
7,75	0,58	0,58	0,57	0,56	0,54	0,53	0,5	0,48	0,45	0,41	0,1	0,1	0,1	0,1	0,1
8,25	0,52	0,51	0,51	0,5	0,48	0,46	0,44	0,41	0,1	0,1	0,1	0,1	0,1	0,1	0,1
8,75	0,45	0,45	0,44	0,43	0,41	0,37	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1
9,25	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1

c (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	
0.25	0,67	0,67	0,67	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,0	0,0	0,0	0,0	0,0	0
0.75	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,0	0,0	0,0	0,0	0,0	0
1.25	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,0	0,0	0,0	0,0	0,0	0
1.75	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,65	0,65	0,65	0,0	0,0	0,0	0,0	0,0	0
2.25	0,66	0,66	0,66	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,65	0,0	0,0	0,0	0,0	0,0	0
2.75	0,65	0,65	0,65	0,65	0,65	0,65	0,64	0,64	0,64	0,64	0,64	0,0	0,0	0,0	0,0	0,0	0
3.25	0,65	0,65	0,64	0,64	0,64	0,64	0,64	0,63	0,63	0,63	0,63	0,0	0,0	0,0	0,0	0,0	0
3.75	0,64	0,64	0,64	0,64	0,63	0,63	0,63	0,63	0,62	0,62	0,62	0,0	0,0	0,0	0,0	0,0	0
4.25	0,63	0,63	0,63	0,63	0,62	0,62	0,62	0,61	0,61	0,6	0,59	0,55	0,55	0,0	0,0	0,0	0
4.75	0,62	0,62	0,62	0,62	0,62	0,61	0,61	0,6	0,6	0,59	0,58	0,55	0,54	0,54	0,0	0,0	0
5.25	0,61	0,61	0,61	0,61	0,6	0,6	0,6	0,59	0,58	0,57	0,56	0,53	0,49	0,43	0,28	0,28	0
5.75	0,6	0,6	0,6	0,6	0,59	0,59	0,58	0,57	0,57	0,55	0,53	0,49	0,43	0,37	0,28	0,1	0
6.25	0,59	0,59	0,59	0,58	0,58	0,57	0,57	0,56	0,54	0,52	0,48	0,43	0,38	0,33	0,1	0,1	0
6.75	0,57	0,57	0,57	0,56	0,56	0,55	0,54	0,53	0,5	0,46	0,42	0,38	0,33	0,1	0,1	0,1	0
7.25	0,55	0,55	0,54	0,54	0,53	0,52	0,5	0,47	0,44	0,4	0,37	0,33	0,1	0,1	0,1	0,1	0
7.75	0,51	0,5	0,5	0,49	0,47	0,46	0,43	0,41	0,38	0,35	0,31	0,1	0,1	0,1	0,1	0,1	0
8.25	0,44	0,44	0,44	0,43	0,41	0,4	0,38	0,35	0,32	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0
8.75	0,39	0,38	0,38	0,37	0,35	0,33	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0
9.25	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0

d (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	
0.25	0,53	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,0	0,0	0,0	0,0	0,0	0
0.75	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,0	0,0	0,0	0,0	0,0	0
1.25	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,0	0,0	0,0	0,0	0,0	0
1.75	0,52	0,52	0,52	0,52	0,52	0,52	0,52	0,51	0,51	0,51	0,51	0,0	0,0	0,0	0,0	0,0	0
2.25	0,52	0,52	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,51	0,0	0,0	0,0	0,0	0,0	0
2.75	0,51	0,51	0,51	0,51	0,51	0,51	0,5	0,5	0,5	0,5	0,5	0,0	0,0	0,0	0,0	0,0	0
3.25	0,51	0,5	0,5	0,5	0,5	0,5	0,5	0,5	0,49	0,49	0,49	0,0	0,0	0,0	0,0	0,0	0
3.75	0,5	0,5	0,5	0,5	0,49	0,49	0,49	0,49	0,48	0,48	0,48	0,0	0,0	0,0	0,0	0,0	0
4.25	0,49	0,49	0,49	0,49	0,49	0,48	0,48	0,48	0,47	0,46	0,45	0,42	0,42	0,1	0,1	0,1	0
4.75	0,48	0,48	0,48	0,48	0,48	0,47	0,47	0,46	0,46	0,45	0,44	0,42	0,41	0,41	0,1	0,1	0
5.25	0,47	0,47	0,47	0,47	0,47	0,46	0,46	0,45	0,44	0,43	0,42	0,4	0,38	0,32	0,2	0,2	0
5.75	0,46	0,46	0,46	0,46	0,45	0,45	0,44	0,44	0,43	0,42	0,4	0,37	0,33	0,27	0,2	0,1	0
6.25	0,45	0,45	0,45	0,44	0,44	0,44	0,43	0,42	0,41	0,39	0,37	0,32	0,28	0,23	0,1	0,1	0
6.75	0,44	0,43	0,43	0,43	0,42	0,42	0,41	0,4	0,38	0,35	0,32	0,27	0,24	0,19	0,1	0,1	0
7.25	0,42	0,41	0,41	0,41	0,4	0,39	0,38	0,38	0,36	0,33	0,3	0,27	0,23	0,19	0,1	0,1	0
7.75	0,39	0,38	0,38	0,37	0,36	0,35	0,33	0,3	0,28	0,25	0,22	0,1	0,1	0,1	0,1	0,1	0
8.25	0,34	0,33	0,33	0,32	0,31	0,29	0,27	0,25	0,23	0,2	0,1	0,1	0,1	0,1	0,1	0,1	0
8.75	0,28	0,28	0,28	0,27	0,26	0,24	0,22	0,19	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0
9.25	0,23	0,23	0,22	0,21	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0
9.75	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0,1	0

Figure 5. Printout of calculated values of V_M in cross-section of the root weld at L = 50 mm and T_0 = 11 (*a*), 70 (*b*), 90 (*c*) and 120 (*d*): *1* ---- FZ boundary; *2* ---- HAZ boundary; *3* ---- boundary where $V_M \geq 0.5$

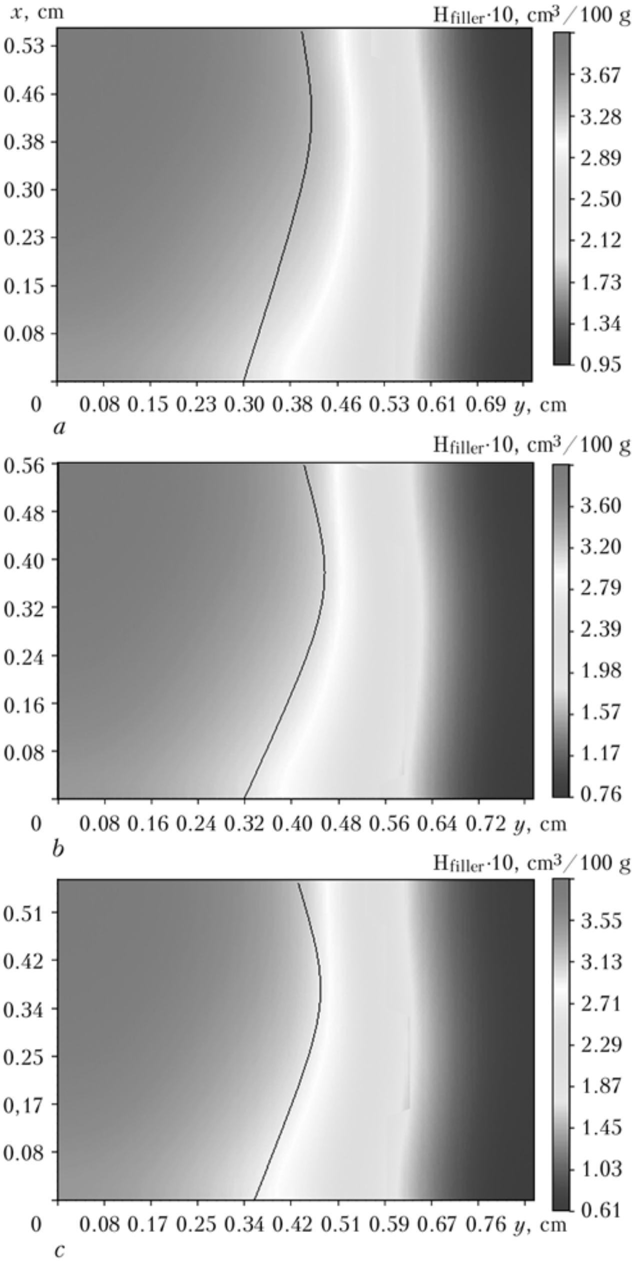


Figure 6. Distribution of diffusible hydrogen in section z = const at time momen t = 195 s after a source has passed the given section at T_0 = 11 (a), 70 (b) and 120 (c) °C

on the T_0 values in the considered limits. Therefore, without the data on the stressed state it is difficult to explain experimental data on the probability of cold cracking given in Table 2 from the content of quench microstructures (martensite, see Table 2) and initial hydrogen content H_{filler} = 7.0–8.6 cm^3/100 g (Figure 6), which must decrease approximately to (2.5 ± 0.3) cm^3/100 g compared with the calculated one.

The calculation data on residual principal maximum stresses σ_1 and transverse normal stresses σ_{yy}, which are responsible for initiation and distribution of cold cracks of the type shown in Figure 4 for the variant given in Table 2, are shown in Figures 7--9.

Processing of these data according (1) for HAZ at V_M > 0.5 (in Figures 7–9 this zone is limited by curve *3*) allowed determining the dependence of parameters A, $\overline{B}$ and η on the hydrogen content in filler metal,

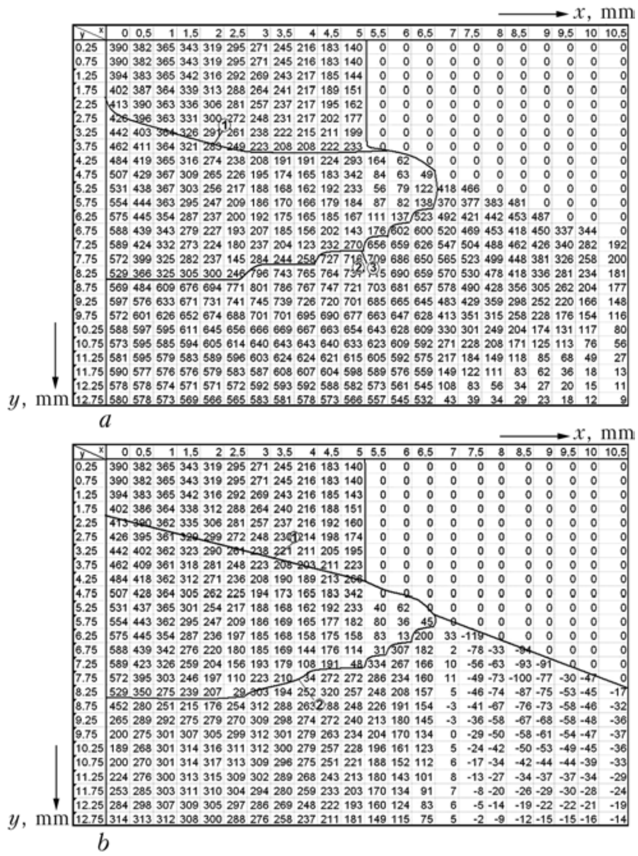


Figure 7. Printout of calculated values of σ_1 (a) and σ_{yy} (b) at T_0 = 11 °C and L = 50 mm (Nos. 1--4, Table 2): *1–3* ---- see Figure 5

H_{filler} (Figure 10). It is characteristic that the $A(H_{filler})$ value is in good correlation with $\sigma_{cr}(H_{filler})$ obtained in the «Implant» tests at a cooling rate corresponding to a martensite content above 50 % (V_M > > 0.5).

Therefore, it can be concluded from the above-said that quantitative characteristics of the conditions necessary for cold cracking in welding of low-alloy high-strength steels show up clearly enough by using the Weibull probability model of brittle fracture. The distribution parameters are a general form of function of

Table 2. Variants of cold crack tests

Variant No.	$2L$, mm	T_0, °C	H_{filler}, cm^3/100 g	Number of samples without cracks	Fracture probability	V_M
1	100	11	4.0	10	0	0.89
2	100	11	6.0	5	0.5	0.89
3	100	11	7.0	0	1.0	0.89
4	100	11	8.6	0	1.0	0.89
5	140	11	8.6	4	0.6	0.89
6	200	11	8.6	9	0.1	0.89
7	100	70	8.6	2	0.8	0.72
8	100	90	8.6	--	--	0.65
9	100	120	8.6	10	0	0.50

a (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8
0.25	369	357	339	319	296	272	247	222	193	161	124	0	0	0	0	0	0
0.75	369	357	339	319	296	272	247	222	193	161	124	0	0	0	0	0	0
1.25	371	358	339	318	294	271	245	220	194	163	126	0	0	0	0	0	0
1.75	376	360	339	316	291	267	243	219	194	165	130	0	0	0	0	0	0
2.25	384	363	338	313	287	262	239	216	194	168	136	0	0	0	0	0	0
2.75	393	367	338	309	281	255	232	212	192	173	147	0	0	0	0	0	0
3.25	404	373	339	306	274	247	223	204	189	177	163	0	0	0	0	0	0
3.75	420	378	339	301	267	237	212	193	183	183	186	0	0	0	0	0	0
4.25	436	387	340	298	260	226	199	178	170	183	222	0	0	0	0	0	0
4.75	455	395	341	294	252	217	186	163	150	159	286	0	0	0	0	0	0
5.25	475	404	342	291	247	209	179	156	146	165	201	32	53	0	0	0	0
5.75	496	410	342	287	241	203	174	153	147	146	159	62	24	53	0	0	0
6.25	513	416	340	281	233	196	170	149	146	134	147	62	14	97	77	-76	0
6.75	528	415	335	273	223	184	166	142	146	122	149	58	-12	224	77	-25	-14
7.25	536	406	323	261	212	169	161	127	153	86	169	-5	271	176	70	-5	-32
7.75	536	388	306	247	198	143	162	95	187	30	233	229	221	148	62	-2	-40
8.25	522	359	281	233	185	92	185	32	239	253	285	210	183	125	56	-1	-42
8.75	493	309	247	217	182	3	232	257	299	257	255	200	162	110	52	2	-36
9.25	425	247	221	190	154	232	293	268	282	254	236	191	150	102	52	7	-29
9.75	250	255	264	250	255	254	283	274	271	248	222	183	142	98	53	12	-21

b (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8
0.25	361	350	334	314	293	270	245	219	190	158	119	0	0	0	0	0	0
0.75	361	350	334	314	293	270	245	219	190	158	119	0	0	0	0	0	0
1.25	363	351	334	313	291	268	244	218	191	159	121	0	0	0	0	0	0
1.75	368	353	334	312	288	265	241	216	191	161	125	0	0	0	0	0	0
2.25	375	356	333	309	284	260	236	213	190	165	132	0	0	0	0	0	0
2.75	386	360	332	306	279	252	230	208	188	168	145	0	0	0	0	0	0
3.25	399	365	332	301	271	244	221	201	185	174	160	0	0	0	0	0	0
3.75	414	371	333	297	264	234	209	190	179	178	184	0	0	0	0	0	0
4.25	431	378	333	293	256	224	196	176	167	179	220	0	0	0	0	0	0
4.75	451	386	334	289	250	215	185	160	147	154	264	0	0	0	0	0	0
5.25	471	394	334	286	244	207	179	155	142	162	195	30	55	0	0	0	0
5.75	492	400	334	281	237	202	174	154	145	148	150	56	13	66	0	0	0
6.25	511	406	331	274	230	193	172	154	141	142	127	59	28	-2	205	-118	0
6.75	529	406	324	266	218	183	168	151	131	135	97	33	-21	278	139	-50	-20
7.25	540	401	314	254	203	166	164	147	111	127	55	-16	301	227	118	-11	-42
7.75	544	385	298	242	189	135	162	152	69	148	-6	299	259	192	102	1	-45
8.25	539	353	274	229	181	82	181	187	-8	231	231	260	222	163	88	8	-42
8.75	503	309	246	215	185	18	247	165	222	277	224	226	191	139	77	12	-34
9.25	428	247	221	188	152	233	267	252	235	253	219	203	169	123	70	17	-25
9.75	249	254	261	245	251	245	271	264	247	242	214	190	156	113	67	21	-18

c (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8
0.25	335	332	323	307	289	268	245	220	192	159	117	0	0	0	0	0	0
0.75	335	332	323	307	289	268	245	220	192	159	117	0	0	0	0	0	0
1.25	338	334	323	306	286	265	243	219	193	161	119	0	0	0	0	0	0
1.75	345	337	322	303	282	261	239	217	192	164	126	0	0	0	0	0	0
2.25	356	340	321	299	277	254	233	212	191	168	136	0	0	0	0	0	0
2.75	370	345	319	294	270	246	224	205	189	173	152	0	0	0	0	0	0
3.25	387	351	318	289	262	236	213	195	184	178	174	0	0	0	0	0	0
3.75	407	357	316	284	253	225	200	184	177	183	202	0	0	0	0	0	0
4.25	429	363	316	278	245	214	187	167	163	182	243	0	0	0	0	0	0
4.75	450	371	317	273	238	205	176	151	140	154	313	0	0	0	0	0	0
5.25	471	377	318	271	232	198	171	146	137	161	209	35	61	0	0	0	0
5.75	492	382	316	268	229	193	169	148	139	141	153	67	27	63	0	0	0
6.25	511	385	312	263	220	195	165	148	138	128	122	87	63	-66	215	-97	0
6.75	527	385	305	249	218	188	164	145	134	110	86	84	15	157	157	-23	-12
7.25	540	379	292	234	206	185	163	138	134	94	56	129	35	247	151	18	-25
7.75	546	368	273	209	193	186	160	117	136	67	35	220	227	196	120	23	-30
8.25	539	352	252	166	183	196	161	66	151	-6	317	280	200	161	96	21	-32
8.75	515	328	228	102	189	221	172	-18	230	240	286	253	187	140	82	20	-26
9.25	455	279	214	42	260	197	152	215	276	239	254	226	173	125	74	22	-20
9.75	341	184	159	246	269	243	238	233	258	238	232	205	161	117	70	25	-13

Figure 8. Influence of T_0 on stresses σ_{yy} at L = 50 mm: *a* ---- T_0 = = 70; *b* ---- 90; *c* ---- 120 °C

a (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8
0.25	256	270	278	281	281	279	277	273	267	256	236	0	0	0	0	0	0
0.75	256	270	278	281	281	279	277	273	267	256	236	0	0	0	0	0	0
1.25	259	272	278	279	278	277	274	272	268	257	239	0	0	0	0	0	0
1.75	265	275	278	277	274	272	271	269	267	260	245	0	0	0	0	0	0
2.25	275	280	277	272	269	265	264	265	267	265	254	0	0	0	0	0	0
2.75	288	285	277	268	261	256	255	259	265	271	268	0	0	0	0	0	0
3.25	303	292	277	263	252	245	244	249	261	279	289	0	0	0	0	0	0
3.75	323	301	278	257	242	231	228	234	253	286	321	0	0	0	0	0	0
4.25	346	311	279	252	232	218	210	213	235	286	371	0	0	0	0	0	0
4.75	372	324	283	246	222	204	194	192	204	247	466	0	0	0	0	0	0
5.25	400	335	285	243	214	196	186	184	198	253	314	62	84	0	0	0	0
5.75	429	344	285	238	207	187	183	183	197	225	238	109	55	73	0	0	0
6.25	455	350	280	232	198	176	181	180	185	212	200	112	36	210	39	-94	0
6.75	475	349	271	223	183	159	180	178	164	206	148	58	315	190	21	-56	-26
7.25	483	338	258	209	169	133	186	186	123	214	77	340	275	179	29	-35	-51
7.75	474	314	239	199	164	85	214	215	44	288	278	294	246	177	30	-31	-58
8.25	443	272	213	197	177	-1	293	200	247	317	263	258	222	177	21	-29	-59
8.75	379	204	192	177	149	225	290	272	258	285	252	236	207	175	14	-30	-52

b (x, mm → ; y, mm ↓)

y \ x	0	0,5	1	1,5	2	2,5	3	3,5	4	4,5	5	5,5	6	6,5	7	7,5	8
0.25	134	167	194	216	234	251	267	282	294	300	299	0	0	0	0	0	0
0.75	134	167	194	216	234	251	267	282	294	300	299	0	0	0	0	0	0
1.25	137	169	194	214	232	249	265	281	294	302	301	0	0	0	0	0	0
1.75	142	172	194	212	228	244	261	278	294	305	307	0	0	0	0	0	0
2.25	152	176	193	208	222	237	255	274	293	309	316	0	0	0	0	0	0
2.75	164	182	194	204	215	228	246	267	292	316	330	0	0	0	0	0	0
3.25	180	190	195	199	206	216	233	256	287	324	352	0	0	0	0	0	0
3.75	200	199	195	193	196	202	216	240	278	331	386	0	0	0	0	0	0
4.25	224	211	198	188	185	187	196	217	258	332	442	0	0	0	0	0	0
4.75	252	225	202	183	175	173	178	191	221	286	552	0	0	0	0	0	0
5.25	283	239	206	181	167	163	169	183	213	289	368	75	102	0	0	0	0
5.75	315	252	207	177	161	155	165	180	209	251	273	127	70	96	0	0	0
6.25	346	260	205	172	152	144	163	175	192	230	224	130	52	223	47	-78	0
6.75	371	262	199	164	139	126	160	171	167	217	166	74	321	201	34	-42	-21
7.25	384	255	189	152	125	101	166	176	122	220	90	344	283	188	43	-23	-42
7.75	380	235	172	145	122	51	193	204	38	289	279	298	251	185	44	-18	-48
8.25	355	196	149	145	138	-37	270	188	234	310	261	260	227	183	37	-16	-49
8.75	300	133	130	126	114	187	262	251	245	276	248	236	210	179	29	-15	-46

Figure 9. Influence of L on stresses σ_{yy} at T_0 = 11 °C: *a* ---- L = 70; *b* ---- 100 mm

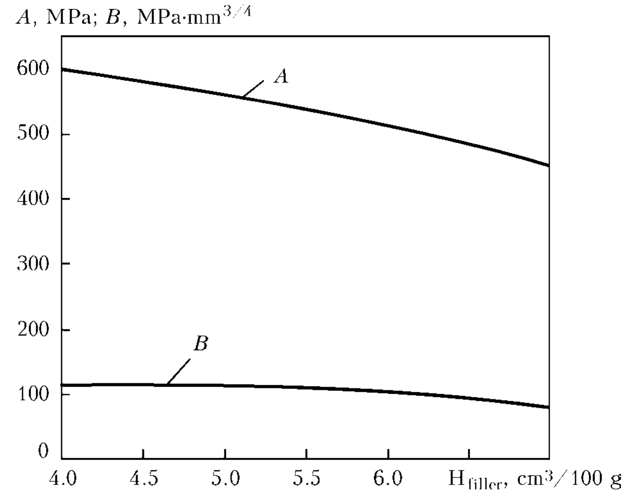


Figure 10. Influence of content of diffusible hydrogen in filler metal on Weibull parameters A and B at η = 4

the content of diffusible hydrogen and microstructural state of a material in fracture formation.

In fusion welding of 14KhG2SAFD steel, the Weibull distribution parameters can be taken as η = = 4, $A(H_{filler}) \approx \sigma_{cr}(H_{filler})$ (Figure 10) and $\overline{B}_j \approx$ ≈ 100 MPa·mm$^{3/4}$ at a martensite content in HAZ equal to more than 50 % (V_M = 0.5). The $A(H_{filler})$ value, like $\sigma_{cr}(H_{filler})$, noticeably increases at lower V_M values in the «Implant» tests, the probability of cold cracking dramatically decreasing in this steel.

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INVESTIGATION OF JOINTS OF TITANIUM ALUMINIDE WITH TITANIUM ALLOY VT8 PRODUCED BY DIFFUSION WELDING

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The welded joints γ-TiAl (Ti--48 at.% Al) with alloy VT8 produced by diffusion welding in vacuum using nanolayered interlayers of Ti--Al system were investigated. The analysis of strength properties of a joint was carried out using microindention in the device «Micron-gamma» and also by mechanical shear tests. It was established that after diffusion welding in vacuum the initial nanolayered layer is transformed into intermetallic being in the state close to nanocrystalline one.

Keywords: *diffusion welding, titanium aluminide, joint zone, nanolayered interlayer, microindention, hardness*

In the last years the new heat-resistant materials based on intermetallics, including titanium aluminides, have been actively developed. These alloys have higher temperatures of melting, elasticity modulus and lower density than superalloys, based on titanium, iron and nickel. Owing to high aluminium content they do not require protection against oxidation in the air and in the products of fuel combustion [1], which allows these alloys to be efficiently applied as materials for the parts of gas-turbine engines, lining of aircrafts, parts of load-carrying structures of items of aerospace engineering, and also in different branches of industry [2].

The aim of work was the investigation of titanium aluminide alloy (Ti--47Al--1.5Cr--2Nb) with two-phase structure ($\alpha_2 + \gamma$), where α_2-Ti_3Al and γ-TiAl, and alloy VT8 (6.5Al--3.3Mo--0.35Si). The diffusion welding in vacuum (DWV) was performed in the installation U-394 applying nanolayered interlayers Al/Ti (Ti--52Al) according to the method described in the work [3] at the optimal conditions: welding temperature is 1200 °C; welding time is 20 min; pressure is 10 MPa. The electron beam heater was used as a source of specimens heating.

The application of nanolayered interlayers (NI) in DWV allows obtaining the composition and structure in the joint zone close to those of base metal owing to proceeding of exothermal reaction of self-spreading high-temperature synthesis. However, the direct precipitation of nanolayers on surfaces being welded is not always technologically performable, therefore more prospective is the application of separate NI in the form of a foil.

At the E.O. Paton Electric Welding Institute the method of producing similar materials using combined electron beam evaporation of elements from two sources in vacuum chamber was developed [4].

Figure 1 shows typical microstructure of cross section of foil specimen in initial state. It is seen from the Figure that foil consists of continuous relatively equal layers. Light fringes correspond to the layers of titanium, dark ones — to aluminium.

According to the work [4] during heating of Al/Ti NI the processes occur in them, resulting in the formation of structure composed of mixture of intermetallics TiAl and Ti_3Al. Thus the conclusion can be made that use in DWV of γ-TiAl NI with titanium alloy VT8 will allow obtaining the structure similar to that of base metal.

The analysis of microstructure of bimetal welded joint of titanium aluminide with titanium alloy VT8 was carried out using microscopes JSM-840 and «Neophot-32». In the joint zone there are no defects in the form of pores and cracks. At the former boundary of NI contact with titanium aluminide the common grains are formed (Figure 2).

The mechanical properties of a joint were determined using microindention which allowed investigating the hard-to-deform alloys without fracture. The given method in correspondence with the standard ISO 14577-1--2002(E) allows determining such characteristics of materials as hardness H_{IT}, Young modulus E_{IT}, creep C_{IT} and elasticity η_{IT}, and also identifying

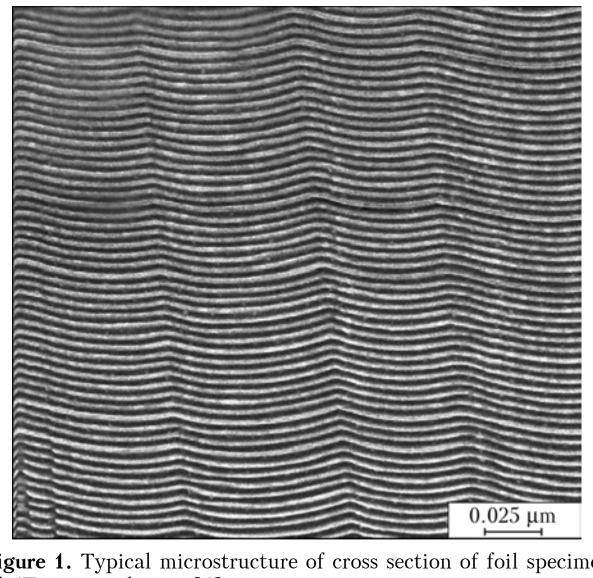

Figure 1. Typical microstructure of cross section of foil specimen Al/Ti in initial state [4]

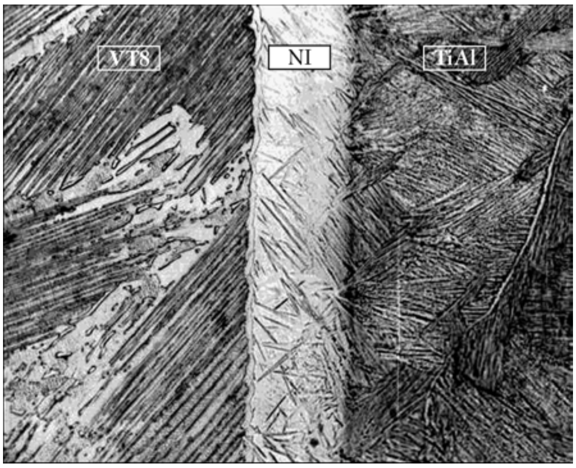

Figure 2. Microstructure (×400) of the joint TiAl + NI + VT8

its structural state according to the hardness relation towards effective modulus of elasticity. The meanings of mentioned values are obtained directly from the curves of automatic recording of kinetic diagram of load–depth of indenter deepening P–h (Figure 3).

This method is based on fundamental equation of indention [5], setting the relation between values of indenting diagram and characteristics of deformation and stress of material (calibrating dependence of indention):

$$H_{IT}/E^* = K(h_s/h_c), \tag{1}$$

where E^* is the effective modulus of elasticity; K is the constant of indenter shape; h_s, h_c are the contact and out-of-contact depth of indenter deepening.

The value h_c is the depth of indenter deepening, at which the contact between indenter and material after complete maximum loading $P_{\max}$ is performed. In this part of print the elastic-plastic deformation (possible fracture of material), and also elastic deformation of indenter occur. The part of depth of indenter deepening, at which the contact with material is absent in result of a dent formed in material around the indenter, is indicated as h_s. In that part of a print the complete elastic deformation of material takes place.

One of the important features of material is the relation of its hardness to the modulus of normal elasticity H/E. It is known that H/E value characterizes the capability of material to resist the changes in sizes and shape in the process of deformation, it reflects the conception about the ratio of their elasticity based on the standard mechanical tests of materials [6].

The H/E^* value is a standard hardness, according to the value of which the structural state of material can be defined [6]. For coarse-crystalline materials the mentioned ratio does not exceed 0.03. The fine-crystalline materials (up to 2–5 μm) have a ratio reaching 0.05. For the metals in nanocrystalline state this ratio is 0.06–0.10. At its value of more than 0.12 the materials are in amorphous and amorphous-crystalline state.

Microindention was carried out in the installation «Micron-gamma» at the room temperature using Berkovich diamond pyramid with automatically performed loading (P = 2 N) and unloading during 30 s, and also with recording of diagrams of loading, holding and unloading in the coordinates P--h. The loading and unloading were performed using electromagnetic effect on indenter. The precision of defining the loading P was $1\cdot10^{-3}$ N, and the depth of indenter deepening h was ±2.5 nm. The values of characteristics P, $h_{\max}$, h_f, h_c, H, E^*, E were determined and fixed auto-

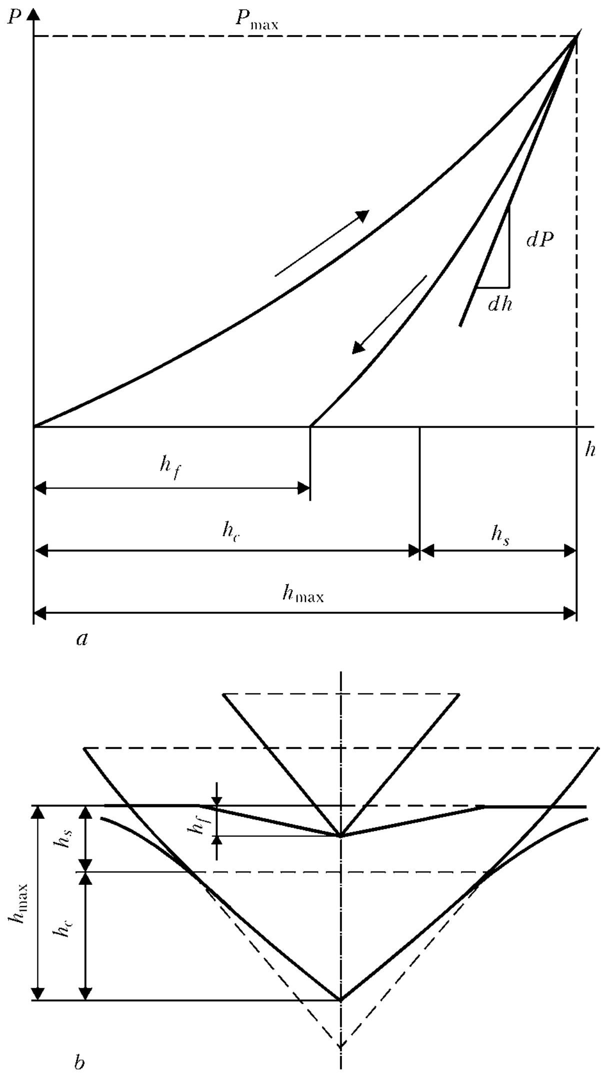

Figure 3. Kinetic diagram P–h (a) and scheme of interaction of indenter with material (b) [5]: h –– residual depth of deepening after removal of indenter; $h_{\max}$ –– maximum depth of deepening at $P_{\max}$

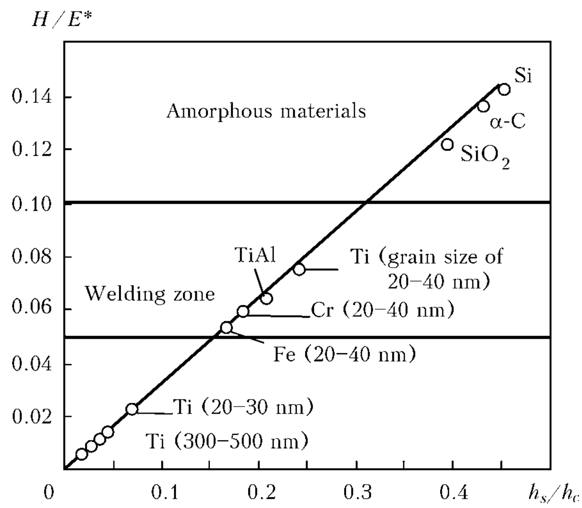

Figure 4. Relation between values of H/E^* and h_s/h_c in materials with different structural state

Mechanical characteristics of welded joint zones obtained according to the data of automatic indention

Area under investigation	H_{IT}, GPa	E_{IT}, GPa	C_{IT}, %	η_{IT}, %	H/E^*	ε_{el}, %	σ_{el}, MPa
Alloy VT8	3.85	101	1.07	31.8	0.0399	0.124	1181
Intermetallic TiAl	4.90	120	1.00	32.0	0.0434	0.135	1503
Welding zone	6.40	120	0.70	35.8	0.0565	0.176	1964
Initial nanolayered foil Ti/Al	4.20	60	1.40	48.2	0.0710	2.192	1218

Note. ε_{el}, σ_{el} are, respectively, elastic deformation and stress of material under indenter.

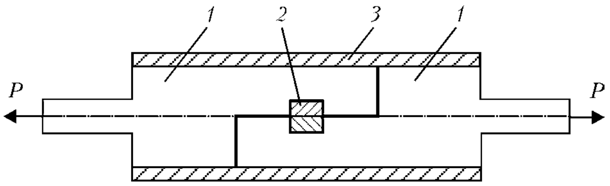

Figure 5. Grips for mechanical shear tests of welded specimens: *1* –– clamping jaws; *2* –– welded specimens; *3* –– limiting pipe

matically using corresponding formulae according to the standard ISO 14577-1–2002(E).

The results of indention of different zones of a welded joint are given in the Table.

For the materials being joined the structure of a grain of the size on the level of tens of micrometers and strength in the elastic zone of about 1100–1500 MPa is typical. The ratio H/E^* for the material of NI in the initial state (see the Table) reaches 0.0710 that corresponds to nanostructured materials (Figure 4). In spite of high values of hardness (H_{IT} = 4.2 GPa) the given material is characterized by a significant ductility C_{IT} = = 1.4 %, i.e. high values of stress relaxation are typical of it as compared with materials being joined, thus improving the contact between them.

The influences of welding temperature and high pressure resulted in significant changes in a transition layer. Its hardness and elasticity modulus increased up to the values characteristic of the alloy on TiAl base. Thus, it was established that after DWV the initial NI is transformed into TiAl being in the state close to nanocrystalline one (see the Table).

Authors of the work [7] state that with decrease in size of structural elements down to nanosize the life of material is sharply increased. In the works [8, 9] it is also indicated that materials being in nanocrystalline state are characterized by increased mechanical properties: tensile strength, microhardness, Young modulus are increased. The authors point out the absence of dislocations in nanometrical crystals, and also the presence of a large volume of intercrystalline phase with atomic disorder which results in growth of tensile strength by 2--2.5 times.

From abovementioned it can be concluded that due to nanocrystalline state the values of mechanical properties of the zone of joint VT8 with TiAl are at the high level.

To evaluate the mechanical properties of welded joints VT8 with TiAl, shear tests were carried out. The specimens were cut in electric erosion installation and brought to the size of 95 × 54 mm on the diamond disc, and then they were subjected to rupture using special grips (Figure 5).

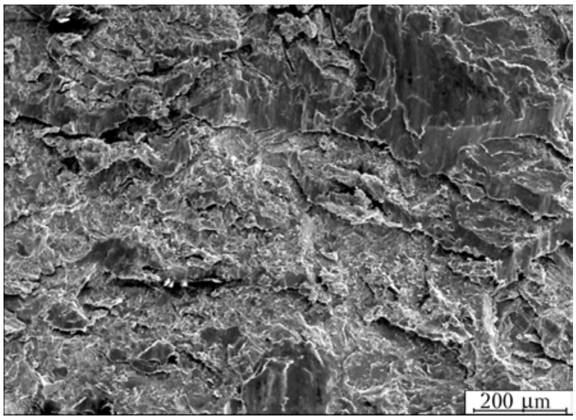

Figure 6. Fractographic pattern of fracture of welded joint VT8 + TiAl

The fracture of specimens was performed at shear strength σ_{sh} = 6000–6500 MPa which corresponds to the strength of base metal. The fracture had a tough-brittle character (Figure 6). The analysis of chemical composition of fracture surface did not reveal the presence of niobium. Thus, it can be assumed that the fracture was on the side of alloy VT8.

Thus, the investigation of joint zone using microindention allowed determining the fact that in the process of thermodeformational cycle of welding the NI is transformed into intermetallic with standard hardness H/E^* = 0.0565, characteristic of nanocrystalline materials. The use of TiAl NI in DWV allows producing welded joints TiAl + NI + VT8 with shear strength at the level of strength of base metal.

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PRESSURE WELDING OF TITANIUM ALUMINIDE TO OTHER TITANIUM ALLOYS

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The paper considers metallographic evaluation of the quality of pressure welded joints between intermetallic alloy Ti--32Al--2Cr and structural alloys VT1-0 and VT6. It is shown that pressure welding provides conditions required for producing defect-free welded joints.

Keywords: *pressure welding, titanium aluminide, titanium, microstructure, joints, microhardness*

Current service conditions of machines and mechanisms require development of new structural materials, possessing high specific strength and resistance to heavy loads.

As proved by earlier investigations, titanium alloys of the Ti–Al–Cr system are characterised by low ductility in the cast state at normal temperature, which substantially limits their application in real products [1]. To improve the set of physical-mechanical properties at room temperature and provide high heat resistance and thermal stability of such alloys, it is necessary to optimise their chemical composition, develop hot deformation parameters, and investigate their structure and mechanical properties in the cast and deformed states.

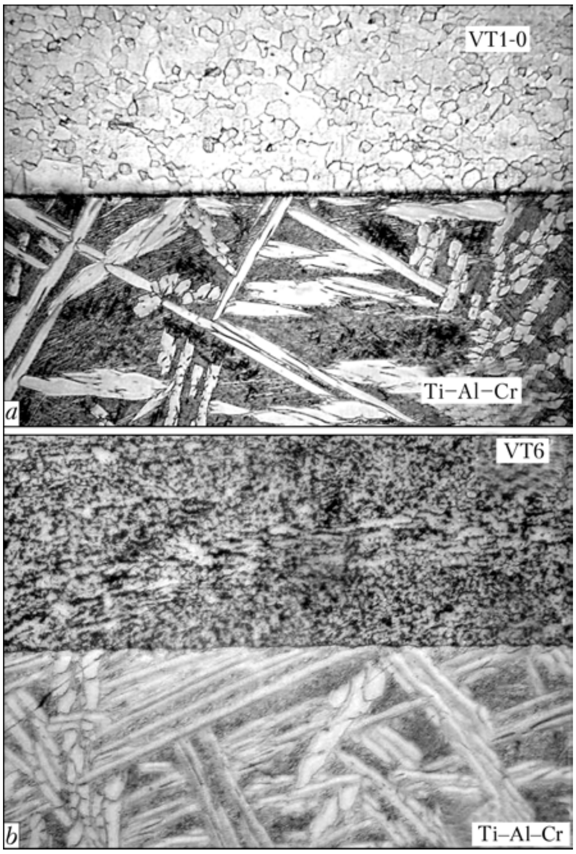

Figure 1. Microstructure of contact zones in welded joints of titanium aluminide to commercial titanium VT1-0 (*a* ---- ×100) and alloy VT6 (*b* ---- ×200)

In this connection, determination of principles of variations in physical-mechanical properties of alloys of the Ti--Al--Cr system at operational temperatures of 20--700 °C and evaluation of the effect of structure and mechanisms of fracture of these materials are topical research and applied problems [2].

Technological experiments and examination were conducted to investigate structures of pressure welded joints between titanium aluminide and titanium alloys of different compositions. The purpose of this study was to carry out a series of investigations to find out peculiarities of structural changes, as well as the effect exerted on them by technological factors.

30 mm diameter rods of alloys VT1-0 (commercial titanium) and VT6 (Ti–6Al–4V) were used to produce welded joints on titanium aluminide Ti–32Al--2Cr. The baseline technology for production of dissimilar welded joints on the above metals was optimized, and processes occurring in the joining zone under the effect of pressure welding parameters were studied in the course of experiments.

In pressure welding of titanium aluminide, the joints are made at temperatures below the $(\alpha + \gamma)$ transition temperature. This prevents changes in structure of the material and eliminates phenomena caused by rapid cooling of a joint from high temperatures (above the $(\alpha + \gamma)$ transition), which are characteristic of the majority of other joining methods (fusion welding in particular).

VT1-0 and VT6 samples 23 mm in diameter and 29 mm long, and titanium aluminide samples of the same diameter and 16 mm long were prepared for welding. Welding was performed in a process fixture with free deformation of ductile metal within 5--8 mm from the joint surface.

Welding of titanium aluminide to the above titanium alloys was carried out in a vacuum chamber of unit U-874 at a temperature of 820–830 °C. The samples were heated to this temperature, and held for 15 min to level the temperature over the entire section of the process fixture. Then a pressure of 300 MPa was applied to them for 10 min. The samples were

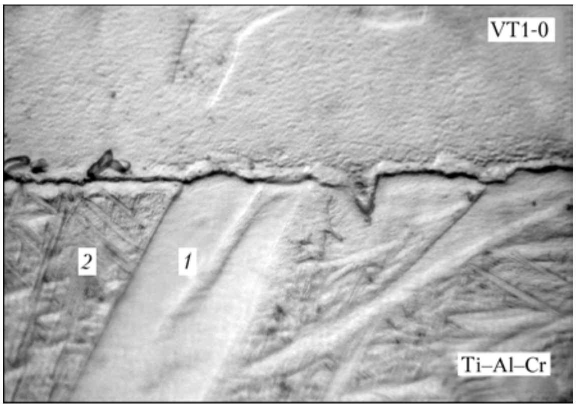

Figure 2. Microstructure (×1250) of diffusion zone in titanium aluminide + VT1-0 welded joint

cooled to 200--300 °C in the vacuum chamber. Heating of the samples in the unit was provided by a molybdenum heater at a rate of about 20 °C/min.

Microstructure of contact zone in the resulting welded joints of titanium aluminide to commercial titanium VT1-0 and alloy VT6 is shown in Figure 1. The contact zones of both joints have a clearly defined interface between the metals and are free from defects.

Examination of the titanium aluminide + VT1-0 joints in the as-welded state (Figure 1, *a*) revealed no common grains (at given welding parameters) in contact zones of the mating surfaces. The presence of the diffusion zone both on the side of titanium and on the side of titanium aluminide can be clearly seen at high magnification (Figure 2).

X-ray microanalysis showed that the lighter phase (position *1*, Figure 2) in intermetallic alloy had the following chemical composition, wt.%: 78.9 Ti, 18.88 Al, 2.16 Cr (Figure 3), while grains of the darker phase containing decomposition products (position *2*, Figure 2) had the following composition: 74.82 Ti, 18.63 Al, 6.55 Cr. These data are indicative of a complex internal structure, in particular, of a presence of

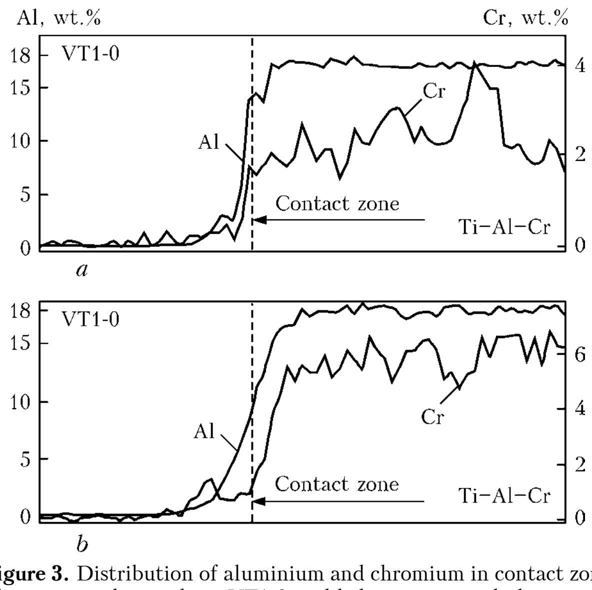

Figure 3. Distribution of aluminium and chromium in contact zone of titanium aluminide + VT1-0 welded joint: *a* ---- light grains; *b* ---- grains with decomposition products

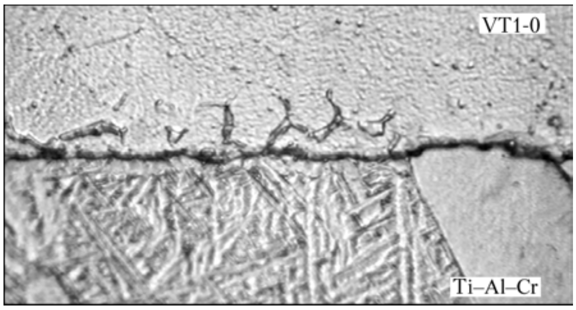

Figure 4. Microstructure (×1250) of diffusion zone with grain-boundary diffusion of aluminium to titanium

fine inclusions of the β-phase formed as a result of increase of the chromium content.

Interaction of titanium aluminide with commercial titanium VT1-0 under the effect of welding parameters is characterised by diffusion of aluminium through the contact zone from titanium aluminide to titanium by the mechanism of grain-boundary diffusion to form a phase. This process occurs most intensively on the side of grains containing decomposition products (Figure 3).

Both aluminium and chromium diffuse to titanium, although chromium diffuses at a much lower rate, during welding on the side of the light phase of titanium aluminide (Figure 4).

Examination of distribution of microhardness in a direction normal to the contact zone of the titanium aluminide + VT1-0 joint (Figure 5) showed the presence of a diffusion zone 5--7 μm wide in a direction to titanium. X-ray microanalysis revealed occurrence of diffusion of mostly aluminium on the side of titanium aluminide (see Figure 3, *a*) and aluminium and chromium on the side of the phase with decomposition products (Figure 3, *b*).

Examinations of structure of the titanium aluminide + VT6 welded joint (Figure 6) showed no

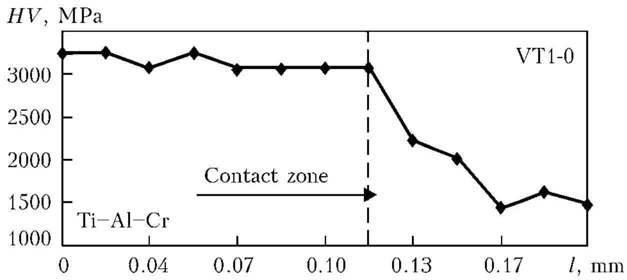

Figure 5. Distribution of microhardness in contact zone of titanium aluminide + VT1-0 welded joint: *l* ---- distance between indentations

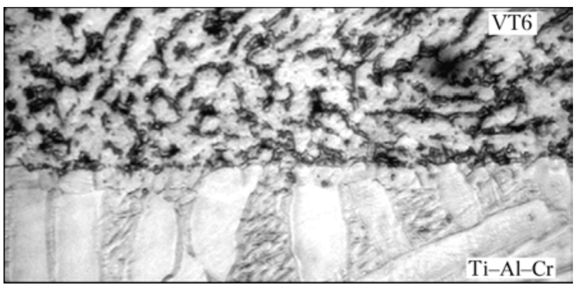

Figure 6. Microstructure (×1250) of diffusion zone in titanium aluminide + VT6 welded joint

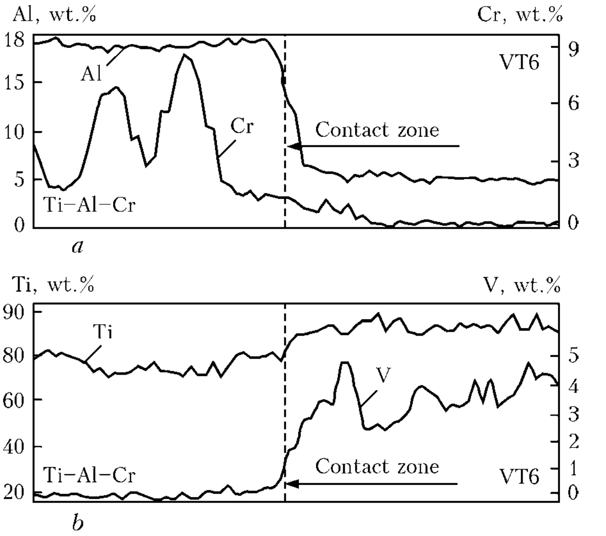

Figure 7. Distribution of aluminium, chromium (*a*), titanium and vanadium (*b*) in contact zone of titanium aluminide + VT6 welded joint

substantial changes in structure of both metals. X-ray microanalysis determined distribution of alloying elements in contact zone of the titanium aluminide + VT6 welded joint (Figure 7). According to the X-ray microanalysis data, width of the diffusion zone from contact zone in titanium alloy VT6 is 2.5 μm, and in titanium aluminide — 2.0 μm.

Optical microscopy of microstructure of the welding zone (see Figure 6) revealed fine grains of the α_2-phase with 11–15 wt.% Al, which formed along the contact zone between the two metals in titanium aluminide. In addition, the diffusion zone contains 1.8–1.4 wt.% Cr and 0.4–1.8 wt.% V, which diffuses from alloy VT6.

The content of aluminium in the diffusion zone of alloy VT6 varies from 6.5 to 11.0 wt.%. The diffusion

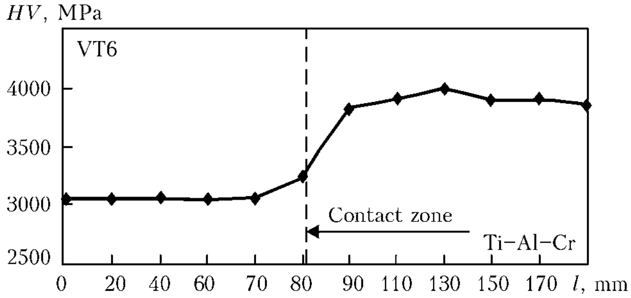

Figure 8. Distribution of microhardness in contact zone of titanium aluminide + VT6 welded joint

zone is depleted in vanadium (from 2.8 to 1.8 wt.%) due to its diffusion to titanium aluminide, but is rich in chromium (from 1.0 to 1.4 wt.%), which diffuses from titanium aluminide.

Distribution of microhardness across the contact zone was investigated. The data shown in Figure 8 prove the presence of the diffusion zone both in alloy VT6 and in titanium aluminide.

Therefore, the defect-free welded joints between titanium aluminide and titanium alloys VT1-0 and VT6 were produced by pressure welding. Characteristic peculiarity of interaction of titanium aluminide and titanium VT1-0 under the effect of welding parameters is diffusion of aluminium through the contact zone by the mechanism of grain-boundary diffusion to form some phase.

Examinations of the titanium aluminide + VT6 welded joint revealed no substantial changes in structure of both metals.

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WELDING AND CUTTING 2009
Essen, Germany, 14–19 September 2009

For 21 years the traditional international «Welding and Cutting» Fair, which is held every four years, has been a peculiar forum of welders of all over the world, demonstrating new achievements in the field of welding and related technologies.

Participating in this Fair were 1015 companies from 42 countries, including five companies from Ukraine and three from Russia. Despite the global economical crisis, the number of participants, compared with 2005, did not decrease. 1000 booths were arranged on the Fair site of over 110,000 m^2. The most representative expositions were those of Germany (417 companies), then of China (137), Italy (122), USA (49), France (38), Great Britain (33), The Netherlands (20), India (18), Switzerland (15), Turkey (14), and Austria (10). The rest of 29 countries had the expositions demonstrating activities of their companies, each having not less than 10 companies. There were eight cooperative booths at the Fair: Great Britain (4 companies), Italy (9), China (22), USA (2 separate booths representing 34 companies), Taiwan (5 companies), France (11), Japan (4), and Ukraine (5).

More than 60,000 visitors from 128 countries were registered during 6 working days of the Fair. Conference «Mathematical Modelling of Stresses and Strains in Welded Joints» was held during the Fair.

The Ukraine cooperative booth exhibited developments of the E.O. Paton Electric Welding Institute of the NAS of Ukraine (Kiev), Open Joint Stock Company «Kakhovka Plant for Electric Welding Equipment», companies SELMA (Simferopol), «Zavod Donmet» Ltd. (Kramatorsk), and «Promprylad» Ltd. (Kiev).

The review below includes impressions of the specialists — members of the delegation from the E.O. Paton Electric Welding Institute, showing the trends in advancement of their respective areas of the welding industry. The review was prepared by Prof. S.I. Kuchuk-Yatsenko (flash butt welding), Prof. A.Ya. Ishchenko and Prof. L.D. Dobrushin (solid-state joining), Prof. S.V. Akhonin (welding of titanium), Dr. V.A. Lebedev (equipment for mechanised arc welding), Dr. A.A. Rybakov (technology, equipment and consumables for welded pipe production), Dr. A.P. Zhudra (surfacing materials and technologies), Dr. V.D. Shelyagin (laser welding, laser and hybrid technologies), Dr. Yu.V. Demchenko (severing, machine tools, post-weld treatment), Dr. P.P. Protsenko (welding simulators), and Eng. D.V. Kovalenko (new capabilities of TIG welding).

Equipment for mechanised arc welding. As to the amount of exhibits, the equipment for mechanised arc welding and surfacing looked traditionally the leading one. Widely presented was the equipment not only of the known firms and companies from the developed countries, but also of new companies from China, Portugal etc. Almost all basic arc processes and technologies implemented by using welding semi-automatic devices are well-known, but there were also some interesting designs solutions, which can be conditionally regarded as the new ones, as they demonstrate modifications of the known developments. A number of companies exhibited components for semi-automatic devices: hose packs, feed mechanisms (ready for any motor to be built into the developed configuration of mechanism).

Arc welding power supplies (mains and inverter). Many companies participating in the Fair exhibited such power supplies: LINCOLN ELECTRIC, KEMPPI, FRONIUS, GRC Evans, Castolin Eutectic,

ESAB, CLOOS, CEA, STARWELD, SINCODA, TELWIN, FIMER S.p.A., FCW International, KHAZAR-TRAnsfo, and Alpha Laser. The Chinese industry was represented by companies: HULONG, HUGONG Welder, AOTAI, Mitec, WTL, UNIPOW, YDULI, VIGEX, KINF, KAIERDA, JING GONG, JASIC, etc.

CNC inverter supplies made up the absolute majority of power supplies for semi-automatic welding devices. Main control algorithms are related to program control via electrode metal transfer, as well as implementation of synergic control. This is the so called «cold process» (CLOOS), and SST-process (LINCOLN ELECTRIC), and a number of processes on their base with modified pulse parameters. For example, FRONIUS substantially advanced the CMT process by timing the welding current pulse source and pulse feed mechanism following a certain algorithm, thus achieving additional technological effects.

Computerised welding current sources have, as a rule, from 24 to 60 programs for implementation of the pulsed arc welding process, depending upon the process parameters, wire type, weld position etc. Moreover, exhibited were the sources, e.g. of TELWIN (Italy), with a possibility of on-line programming using the data display.

Most companies produce inverter sources for a current of up to 350 A, but there are also models designed for currents of up to 600 and 1000 A.

It should be noted that rather simple welding current sources exhibited at the Fair were claimed to be reliable and requiring no special maintenance.

Electrode wire feed systems. The main product line includes traditional pairs of feed and pressure rollers (one and two pairs) with different configurations of grooves and other means for increasing the pulling force in a feed mechanism of the push type. However, there are feed systems of the pull type with a mechanism located in the hose pack holder. In these systems both geared mechanisms and mechanisms based on planetary rollers can be used as such a mechanism.

Electric drive packages with DC motors (commutator and commutatorless) are used as an electric drive. For pulsed feed, CLOOS and FRONIUS use special designs of step motor drives. Controllers of the electric drives are mostly of the transistor type, having a programmed control with feedback systems. Novelty in this area is fitting the semi-automatic welding station with two independent feed mechanisms with two hose packs, which are mounted on a common structure with a common control system and welding current source. In this case, one feed system is intended for welding of steels, and the other — for welding of non-ferrous metals. Such semi-automatic devices find application in motor car construction, where the car structures also comprise assemblies and components of aluminium alloys and copper, in addition to steel elements. These semi-automatic devices are also efficient for welding of long-length structures.

Designs of semi-automatic devices. Many semi-automatic devices, mostly of general application, for welding of steels and aluminium in inert atmosphere were exhibited at the Fair. Utilisation of multi-component mixtures is insignificant. Few companies, including the known Castolin Eutectic, use flux-cored electrode wires in semi-automatic devices. Of interest are also semi-automatic devices based on several work algorithms, for example, pulse control of electrode metal transfer and mode modulation. Single-block designs and designs with portable feed mechanisms were demonstrated. In this case, control and regulation of the welding process are concentrated in one place. Semi-automatic device casings made from plastics are widely applied. A number of companies are ready to develop and manufacture at a customer request any casing parts (special cases, reels, fasteners, etc.) for mechanised equipment.

No mechanised equipment for underwater welding and cutting, semi-automatic devices using increased-diameter electrode wires (flux-cored and from aluminium alloys, with diameters of about 3.0 mm or more), semi-automatic devices with controlled pulsed feed, based on commutatorless motors, and a number of others were presented at the Fair.

Such leading companies as LINCOLN ELECTRIC, ESAB, Air Liquide Welding, Castolin Eutectic, A&N Europe, Weber SHELD, FRONIUS and a number of Chinese companies demonstrated in operation, on assemblies and components characteristic of metal structures, the advantages of stationary automated modular systems and units for making butt and fillet joints, planar and cylindrical metal structures with straight-lined and curvilinear surfaces, as well as for surfacing. Different samples of such equipment are intended for implementation of the technologies of welding using solid or flux-cored wire, in shielding gas atmosphere and by the submerged-arc method, using self-shielding wire, or tungsten electrode with filler wire. The systems are made of unified functional modules and include a process module, process tool manipulator, control module, adaptation module, and environment protection module. These systems are based on advanced designs of drives, actuating mechanisms, specialised fixture and environment comfort ensuring systems. They can be taken as a basis for development of the equipment to realise welding and surfacing technologies by small and medium business firms: surfacing of railway and crane wheels, shafts, rollers and augers, welding of tanks, cylinders, ladles, flat metal structures of lighting supports, welding of elements and necks to tanks, etc.

Of high interest among visitors were versatile light-weight carriages (made mostly by ESAB, FRONIUS and some Chinese companies). They are intended for displacement of gas-oxygen cutters and torches in any spatial positions, and can be successfully used in field and under stationary conditions for cutting, welding, surfacing of straight-lined and curvilinear surfaces, as well as annular pieces. Weightdimension and technical characteristics of these products are such that they can be moved on guide rails, flexible strips, or without them. Undoubtedly, they can be widely applied for automation of welding, surfacing and cutting processes under factory conditions at small business firms and workshops.

New capabilities of TIG welding. Characteristic feature of this Fair is that not only the world leading companies, such as LINCOLN ELECTRIC, ESAB, FRONIUS, EWM and ITB, but many others, including small and little-known ones, pay much more attention to development of equipment, consumables and accessories for TIG welding. The obvious focus at previous exhibitions was on MIG/MAG welding, out of other arc welding methods. The following can be marked out among a wide variety of presented developments and equipment.

Technische Universitaet Chemnitz (Germany) presented a device providing an increased penetration depth in TIG welding. The principle of its operation consists in the pulsed feed of a shielding gas (argon) at a certain frequency (5 Hz), the argon flow rate in pulse being 30 l/min, and that in pause — 5 l/min. Samples of butt joints on stainless steel 5 mm thick, welded in one pass without groove preparation, were demonstrated. VBC Group (Great Britain) exhibited new power supply InterPulse, which provides contraction of the arc with decrease in HAZ, reduction of heat input by a factor of 1/3, compared with traditional TIG welding, possibility of welding a new generation of single-crystal superalloys, and welding of titanium alloys using no protective chambers and spouts.

Jetline Engineering (USA) and United ProArc (Taiwan) offer a wide range of units for TIG welding of longitudinal and circumferential welds, including simple and inexpensive ones. WELMAX (Norway), having a wide experience in field welding of pipes at oil deposits, presented automated units for roll and position butt TIG welding, including narrow-groove TIG welding, by using a heated filler wire.

Astral Engineering (Germany) demonstrated integrated equipment lines for spiral seam welding of hot rolled steel pipes of different standard sizes, with diameters ranging from 170 to 3050 mm, thickness — from 4 to 25.4 mm, and length — from 6 to 20 m.

Systec Elektronic und Software (Germany) presented the integration-ready positioning systems DriveSets for translational and rotational movements. These are complete versatile mechanotronic systems, which are delivered in a fully assembled state and include not only kinematics and control devices, but also software and documents. Their key advantages are as follows: a wide range of technical parameters (load, speed and grade of accuracy), over 36,000 modifications, simple on-line selection by a diagram, and delivery term of 3 to 5 weeks.

About 40 companies presented different types of equipment for orbital TIG welding, such as highly automated and computerised equipment with seam tracking and process visualisation systems manufactured by such German companies as Arc Machines GmbH, ORBIMATIC and Orbitec GmbH, POLYSOUDE (France), ESAB AB (Sweden), and Liburdi Automation Inc. (Canada).

Meta Vision Systems (Great Britain) and SERVO-ROBOT (Canada), which are the leaders in the field of laser seam tracking systems, demonstrated a range of sensors and systems to be applied with different welding methods (TIG, MIG/MAG, submerged-arc and laser welding) for manufacture of pipes, tanks, casing structures, etc., and robotic technologies for automotive industry and space engineering. Scansonic (Germany) also exhibited a versatile optical sensor for seam tracking systems to monitor different welded joints. CAVITAR (Finland) and BFi OPTILAS (Germany) introduced visitors to an interesting joint development — high-speed laser-optical system Cavilux Welding Monitoring, which allows visual observation of the entire welding process (both in low- and high-temperature zones) at a very high quality and in real time. BFi OPTILAS also demonstrated a wide range of different digital video cameras, displays and software, which can find wide acceptance for research purposes in the field of various welding processes, as well as for commercial application.

Ing. Grimm Schweisstechnik (Germany) presented the high-precision CNC welding head DKS 9000 for filler wire TIG welding, designed for automated systems and robotic complexes. Wire diameter ranges from 0.8 to 2.4 mm, and wire feed speed (continuous and pulsed) is adjustable from 0 to 15 m/min. STB Schweisstechnik (Germany) demonstrated machine TIP TIG with a manual welding torch for heated filler wire TIG welding. Key advantages of this machine include high productivity (deposition rate — up to 2 kg/h, and manual welding speed — up to 80 cm/min), and up to 150 % reduction of costs compared with conventional TIG welding. Rohrman Schweisstechnik (Germany) presented removable nozzle Champagne Nozzle II for manual TIG welding torches. The main advantages are a large diameter of the nozzle — 28 cm, and a laminar flow of gas at its increased rate, this allowing a substantial improvement of the protective potential of the nozzle, which is particularly important for TIG welding of stainless steels and reactive metals. Moreover, the possibility exists of considerably increasing the tungsten electrode extension — up to 50 mm, which will allow a welder to better watch the weld pool during welding.

Ges. fuer Wolfram Industrie (Germany) offered tungsten electrodes of the WIT-STAR and ORBISTAR types, containing no thoria, which is a radioactive element. In addition to improved safety, these electrodes are characterised by an increased life compared with conventional ones. Several companies presented different devices for sharpening of tungsten electrodes: small-size versatile tools of the Trix series, as well as tool Neutrix, which is delivered in a case (total weight in a set — 2.8 kg, power — 650 W).

Aquasol (USA) offered the following range of materials increasing the efficiency of welding: Aquasol — water-soluble paper and strip, EZ Purge — ready-made self-adhesive plugs of water-soluble paper for gas purging, Solugap — water-soluble gaskets of a unique design for bell-and-spigot welding, Fiback — fibreglass gasket strip for elimination or reduction of the need for gas purging and ensuring of back shielding of the weld pool, EZ Zone — two-layer aluminium strip for sealing the joint gaps, Liqui-Film — water-soluble polymeric film to be used as a barrier for purging gas, and EZ Wipes — multi-purpose wiping napkins. The Company demonstrated a portable self-contained oxymeter OX-100 with a resolution of –0.1 % (1000 %) for precise measurement of oxygen concentration after purging the pipes with shielding gas (argon).

NITTY-GRITTY S.R.L. (Italy), Chemetall AG (Germany) and other companies presented different devices of the Clinox and Antox types for cleaning the welds after welding.

Welding technology, equipment and consumables for pipe production. Technology and equipment for production of large-diameter pipes were exhibited at the Uhrhan-Schwill and ESAB booths. In contrast to the 2005 Fair, Uhrhan-Schwill did not have its own booth and arranged its exposition at the LINCOLN ELECTRIC booth. Again, unlike the previous Fair, only the four-arc device for welding the internal welds in pipes, a full analogue of the 2004 device, was exhibited at the LINCOLN ELECTRIC booth. The device is equipped with a system of support and guide rollers, adjustable rod, laser system for maintaining the electrode extension, digital system for control of the welding process and other elements. Such devices were integrated into the equipment supplied by SMS Meer to fit new pipe production shops at the Vyksunsky Metallurgical, Izhorsky Pipe and Chelyabinsky Pipe Rolling plants.

It is a known fact that in 2008/2009 Uhrhan-Schwill offered, e.g. for the Khartsyzsky Plant, a new design of the apparatus for inside welding using no support rollers (that does not bear on the internal surface of a pipe). This design of the apparatus is now at a stage of optimisation. The five-arc apparatus manufactured by the Company for outside welding of pipes was not exhibited at the Fair. According to the available information, the Company does not have any new technological solutions for welding of pipes, and recommends using the submerged four- and five-arc welding processes, similar to the developments of the E.O. Paton Electric Welding Institute. Inverter power supply Power Wave 1500 developed by LINCOLN ELECTRIC in collaboration with Uhrhan-Schwill, which was exhibited at the previous Fair but is not presented at this Fair, has not yet found an application in pipe welding production. Europipe bought a batch of such power supplies four years ago. However, no information is available as yet concerning their application and technological advantages.

LINCOLN ELECTRIC offers the known agglomerated aluminate-basic fluxes 995L and 998L and wire of the Fe–Mn–Mo (L-70) and Fe–Mn–Mo–Ti–B (LNS 140 TB) systems to be used as consumables for pipe welding production. There are no new developments in the field of consumables for welding of pipes.

A four-arc device for inside welding of pipes was exhibited at the ESAB booth. This device uses a ram-type flat contact tube arranged across the welding direction, instead of a sleeve-type one.

In addition, a three-arc apparatus was exhibited at the ESAB booth. It was used to demonstrate welding of thick-walled (about 60 mm) shells. The process employed is similar to three-arc welding of pipes.

ESAB, like LINCOLN ELECTRIC, offers the known aluminate-basic flux of the OK 10.71 and OK 10.74 grades, as well as wires of the same alloying systems for welding of pipes. According to the results of investigations conducted by the E.O. Paton Electric Welding Institute, flux OK 10.71 is unsuitable for multi-arc welding of pipes, and is not applied at pipe welding plants of Russia and Ukraine. New developments in the field of consumables for pipe welding production are not available.

Surfacing. No substantial changes in terms of development of new technologies have occurred during the last four years in the field of arc surfacing. Traditionally, among the exhibitors were such companies as Sulzer Metko Woka (Germany), Castolin Eutectic (Switzerland), WELDING ALLOYS GROUP (Great Britain), VAUTID GmbH (Germany), EIPA Eiseh Palmen (Germany), Contex (Germany), DURUM SA (Germany), ERGOTEM SA (Greece), SV Schweiss-und Verschleisstechnik GmbH & Co. KG (Germany), Kalenborn Kalprotect GmbH & Co. KG (Germany), Beijing Advanced Materials Co., Ltd. (China), and the Chinese branch of Asiamet Inc. (USA), as well as a number of smaller companies from different countries.

The majority of these companies presented samples of deposited parts mostly for metallurgical, mining, ore-dressing, cement and other industrial sectors. The dominating place among a wide range of surfacing technologies is still taken by automatic flux-cored wire open- and submerged-arc surfacing, while the most common product among the corresponding ones is still a wear-resistant bimetal plate. In contrast to the earlier widespread technology for surfacing over a charge layer, today such major manufacturers in surfacing operations as Castolin Eutectic, EIPA, Contex, etc. perform surfacing of plates by the flux-cored wire open- or submerged-arc methods. VAUTID has up 12 machines in operation, and 10 machines are used round the clock for surfacing of plates at a German factory of Castolin in Kriftel.

The scopes of production of bimetal plates clad by the PTA process, where a steel or nickel-chrome-boron matrix is reinforced by the spherical or crushed tungsten carbide granules, have substantially grown. DURUM demonstrated a 2 + 2 mm thick plate clad by using the above materials. Sulzer Metco Woka, Castolin (Austrian subsidiary) and a number of other companies combine the PTA process with laser to deposit composite layers on drilling equipment parts, such as calibrators, reamers, bits, etc.

Traditionally, almost all the companies presented a wide range of surfacing consumables, primarily flux-cored wires, electrodes, and, to a lesser degree, sintered strips. Chromium carbide based flux-cored wires, alloyed with niobium (up to 7 %) and vanadium (up to 8 %), are offered as an achievement. The metal deposited with these wires is resistant to intensive abrasive and gas-abrasive wear at temperatures of up to 750 °C. Of special interest is a flux-cored wire produced by Castolin, which provides a nanostructure with hardness of up to *HRC* 70 in the deposited layer. The quantity of companies producing and consuming tungsten carbides has markedly grown. Sulzer Metco Woka, DURUM, Technogenia, BAM (China), Asiamet (USA) and Carbide and Metal (C&M) (Germany) offer today several types of hard-facing powders based on tungsten carbide: macrocrystalline WC with 6 % C, fused WC + W_2C, crushed and spherical (produced by melting of crushed tungsten carbide in a jet of induction plasma), as well as synthesised cermet alloy of tungsten with 2–6 % Co. It should be noted that spherical tungsten carbide produced by the technology of the E.O. Paton Electric Welding Institute, which is based on centrifugal spraying, features the best properties and is beyond comparison, according to the unanimous conclusion.

Equipment for surfacing and cladding operations was exhibited at the Fair by an example of a number of specialised machines and a wide range of robots offered by different companies.

Specialised machines designed for surfacing and welding of large-size parts are characterised by a massive modular frame mounted on a strong column or gantry, this providing a high accuracy of surfacing and welding operations. An example is a machine offered by Key Plant (Germany). Of special interest are the WELDING ALLOYS machines for cladding of cylindrical parts up to 3 t in weight, as a well as a machine for inside surfacing of casing parts and pipes up to 3 m long. Some companies presented small modular surfacing units.

Laser equipment, laser and hybrid technologies. Laser equipment and laser and hybrid technologies were presented at the Fair by over 15 companies: IPG Photonics (USA), IPG Laser GmbH (Germany), ROFIN SINAR, TRUMPF, JENOPTIK, LASERMAK TURKEY, HIGHY AG, Alpha Laser (Germany), Scansonic, WINLaser NC, PEIS-LASER-MATERIAL, BEARBEITUNG, GNLASER (China), BAM, SLV-Haller (Germany), etc.

Of high interest was exposition of IPG, which offered new samples of high-power fibre lasers, the technical and operational characteristics of which are superior to those of other laser designs:

• service life — 50,000–100,000 h with a possibility extending it at low costs;

• absence of consumables and minimal operating costs;

• minimal time for commissioning, preparation of premises and starting-up;

• possibility of multi-fold increase in power by adding extra units;

• possibility of transporting the beam via an optical cable 10–100 m long and switching the beam to 6–8 such cables for arranging multi-functional workshops;

• possibility of operating the equipment by a staff with primary and secondary technical education.

The IPG single-mode ytterbium fibre lasers with a power of up to 2 kW have superior beam characteristics. Lasers of the YLR-1000SM and YLR-2000SM types feature a beam divergence (BPP) of 0.4 mm·mrad in operation from active optic feeder 20 μm in diameter, and 2 mm·mrad in operation via transport feeder 50 μm in diameter.

The 30 kW fibre laser YLS-30000 was demonstrated at the Fair, having a beam quality index of less than 2 mm·mrad at a 5 kW power, this being several times lower compared with other laser designs. This laser can be completed with cutting and welding heads of the HIGHYAG Company, as a well as with a scanner allowing an extensive deflection of the laser beam to 160–200 mm at a workpiece to scanner distance of 600 mm.

ROFIN SINAR also demonstrated the single-mode ytterbium fibre laser with a power of 1 kW and high beam quality. TRUMPF presented a 4 kW disk laser (with optical fibre) connected to a three-coordinate manipulator with a scanner mounted on it, having the following technical characteristics: focal distance — 450 mm, time of full deflection — 30 ms, beam diameter on a workpiece — 600 μm, and sizes of a work volume: *X* — 206 mm, *Y* — 352 mm, and *Z* — 140 mm. The technology of connecting two laser beam control systems makes it possible to substantially increase the productivity of the unit and perform welding «on the run». Rapid «jump» of the laser beam from one welding point to the other by means of the scanning optics reduces the losses of time for movement of the welding head by the manipulator, and the time is spent only for welding. Power and quality parameters of disk lasers have been considerably improved. For example, BPP is 2 mm·mrad at a power of 1 kW, and 8 mm·mrad at 2–8 kW. Power of a single unit increased to 10–16 kW.

Interesting devices, scanners and accessories were demonstrated by Scansonic and ILV DC-SCANNER. Samples of the head for hybrid laser-arc welding were presented by HIGHYAG, FRONIUS, ESAB, CLOOS, SLV-Halle, etc.

Samples of 900 mm diameter pipe with a wall thickness of up to 14 mm, welded by the hybrid laser-arc method, were demonstrated by IPG, BAM, SLV-Halle (video) and VIETZ.

IPG presented samples and leaflets on laser-resistance welding. Equipment for laser, plasma and gas cutting was demonstrated by such companies as ESAB, MESSER, KARABASIS, HUGONG, Koike, HONEYBEE, Eckert, PROARC, TECHNO, WTL, Szhuayilong, AUTOREX, etc. Most impressive were the ESAB, Koike and Eckert machines for oxygen cutting. The samples made by using these machines have a smooth surface and minimal inclination of walls, as well as good surface with a bevel.

Of high interest are 5- and 6-coordinate manipulators and robots performing cutting and welding of complex-configuration parts, e.g. cutting-in of pipes at different angles. Undoubtedly, the laser cutting units are beyond comparison for treatment of thin metal. LASAG presented a series of units performing laser cutting and drilling with record-breaking characteristics: cutting of metal 1–0.04 mm thick, and drilling of metal up to 0.5 mm thick at an angle of 30° with 0.1 mm diameter hole.

Welding of titanium. Traditional technologies for welding of titanium were presented at the Fair: electron beam welding and TIG welding in argon atmosphere.

The Technology for EBW of titanium is offered mostly for aircraft engineering and power machine building. EBW units were presented by such companies as Probeam Systems GmbH (Germany), TECHMETA (France), and Cambridge Vacuum Engineering (Great Britain). All the companies offer an entire package of services for delivery of the EBW equipment and technologies. Deliveries of the equipment include vacuum chambers with dimensions ranging from 300 × × 300 × 300 to 7000 × 7000 × 14000 mm, electron beam guns with accelerating voltage of 60 to 175 kV and beam power of up to 80 kW, together with power supplies, automated loading and unloading systems and manipulators, control systems, vacuum systems allowing a chamber to be evacuated within less than 30 min, as well as other auxiliary systems. In addition to welding, the companies offer technical and technological solutions for electron beam surface treatment and cutting (hole drilling).

It should be noted that Cambridge Vacuum Engineering since 2006 has been active in implementation of new developments of TWI under licence agreements, offering, in particular, the technology for electron beam surfacing of near net shape billets (near net shape technology), EBW under low vacuum conditions (reduced pressure EBW), etc.

Technologies for TIG welding of titanium are offered primarily for application in chemical engineering (welding of heat exchanger tubes to tube plates), the focus being on the orbital position butt welding process. Units for orbital welding were presented by such companies as Orbitalum Tools (Germany), Stelin Srl (Italy), Progettazione Apparecchiature Industriali Srl (Italy), Arc Machines, Inc. (USA), and POLYSOUDE (France). All suppliers of such equipment offer integrated deliveries, including specialised welding heads with 100 % shielding of the welds with inert gas in welding of 30 to 300 mm diameter pipes, welding arc power sources with computer control of welding parameters, groove preparation equipment, auxiliary fixture and devices. In addition, the above companies provide training of personnel in operation of the equipment supplied.

For position and roll but welding of pipes with a wall thickness of up to 150 mm, made from conventional and stainless steels, Arc Machines offers a narrow-gap TIG welding technology and equipment, and POLYSOUDE — narrow-gap MIG welding technology and equipment.

Resistance welding. Equipment for resistance welding was demonstrated at booths of 15 companies. Among them, the widest range of the equipment was exhibited by DALEX Schweissmashinen GmbH (Germany), GF Welding S.p.A. (Italy), Semsa (Italy), Wantec (Germany), ANTECH ELECT Ltd. (China), etc. In the most part, the equipment consists of versatile and specialised machines for spot and projection welding, as well as power supplies for them.

The common trend in the last years for all classes of this equipment has been the use of inverter power sources, which provide a three-phase mains supply, improvement of energy indicators, and wider capabilities of adjustment of welding process parameters.

Over 80 % of all machines for resistance welding with a power of over 100 kV·A, which were exhibited at the Fair, were equipped with the transducers providing the three-phase mains supply, as well as the use of the direct current in the welding circuit and direct current in the secondary welding circuit. It should be noted that a dramatic reduction in price of such transducers has occurred within the last three or four years. This, for sure, promoted their wider application in the up-to-date resistance welding equipment. It should be emphasised that decrease in dimensions and weight of the transducers allowed their extensive utilisation in mobile tongs for spot welding. Many types of tongs with built-in power supplies (rectifiers, high-frequency transformers) were exhibited. The second peculiarity of this equipment consists in using a modular principle of packaging of the tongs assembled from typical elements (rectifier blocks, transformers, control systems). This resulted in the specialised equipment adapted to the maximum possible degree to peculiar designs of weldments, and allowed using it as part of robotic complexes.

In addition to the spot welding equipment, many types of portable units for welding of studs of different sections and configurations were exhibited at several booths. The units provide welding by the capacitor energy storage and electric arc discharge methods.

DALEX Schweissmashinen (Germany) presented at its booth a complete set of inverter power sources for spot welding, with a power of 100 to 1000 kV·A. In addition to a uniform three-phase supply, the inverters allow substantial decrease in impedance of the secondary circuit of a welding machine, and increase in the welding currents owing to the use of the direct current.

Semsa demonstrated at its booth a wide range of spot welding equipment integrated into high-efficiency production lines, including with robot part loading. Of interest is an original unit for resistance seam welding of thin-walled cylindrical shells made form galvanised steels (with a productivity of up to 2 m/min), as well as for welding of longitudinal stiffeners.

A set of modules for spot welding, mounted on a gantry with a possibility of their multi-axis spatial displacement, was presented. The set of integrated modules for packaging of specialised tongs for spot welding was exhibited at the booth of CF Welding. They include transformers with an intermediate frequency of 1000 Hz, which are most commonly used in inverters for spot welding.

The stud welding equipment, with a capacitor or electric arc discharge used for welding, was demonstrated by Nelson, HBS, Soyer, Koco (Germany) and SILICON (USA).

In the first case, small diameter (2--10 mm) parts are welded to a thin sheet (0.6–1.0 mm). Advantages of this technology are minimal distortions, absence of incipient melting of the reverse side, and possibility of welding to a thin point, including in dissimilar materials. Welding of large-diameter (up to 25 mm) studs is performed by the electric arc discharge technology, which allows welding of threaded studs, anchor bolts and other fasteners. The portable hand tool makes it at a high productivity (the welding time is no more than 1 s) by using standard electric arc welding power supplies.

Silicon developed machines for welding of bolts and anchors up to 50 mm in diameter by using the inverter power supplies designed for currents of up to 4000 A. In this case, to form the weld it is necessary to use special preparation of edges of the rod being welded, as well as special ceramic rings placed in the welding location. Welding of rods more than 20 mm in diameter was demonstrated for the first time at the Fair and aroused visitors' interest.

Solid-state joining. This joining technology, including explosion welding, friction stir welding and other related processes, was presented at the Fair by such companies as DMC (USA), Uhde GmbH (Germany), Van Campen Exploform (The Netherlands), Druseidt (Germany) and ESAB (Sweden).

American Dynamic Materials Corporation (DMC) is a world leader in the field of explosion welding and cutting of metals. Today the Corporation includes such European companies as Dynaplat (Germany), Nitro Metall (Sweden) and Nobelclad (France). DMC covers over 60 % of the world market in production of large-size bimetal plates by explosion welding.

Uhde is a world leader in manufacture of electrolytic cells for production of caustic soda. The cells use electrical bimetal adapters, i.e. long Ti + Ni strips 1.0 + 1.0 mm thick, respectively, which are manufactured only by explosion welding. The annual demand for the Ti + Ni adapters is 240,000 pcs.

Van Campen Exploform B.V. is involved mostly in explosion forming of complex and high-precision parts from metal plates. The Company is planning to widen its interests in the field of explosion welding and make evacuated explosion chambers.

Among the related areas presented at the Fair, noteworthy are such companies as Druseidt producing Cu + Al bimetal by cold rolling, Cytec manufacturing equipment and tools for friction stir welding, and Orbitalum Tools manufacturing guns for semi-automatic welding of tubes into explosion welded bimetal tube plates.

ESAB demonstrated friction stir welding of aluminium alloys in different spatial positions by using a robot and five sets of assembly-welding devices. Billets of semi-finished products up to 5--6 and 10--20 mm thick were welded with partial and full penetration by the one- and two-pass methods. Butt straight-lined and curvilinear welds were made on flat and cylindrical parts. Fillet, edge and T-joints, as well as curvilinear welds were welded following the preset program owing to the use of robot and precise, rigid assembly fixture. The effective welding head with a work tool is connected via adapter to the drive spindle and motor. Available is a table of technical parameters when using a spindle with a rotation speed of 3000 rpm (force --- 13 kN, and torque --- 44 Nm).

Of interest among the other ESAB developments as applied to aluminium are orbital heads (series of three standard sizes) for position butt welding of pipelines.

Severing, mobile machine tools and equipment for mechanisation of welding processes. *Severing*. In the cases where traditional gas cutting equipment is unacceptable, the world practice in the field of severing, dismantling of structures or grooving of defects on high-alloy and carbon steels, cast iron, aluminium and copper alloys is to use electrodes with special coverings, which require no oxygen or compressed air to be fed to the cutting zone. Such developments were demonstrated by ESAB, LASTEK, LINCOLN ELECTRIC and other companies. Almost all electrodes provide a sufficient speed of cutting of such metals in all spatial positions, they do not overheat and are fully utilised. In cutting of corrosion-resistant and low-carbon steels the cut edges are not carbonised, this allowing avoidance of their subsequent cleaning before welding.

Mobile machine tools. Machining before and after welding is a pressing problem when performing comprehensive repairs, for example, of unique cast and welded structures of metallurgical equipment, mining equipment, different-application main and industrial pipelines and power plant equipment by welding and related technologies. Therefore, mobile equipment for machining, including for groove preparation, removal of defective areas, removal of cold-worked layers, high-frequency treatment of mating locations on structures, or partial dismantling, is in great demand. Such mobile equipment was presented at the Fair by such companies as PROTEM, COFIM, AXXAIR, PIPEWORK EQUIPMENT, TechnoPipe, TRUMPF, etc. Among them of interest is the following equipment:

• machine tools designed for treatment of ends of pipes and shafts with diameters ranging from 27 to 1460 mm. They can be fitted with a pneumatic or electric drives, depending upon their standard sizes;

• machine tools designed for boring after repair of stop valves, flanges and mating surfaces. The drives here are mostly electric;

• boring machine tools with a possibility of being connected to the inside surfacing equipment. In such cases surfacing and machining are performed by one unit. They are characterised by efficient design and technological solutions for utilisation in restricted volumes, as well as by a wide variety of drives.

All types of the equipment feature rigid load-bearing and articulator connections designed for severe operational conditions, as well as compact drive systems to achieve an optimal power, weight and dimensions ratios. Assembly is performed by using setup brackets, spherical bearings and self-aligned cones.

The known methods for postweld treatment of welded structures, which improve fatigue resistance, are conditionally subdivided into five groups: mechanical, thermal, deformation, pulse, vibration and special. Owing to availability of equipment and sufficient efficiency, the deformation methods have received the widest acceptance. They are based on the use of the mechanical energy introduced in different ways to induce deformations in different zones of welded joints. PFEIFER and PITEC offered corresponding specialised equipment and technologies, and demonstrated the results evidencing an increased fatigue resistance of welded joints provided by peening the weld metal and near-weld zone with one- and multi-striker tools. Examples of practical application are metal structures of off-shore stationary platforms, mast structures, cranes, bridges, rolling stock, excavating machines etc.

Welding simulators. The exposition of technical means for practical training of welders was arranged at the DVS booth. They include welding simulators, in particular, of eight companies: FRONIUS (Austria), FWBI (Germany), LINCOLN ELECTRIC, Nave (Hungary), SIMFOR (Spain), SLV (Germany), 123 Certification (Canada), and E.O. Paton Electric Welding Institute (Ukraine).

The training devices can be subdivided in the method of simulation of a welding process into two big groups: electronic (virtual) and low-amperage (arc). They realise the idea of computer simulation of movements of a welder in performing practical tasks. The virtual welding software programs are available, used to optimise the main motive habits, e.g. at different welding speeds, different electrode tip to workpiece distances, and different electrode inclination angles. The training devices software includes simulation of welding exercises in different spatial positions, in butt and fillet welding. The feedback and in-process analysis helps a trainee to faster acquire the motive habits required to perform manual arc welding.

Special sensors of seam tracking systems, which trace position of a work tool (electrode holder/torch) and its movement speed are employed to simulate the weld shape and welding quality.

Electronic training devices simulate the welding situation on the monitor screen built into the welder's helmet, and/or on the display built into the device console. Simulator of a structure welded is present not in all the devices, and serves for initial orientation of a trainee in virtual reality, as a similar structure is displayed on the monitor screen. As a rule, ergonomic indicators of the hand tool simulators are substantially different from the real hand tools. At the Fair, the electronic simulators were presented by FRONIUS, FWB, LINCOLN ELECTRIC, Nave, SIMFOR, and 123 Certification. Electronic simulators can serve as an additional technical means to fix theoretical information at a level of educational films and animation cartoons. They give a good idea of key elements of the welding situation and their interaction. Nevertheless, at present they do not form the psychomotor (motive) habits of the trainees in performing the welding process, as the main ergonomic peculiarities of welding are not taken into account. Noteworthy among the exhibited electronic simulators are the FRONIUS and LINCOLN ELECTRIC ones, which have a friendly interface, are convenient in operation and provide good visualisation of elements of the welding situation (weld, heated metal, pool and arc).

Welding simulators with the technology of a simulated or virtual welding process allow simulation of movements of a welder during welding by visualising the welding process and analysing the results.

The virtual welding process and its results are displayed on a special screen built into the welder's shield and on a separate monitor. All parameters of the training process are saved and can be further used for detailed analysis by a trainer. The main idea is to simulate the necessary conditions to acquire the psychomotor habits in practical training of welders on the basis of computer technologies using no real arc welding process. Application of such simulators is meant to solve the problems of arrangement of training, improve the quality of vocational training, and reduce the training cost and terms.

It should be noted that the electronic virtual simulators are costly (their price is from 50,000 to 80,000 Euro).

The low-amperage arc welding simulators are based on simulation of the welding situation by using the real low-amperage arc. Ergonomic characteristics of such a model are as close as possible to the real process. In turn, this makes it possible to use such simulators at the initial stages of formation of the psychomotor habits in performing the welding process.

The low-amperage arc simulators were presented at the Fair by SLV and E.O. Paton Electric Welding

Institute. They are similar in their functional capabilities. So, we will dwell on their differences.

The SLV simulator is an original optical method for defining a spatial position of the hand tool simulator. This is done by using a video camera, as well as two red light diodes on the hand tool simulator. The spatial position of an electrode simulator is determined from a relative position of the light diodes with respect to a fixed position of the video camera. This method gives good results, but requires additional soft- and hardware costs, thus leading to a marked increase in price of the simulator.

Software is well organised, and a touch screen is used to control the program.

Thickness of a simulator of the mating surfaces (metal plate about 2 mm thick) and insufficient power of the electric current source limit the possible length of the arc gap to 2 mm. The arc is hard to maintain. As a result, performance of the welding process requires the psychomotor habits. Therefore, it is difficult to use the simulator at the early stages of training, but it can justify itself in maintaining the habits required to perform the welding process. The price of the simulator is from 20,000 Euro, depending upon the components.

The simulator of the E.O. Paton Electric Welding Institute (MUATs) uses real work tools (electrode holders and torches) with built-in position sensors used as hand tool simulators. This approach allows preserving the ergonomic characteristics of the hand tools. The simplified software provides operation of the simulator controlled by the up-to-date and obsolete computer models without any loss of its functional capabilities. The price is 1500 Euro.

FEATURES OF LASER-MIG WELDING OF HIGH-STRENGTH ALUMINIUM ALLOYS

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The paper deals with the influence of the intensity of evaporation of base metal and electrode wire elements, as well as shielding gas atmosphere composition on laser radiation propagation to the metal being welded in hybrid welding of aluminium alloys. Technological features of laser-MIG hybrid welding were studied, modes were selected and the obtained results were compared with consumable electrode pulsed-arc welding.

Keywords: *laser-arc welding, aluminium alloys, pulsed arc, consumable electrode, hybrid process, butt joints, mode parameters, characteristic defects, mechanical properties*

Aluminium alloys are applied for welded structures of motor and railway transport, various-purpose ships, aeronautical and space engineering, instrument casing, etc. The main problem in fabrication of such structures most often is producing sound welded joints, which are made using filler or electrode wires, as well as edge flanging. Wall thickness of the parts being joined is predominantly equal from tens of a millimeter up to 1--3 mm (less often 4–8 mm) [1]. One of the important points in selection of a particular aluminium alloy for fabrication of elements of the above structures is the maximum possible reduction of the total product mass at preservation of their mechanical characteristics. This approach necessitates application of alloys with different alloying systems. In critical modern structures a transition is in progress from alloys of Al--Mg--Mn (AMg6 alloy) and Al–Cu–Mg (D16 alloy) alloying systems to alloys, for instance, of Al–Mg–Li system (1420 alloy), having high mechanical characteristics at low density and improved modulus of elasticity [2].

In fabrication of structures with the above range of wall thicknesses of individual elements, laser welding (LW) can be used in addition to arc and plasma (microplasma) welding processes [3]. This process was not widely accepted in practice, primarily, because of the high cost of process lasers. However, application of laser-arc welding allows lowering the cost of one running meter of weld by approximately 50 % due to partial replacement of laser power by arc power and increasing process efficiency by 50 % [4]. Such a process should allow retaining most of LW advantages and making it more attractive for the user.

Experimental studies were preceded by analysis of publications devoted to laser-arc hybrid welding of aluminium alloys for a more accurate determination of welding mode parameters. Study [5] deals with the technological features of welding aluminium and its alloys by radiation of CO_2 laser of power $P = 0.6$ kW in combination with non-consumable tungsten electrode arc. It was proposed to weld 5052 alloy of thickness $\delta = 3.2$ mm at speed $v_w = 30.5$ m/h and current $I_w = 70$ A in a shielding atmosphere of helium. Ratio of laser to arc power was equal to approximately 1:3. In view of the low power of laser radiation, the nature of weld formation was typical for arc welding. At the ratio of laser to arc power of approximately 1:1, weld formation had the form of a keyhole, which was close to that characteristic for LW [6, 7]. At increase of laser radiation power from 0.1 to 1.5 kW (10 mm arc length) to achieve reliable penetration, speed rose

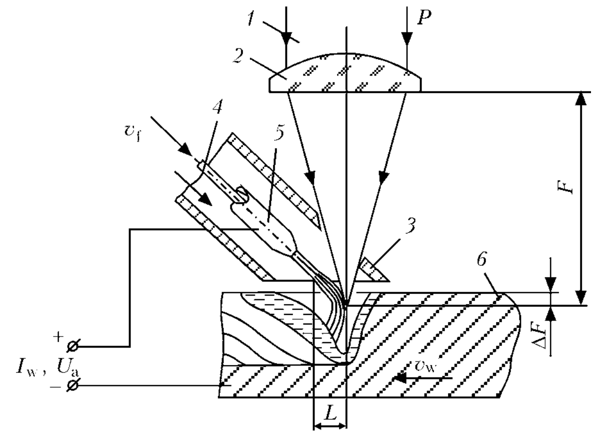


Figure 1. Schematic of conducting experiments on laser-arc hybrid welding: *1* –– laser radiation of power P; *2* –– focusing lens with focal distance F; *3* –– shielding nozzle; *4* –– welding wire; *5* –– copper current-conducting nozzle; *6* –– sample; ΔF –– immersion of radiation caustic neck relative to sample surface; L –– distance between the consumable electrode tip and laser radiation axis

from 0.5 to 2.0 m/min. Ratio of penetration depth to weld width varied from 0.5 up to 2.0, while the heat input changed from 3.2 to 0.5 kJ/cm.

It is noted in [8] that unlike LW, in which the gap between the abutted elements should not be more than 10 % of metal thickness, in hybrid welding this parameter can be equal to 25–30 %. Work [9] deals with hybrid welding of aluminium alloys by radiation of CO_2 and Nd:YAG lasers in the power range from 0.4 up to 6.0 kW. The criterion of cracking susceptibility lowering was used to select the mode of hybrid welding of 6000 series aluminium alloy (δ = 2 mm), which exceeded LW by 40 % in terms of speed. The review work by German scientists [10] separately considers the technological capabilities of the combined laser-arc welding (in which the arc and laser beam act on the product at a certain distance from each other), and hybrid welding (both heat sources acting on one item within a common weld pool). The authors give special attention to welding aluminium alloys by a hybrid of laser radiation and consumable-electrode arc and even consider a twin-arc hybrid process. In review work [11] the recommended range of variation of the distance between focused radiation of Nd:YAG laser and consumable electrode arc was equal to 0–10 mm (better 4–10 mm) for welding aluminium alloys (5052 and 6008). The arc current was varied in the range of I_w = 60–240 A, with continuous laser radiation power P = 1.5–3.5 kW.

Analysis of the published data can lead to the conclusion that for hybrid welding of aluminium alloys of thickness δ = 4–6 mm, it is rational to use laser radiation with wave length 1.06 μm in the power range P = 2–5 kW and consumable-electrode arc. The power ratio of laser radiation and arc should be within 1:1 up to 1:1.5.

Table 1. Mechanical properties of welded aluminium alloys

Alloy	σ_t, MPa	$\sigma_{0.2}$, MPa	$\sigma_{0.01}$, MPa	δ_5, %
D16	$\frac{458–462}{460}$	$\frac{318–348}{330}$	$\frac{235–265}{257}$	$\frac{14.6–16.2}{15.4}$
1420	$\frac{465–477}{470}$	$\frac{236–252}{244}$	–	$\frac{9.1–10.1}{9.5}$

This study was aimed at optimizing the technique and technological parameters of the modes of welding aluminium alloys AMg6, 1420 and D16 by the hybrid process using radiation of Nd:YAG laser and consumable electrode pulsed arc (CEPA), as well as studying the technological features of such hybrid laser-arc welding.

To achieve the defined aim, we have conducted a number of experiments according to the schematic given in [12] (Figure 1). As shown in [13], this schematic is fully suitable for aluminium alloy welding. Used as the laser radiation source was Nd:YAG laser of DY 044 model (Rofin Synar, Germany) with radiation power of up to P = 4.4 kW. Consumable electrode pulsed arc was powered by Fronius TPS-2700 system (Austria), providing welding current of up I_w = 270 A.

The hybrid head was placed on a manipulator, moving it relative to a stationary sample, clamped in the welding jig. Samples of 300 × 100 × δ mm size were butt-welded. Alloys AMg6 (δ = 6 mm), D16 (δ = 5 mm) and 1420 (δ = 4 mm) (GOST 4784–74), and 1.2 mm wires SvAMg6 and SvAK5 (GOST 7871–75) were used. Mechanical properties of the metals being welded were determined before conducting the experiments (Table 1). Tensile testing of the samples was performed in UME-10TM machine. Welding was conducted on a removable stainless steel backing with 2 mm groove in argon (GOST 10157–79) or helium of grade B (TU 51-940–80) fed with the flow rate of 20 and 30 l/min, respectively. Welding was performed by «backward inclined» electrode. The angle of the axis of laser radiation inclination relative to the normal to the sample was equal to 9°, and the angle of the arc torch inclination was 55°. Welding speed was varied in the range of v_w = 30–60 m/h. At the moment of completion of each experiment on hybrid welding, when the welding head stopped, first CEPA was switched off, and in 1–2 s the laser radiation was off, thus allowing accurate determination of the position of the focused laser radiation relative to the zone of CEPA action. The greatest penetration depth corresponded to 2–4 mm distance. In addition, the relative influence of laser radiation power and electrode wire feed rate (welding current) on electric parameters of CEPA process was studied.

The following procedure was accepted for investigations performed to select the modes of hybrid welding of AMg6, D16 and 1420 alloys. A stable formation of the weld root at minimum power of both the heat sources and maximum welding speed v_w was a criterion for mode optimization. A combination of the laser and arc source powers was selected close to the ratio of 1:1 recommended in publications. Mode selection was performed by making sample beads and their welding. Geometrical parameters of the welds were determined

Table 2. Influence of modes of CEPA and CEPA-laser hybrid welding of AMg6 aluminium alloy in argon on weld geometrical parameters

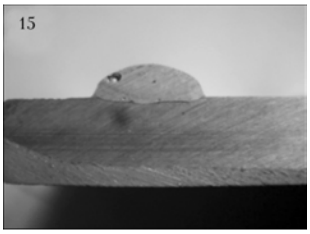
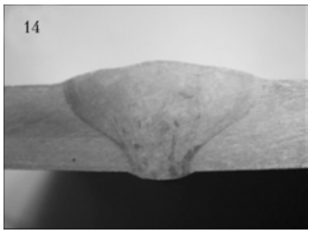
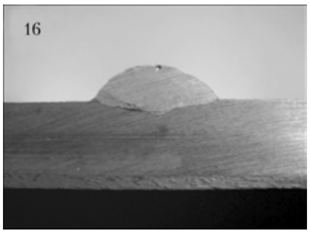
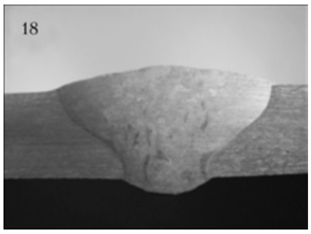
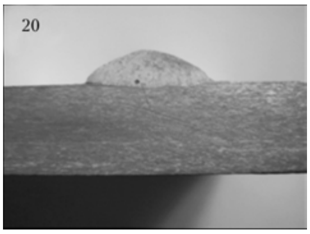
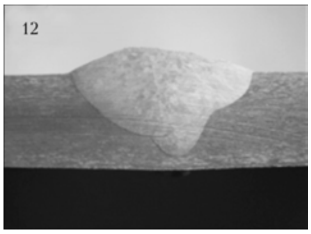
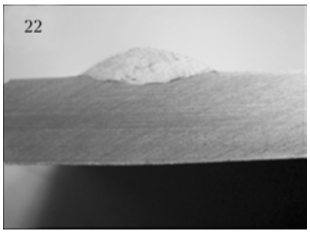
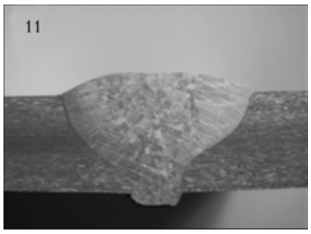
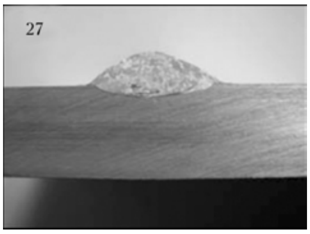
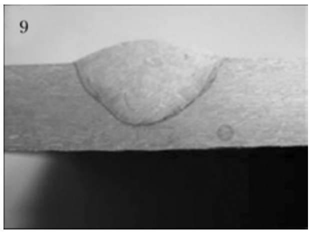
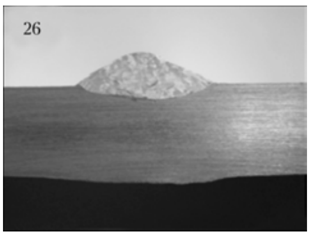
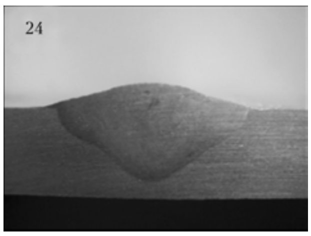
Sample #	v_w, m/h	I_w, A	U_a, V	v_f, m/h	P^*, kW	B, mm	H, mm	b, mm	h, mm
1	30	126	20.0	8.3	--	9.0	3.0	--	--
2-1	30	113	21.9	8.3	2	9.5	2.7	--	--
2-2	30	119	20.6	8.3	2	10.0	3.0	--	--
3	30	121	20.1	8.3	3	--	--	--	--
4	30	120	20.0	8.3	4	9.0	2.5	5.0	2.0
15	30	119	19.0	7.5	--	8.0	2.8	--	--
14	30	111	20.5	7.5	4	14.0	2.5	2.5	1.0
16	30	130	20.5	8.3	--	8.8	2.7	--	--
18	30	122	21.0	8.3	4	14.2	1.5	5.5	1.4
17	30	145	21.5	9.3	--	9.0	3.3	--	--
19	30	138	21.5	9.3	4	16.0	2.0	4.0	1.3
20	45	131	19.6	8.3	--	6.2	2.7	--	--
12	45	123	21.1	8.3	4	11.0	2.3	--	--
22	45	150	21.3	9.3	--	8.5	2.2	--	--
11	45	142	21.1	9.3	4	12.0	2.0	3.0	1.2
23	45	164	21.9	10.1	--	9.0	2.3	--	--
21	45	156	22.6	10.1	4	13.0	2.0	--	--
25	60	150	21.0	9.3	--	7.0	2.2	--	--
6	60	140	21.7	9.3	4	10.0	2.2	--	--
27	60	177	22.0	10.9	--	8.0	2.5	--	--
9	60	162	22.4	10.9	4	11.0	1.5	--	--
26	60	198	22.3	12.2	--	8.5	2.2	--	--
24	60	194	23.0	12.2	4	12.0	2.0	--	--
7	60	126	20.5	8.3	4	9.0	2.0	--	--
8	60	157	22.0	10.1	4	10.0	2.0	--	--
10	60	182	23.7	11.6	4	12.0	1.7	--	--

*Continuous radiation with 1.06 μm wave length.

from transverse macrosections with the accuracy of ±0.1 mm. Weld width B, their reinforcement height H, width b and height h of the weld root at complete penetration of the metal (Table 2), weld depth (in case of metal incomplete penetration) and weld cross-sectional area S in different weld zones were measured. Quantity and diameter of pores and voids in the welds were also evaluated. Weld macrostructure was revealed by chemical etching of the sections in a solution, consisting of three acids — 72 cm^3 HCl + 24 cm^3 HNO_3 + 4 cm^3 HF. Strength characteristics of welded joints were determined using samples with weld reinforcement and removed root.

During experiments it was established that 5--10 s after the start of hybrid welding an intensive absorption of laser radiation by plasma plume forming above the weld pool began, leading to reduction of penetration depth. In our opinion, this is related to intensive evolution of welding aerosols forming above the melt pool under the action of the melting electrode [14]. Investigations conducted at PWI showed [15] that with current increase in inert-gas consumable-electrode welding the average temperature of electrode metal drops rises, reaching that of boiling of aluminium alloy, from which electrode wire is made. At unchanged welding current, increase of wire diameter leads to lowering of average temperature of electrode metal drops. With increase of helium content in helium-argon mixtures, drop temperature also decreases, reaching the lowest values in welding in pure helium [15]. This, in its turn, leads to lowering of magnesium evaporation in the drops, increase of its content in the weld, and improvement of mechanical properties of the joints. In CEPA + laser hybrid welding, glowing of laser radiation above the weld pool near CEPA action zone was observed, which is indicative of a greater absorption of radiation. The number of electrode metal drops and volume of products of evaporation from them and base metal increase with increase of wire melting rate (welding current) [14]. This in-

Table 3. Weld shape depending on welding speed and feed rate of SvAMg6 electrode wire in CEPA welding and CEPA-laser hybrid welding of AMg6 alloy

Welding mode		CEPA*	CEPA + LW* (P = 4 kW)
v_w, m/h	v_f, m/min		
30	7.5		
	8.3		
45	8.3		
	9.3		
60	10.9		
	12.2		

*Section numbers correspond to sample numbers from Table 2.

creases the gas atmosphere density, promotes absorption of laser radiation and reduction of penetration depth, respectively.

As shown in [16], at LW in helium and in argon, the process of weld pool metal evaporation will be different. At evaporation in helium a more intensive lateral unloading of the vapour plume results in an essentially lower density of metal vapours in the path of laser radiation, than that found in evaporation in argon. This accounts for the observed effect of achievement of a stable deep penetration, when helium or helium-containing mixtures are used.

In connection with the assumption of a change of spreading of metal vapours formed above the weld pool in a particular shielding gas, it was proposed to use pulsed radiation instead of continuous radiation. It was anticipated that in the case of argon shielding, metal vapour spreading necessary for elimination of laser radiation shielding will take place during the pause. The ratio of the time of radiation pulse and pause was selected by the criterion of absence of the characteristic reduction of penetration depth in the hybrid process. The selected ratio was equal to 3:1, i.e. pulse ratio Q_p = 3 at pulse repetition rate f = = 250 Hz. Such a pulsed radiation mode allowed conducting hybrid welding in argon shielding gas. It is possible that the selected ratio is not optimum, and pulse repetition rate of laser radiation should in a certain way correspond to the consumable electrode arc pulse frequency. This aspect, obviously, requires further investigation.

Table 3 gives an example of the influence of modes of AMg6 alloy welding on weld shape. It is seen from the Table that in the range of welding speeds v_w = = 30–45 m/h and electrode wire feed rates v_f = 7.5–9.3 m/min CEPA cannot completely penetrate a sample of AMg6 alloy, unlike CEPA + laser. Optimum modes of argon-shielded CEPA + laser hybrid process are observed at v_w = 30 m/h, P = 4 kW, $I_w \approx$ 120 A and v_w = 45 m/h, P = 4 kW, $I_w \approx$ 140 A. Helium application enables increasing the welding speed up to 60 m/h at simultaneous lowering of radiation power and CEPA current (Figure 2). Results of argon-shielded hybrid welding of D16 alloy using pulsed laser radiation with the peak power P_{peak} = 4 kW and average power P_{av} = 3 kW are shown in Figure 3. The optimum mode for such a welding process is I_w = = 200 A, U_a = 21.5 V, v_f = 12.4 m/min. Application of pulsed radiation necessitated an increase of CEPA power, however, the penetration shape, HAZ and grain size remained on the level characteristic for continuous radiation hybrid welding (Table 3). At the same wire feed rate (v_w = 30 m/h), the CEPA + LW hybrid process allows increasing weld width 1.6–1.9 times and lowering their reinforcement height H 1.1–1.6 times, compared to CEPA welding. Such dependencies are also observed at higher welding speeds, but at lower absolute values of geometrical parameters of welds. A characteristic drawback of hybrid welding is pore formation in the welds. In welding of the considered alloys, this phenomenon is the most pronounced in alloy 1420 (Figure 4). This, in all prob-

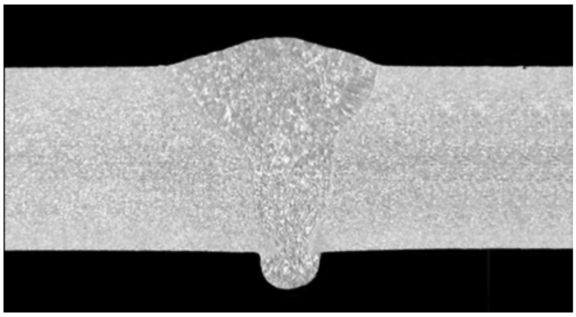


Figure 2. Macrosection of a joint of AMg6 alloy made by helium-shielded hybrid process: v_w = 60 m/h; P = 3 kW; $I_w \approx$ 74 A; U_a = = 17 V

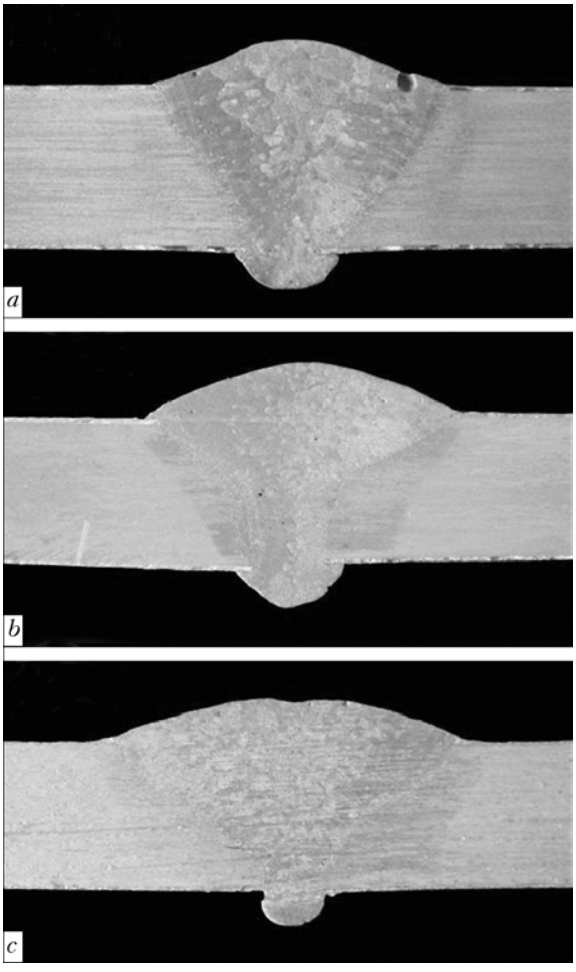


Figure 3. Macrosections of butt joints of D16 alloy made by hybrid welding with pulsed laser radiation in argon with SvAMg6 wire (P_{av} = 3 kW, P_{peak} = 4 kW, Q_p = 3, f = 250 Hz, v_w = 60 m/h): *a* — $I_w \approx$ 185 A, $U_a \approx$ 21.5 V, v_f = 11.6 m/min; *b* — $I_w \approx$ 200 A, $U_a \approx$ 21.5 V, v_f = 12.4 m/min; *c* — $I_w \approx$ 210 A, $U_a \approx$ 21.5 V, v_f = = 13.0 m/min

Table 4. Modes of hybrid welding of aluminium alloy butt joints (v_w = 60 m/h)

Alloy (wire)	I_w, A	U_a, V	v_f, m/min	P, kW
D16 (SvAMg6)	185–190	21.5–21.6	11.6	4.0
D16 (SvAK5)	190–200	22.5–23.0	10.3	4.0
1420 (SvAMg6)	48–50	13.8	3.1	2.0

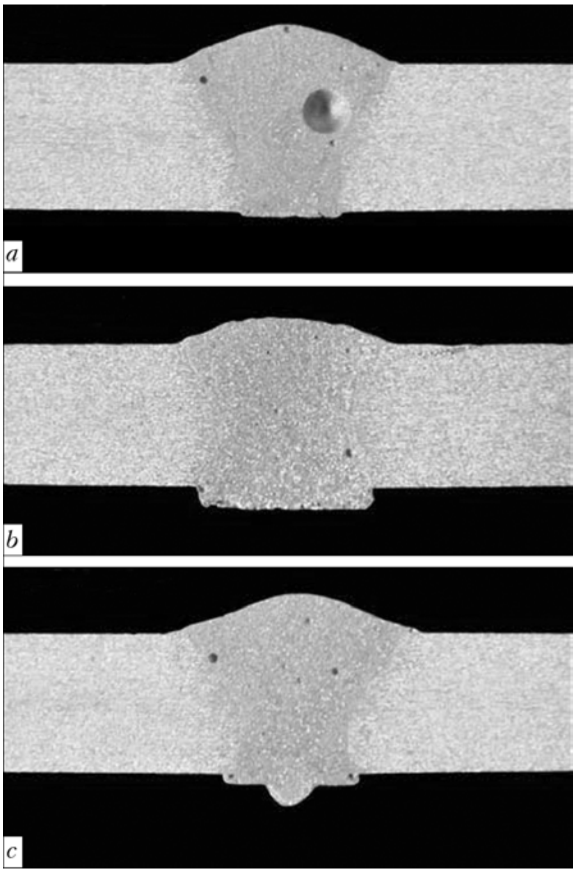


Figure 4. Influence of CEPA welding mode parameters (v_w = = 60 m/h) in hybrid welding (continuous radiation, P = 2 kW) in argon on geometrical parameters of 1420 alloy weld: *a* — I_w = = 40 A, U_a = 12.3 V, v_f = 2.3 m/min; *b* — I_w = 42 A, U_a = 12.5 V, v_f = 2.7 m/min; *c* — I_w = 51 A, U_a = 14.3 V, v_f = 3.1 m/min

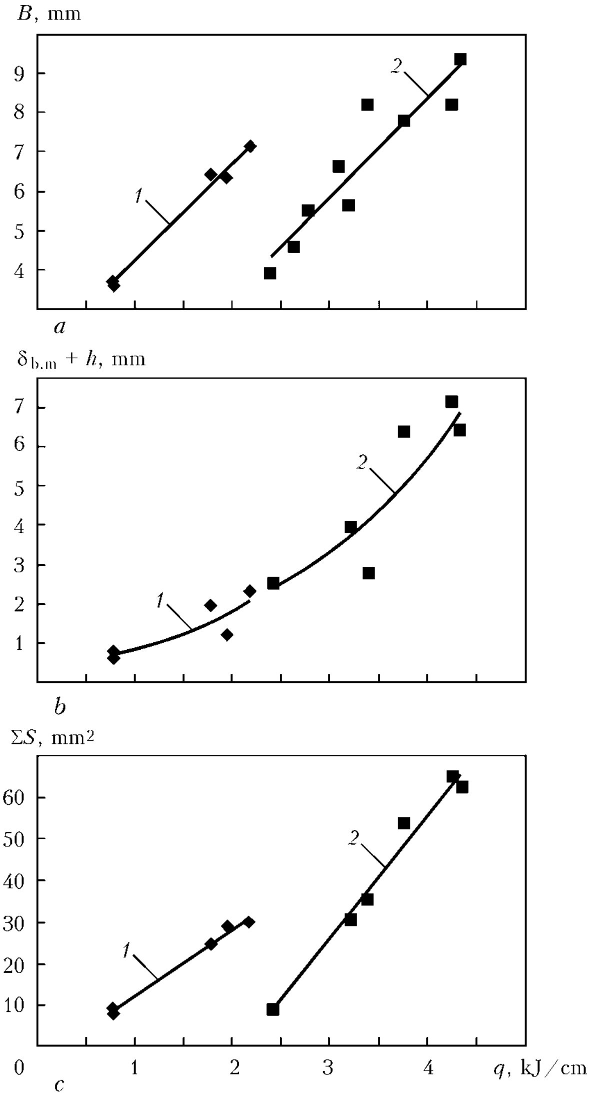


Figure 5. Influence of heat input q of CEPA (*1*) and CEPA + laser (*2*) welding of AMg6 alloy using continuous radiation of power P = 4 kW on weld width B (*a*), penetration depth $\delta_{b.m} + h$ (*b*) and weld cross-sectional area ΣS (*c*)

ability, is related to intensive evaporation of lithium and magnesium from the base metal under the impact of laser radiation.

It is established that irrespective of wire feed rate (from 7.5 up to 13.2 m/min) laser radiation of 4 kW power increases arc voltage (observed arc length) by 1–2 V and decreases welding current by 10–15 A. With increase of laser radiation power from 1 up to

Table 5. Mechanical properties of aluminium alloy joints made by hybrid welding

Alloy (wire)	σ_t, MPa	$\sigma_{0.2}$, MPa	$\sigma_{0.01}$, MPa	$\sigma_t^{w.j}/\sigma_t^{b.m}$	$\sigma_{0.2}^{w.j}/\sigma_{0.2}^{b.m}$
D16* (SvAMg6)	290–324 / 304	229–238 / 234	101–161 / 139	0.66	0.71
D16** (SvAMg6)	291–300 / 294	211–218 / 216	96–122 / 111	0.64	0.65
D16* (СвАК5)	311–326 / 319	236–245 / 240	126–155 / 139	0.69	0.77
D16** (SvAK5)	286–306 / 293	200–228 / 217	93–134 / 117	0.64	0.66
1420* (SvAMg6)	293–318 / 302	179–184 / 181	86–96 / 92	0.64	0.74
1420** (SvAMg6)	275–308 / 294	167–180 / 173	91–120 / 106	0.63	0.71

*Weld root reinforcement was removed in the samples. **Upper reinforcement and weld root reinforcement were removed in the samples.

4 kW at constant electrode wire feed rate, a reverse dependence is observed — welding current rises and arc voltage decreases (Tables 2 and 4). This is related, primarily, to increase of arc region ionization by laser radiation and change of the arc volt-ampere characteristics, respectively.

Another important parameter, characterizing the welding process, is the heat input, which was determined for arc and hybrid welding of AMg6 alloy. Here, the argon-arc welding efficiency was taken to be 0.72, and that of helium-arc welding was 0.88 [17]. The efficiency of the hybrid process laser component was taken to be a unity, as deep penetration welding was performed. The calculations allowed plotting a dependence of heat input influence on weld width, their total height (penetration depth δ and weld root height h), as well as cross-sectional area of the remelted metal (Figure 5). It is established that at the same heat input, the hybrid welding compared to CEPA welding allows increasing the depth of metal penetration, as well as reducing weld width and cross-sectional area.

Analysis of the results of mechanical testing of high-strength aluminium alloys showed (Table 5) that D16 alloy joints made with SvAK5 wire have higher strength characteristics than joints welded with SvAMg6 wire. In all the cases, fractures in D16 alloy joints start from the zone of fusion of the weld root with the base metal and propagate into the weld. 1420 alloy joints, both with and without upper reinforcement, fail in the weld center. Coefficients of strength of D16 and 1420 alloy joints made by laser-MIG hybrid welding are equal to $\sigma_t^{w.j}/\sigma_t^{b.m} = 0.63$–$0.69$, and of yield point of the joints $\sigma_{0.2}^{w.j}/\sigma_{0.2}^{b.m} = 0.65$–$0.77$. Removal of upper and weld root reinforcement leads to a certain lowering of the strength properties of the joints.

CONCLUSIONS

1. In laser-MIG hybrid welding (CEPA + LW) of aluminium alloys the intensity of evaporation of individual elements from the base metal and electrode wire, as well as the composition of the shielding gas atmosphere, have an essential influence on laser radiation propagation to the metal being welded. Use of argon and high welding currents leads to radiation shielding, and, hence, considerable reduction of penetration depth. To eliminate this effect, it is rational to apply mixtures of argon with helium or pure helium for weld pool shielding, and also use pulse modulation of laser radiation.

2. In the speed range of 30–60 m/h, hybrid welding, compared to CEPA welding, allows increasing 1.8 to 2.6 times the speed of welding metal 6 mm thick, lower 1.3–1.6 times the heat input into the metal being welded and considerably lower deformations of joints 4 mm thick. Investigation of the nature of weld formation leads to the conclusion that in hybrid welding of metal of 6 mm and greater thickness with application of laser radiation of 1–4 kW power, the CEPA process has the leading role.

3. Such characteristic defects as porosity and blowholes in hybrid welding of aluminium alloys of Al–Mg–Mn, Al–Cu–Mg and Al–Mg–Li alloying systems can be eliminated by improving the weld pool shielding, as well as thorough selection and optimization of welding modes.

4. Such mechanical characteristics of welded joints as strength and yield, are somewhat higher for the hybrid process than the level of similar values obtained, when CEPA is used. Taking into account an increase of efficiency, this demonstrates the rationality of CEPA process replacement by CEPA + LW process.

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APPLICATION OF PLASMA-ARC METALLISATION FOR RESTORATION OF WHEEL PAIRS

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Method for repair of journals and under-hub parts of axles of freight carriage wheels by plasma-arc metallisation is considered, results of fatigue rig tests with the recommended service life of the repaired axles are presented.

Keywords: *plasma-arc metallisation, axial flow, intermediate anode, wheel pairs, journals, under-hub parts, coating structure, resistive-strain sensor*

Railway transportation has several tens of thousands of wheel pairs, the axles of which have been rejected because of defects of journals and under-hub parts of axles, namely wear, scoring, scratches, work-hardening of the journal. Reconditioning of these parts allows them to be reused, thus yielding a considerable cost saving.

The material for carriage axles is carbon steel of OSV grade (GOST 4728--96) with carbon content of 0.38–0.47 %, which is characterized by a high wear resistance and contact fatigue strength.

Successful reconditioning of wheel pair axles is performed in Germany, Sweden, Rumania, Russia, as well as in other countries [1--3].

PWI and PKTB TsV UZ developed a new technology of plasma-arc metallisation in an inert atmosphere.

Technique of such coating spraying differs by that atomisation is performed by the plasma arc in argon by a current-conducting wire-anode, which is the initial material for coating formation, with simultaneous mechanical treatment of the latter by a special brush device, cleaning the coating from oxides and particles hitting it at a high angle.

In this work an argon-arc plasmatron with a tungsten cathode and air cooling was used for coating spraying. Ignition was performed to an intermediate air-cooled anode, forming the plasma jet. After ignition the electric potential shifts to the atomized wire. Wire application as the atomized anode improves process efficiency, and plasma energy is consumed in wire atomization and producing coatings, and not plasmatron heating. The cathode is in argon atmosphere, thus increasing its resistance.

Argon plasma flow is axially blown over by an air flow around the circumference, which simultaneously cools the plasmatron, having a qualitative effect on the plasma shape and composition.

The mode of the blowing flow was selected so that the pressure in it was equal to that of the plasma jet. Conditions were created, when the contours of the visible cone of outflowing plasma were almost parallel, which was indicative of a slight mixing of plasma with the cooling air.

In view of the considerable difference of temperature of the plasma flow and the axially outflowing air flow, no flow mixing is observed. Presumably, because of the high velocity of the outflow, the zone with maximum argon content is of a considerable (up to 150–200 mm) length, thus allowing spraying to be performed in it without any significant oxidation.

The above-said is in good agreement with the data obtained from the calculation models (Figure 1, *a*, *b*) [4].

Used as coating material was wire from steels 65G, 70, 20Kh, 30KhDS, as well as flux-cored wires [5].

The proposed technology allows lowering coating porosity to 2--5 %, eliminating oxide formation and increasing the adhesion of the obtained coating to the substrate up to 40–60 MPa. Figure 2 gives the microstructure of a coating, produced by plasma-arc metallisation with wire from steel 65G. No porosity, oxides or other defects were found in it. Coating hardness was *HRC* 30–35, which corresponds to the code documentation. Indices of the coating mechanical properties and composition are close to those of steel of OSV grade.

Figure 3 shows the general view of KT-088 system for reconditioning the journals and under-hub part of wheel pair axles, developed and manufactured at PWI and PKTB TsV UZ. The system is a plasmatron with the current source and sound-absorbing chamber with the axle fixed in it.

Spraying is performed by air-cooled plasmatron (14–16 kW power) in argon, thus greatly increasing the service life of the plasmatron nozzle (more than 100 h) (Figure 4). Before metallisation, the axle surfaces to be reconditioned are turned to the required size, hardened by rolling, degreased and activated by metal shot DChK-1-3. Deposition of not more than

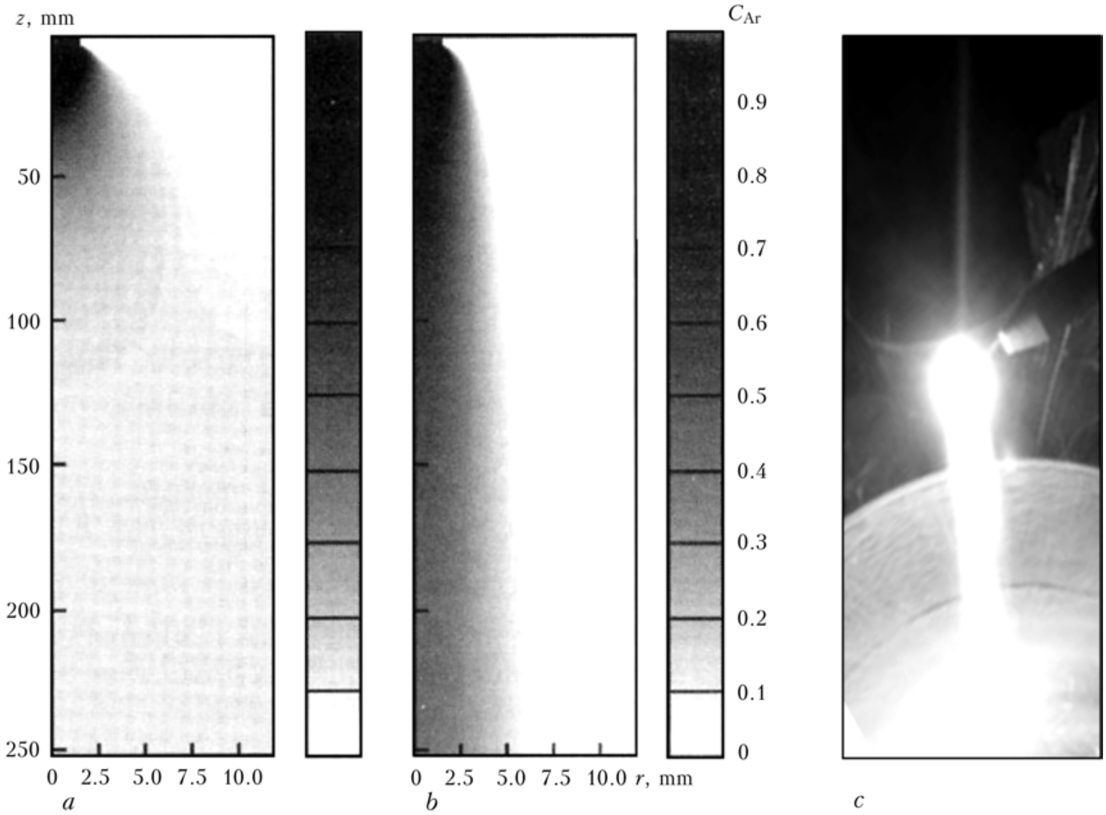

Figure 1. Calculated distribution of relative concentration of argon C_{Ar} in the plasma jet outflowing into the air space without blowing (*a*), with blowing (*b*), and appearance of plasma flow (*c*)

2 mm coatings on wheel pair axle is followed by its machining.

Table 1 gives the data on measurement of hardness after spraying of a pair of journals of axles of RU1 and RU1Sh types by wire from steel of grade 65G.

External examination and metallographic studies of reference samples confirmed the satisfactory condition of the coatings sprayed on the axle journals.

Press-fitting and pressing-out of wheels on the axle under-hub part were performed in Darnitsa railway car repair works by a standard technology. Press-fitting force was equal from 630 up to 800 kN, depending on tightness. Pressing-out was performed one week after press-fitting. External inspection of the axle under-hub part showed the satisfactory condition of their surface –– no scratches, spallation or cracks.

The developed technology of reconditioning the journals and under-hub part of the axles has the following advantages:

• process of plasma-arc metallisation does not lower the strength properties of the reconditioned part (item heating to not more than 200 °C) and does not affect its mechanical properties;

• does not cause distortion of the reconditioned part;

• allows spraying a coating of thickness from 0.1 up to 20 mm;

• porosity is not more than 2--4 %;

• a high stability of the spraying process is found (service life of the nozzle forming the plasma arc and

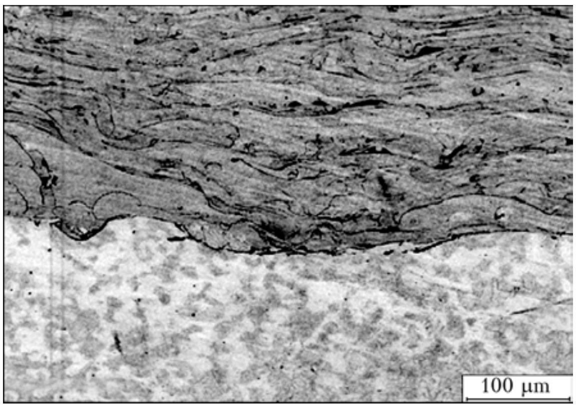

Figure 2. Microstructure of a coating from steel 65G produced by plasma-arc metallisation

Figure 3. General view of KT-088 unit for reconditioning the journal and under-hub part of wheel pair axle by plasma-arc metallisation

Figure 4. Process of plasma-arc metallisation of axle journal

Table 1. Hardness values of axle journal after spraying

Axle type	Axle number	Average *HB* hardness value of journal surface	
		Right	Left
RU1Sh	42097	343	358
	52073	319	305
	42827	312	344
RU1	49764	387	376

Note. After spraying axle journal is ground to album size. 2. Hardness measurements of each journal surface were taken in five points by TDM-1 hardness meter.

of plasmatron cathode is not less than 100 h of machine time).

Conducted research work demonstrated the rationality of application of plasma-arc metallisation in enterprises of carriage facilities of Ukrzaliznitsa. Further testing of axles in SE UkrNIIV confirmed the obtained results.

Fatigue testing of axles was conducted in hydropulsator rig TsDM-200Pu by the coordinated and approved PM 07.00307–2007 «Axles with reconditioned journals and under-hub parts (types RU1 and RU1Sh). Program and procedure of fatigue testing». Before testing the cut up axle samples were fitted with resistive strain-sensors for adjustment and monitoring of testing mode. Figure 5 shows the schematic of axle sample loading with the indicated location of resistive strain-sensors. A sample was mounted in the rig on two supports. Load was applied to under-hub part of axle sample through a special pusher. Support spacing and point of application of load *P* were selected proceeding from the capabilities of the testing equipment and need to guarantee fatigue fracture of the axle journal in the fillet zone.

Based on calculation results, support spacing is taken to be 1000 mm, arm of vertical load application was 730 mm (see Figure 5) from the right support, vertical load being not more than P = 883 kN.

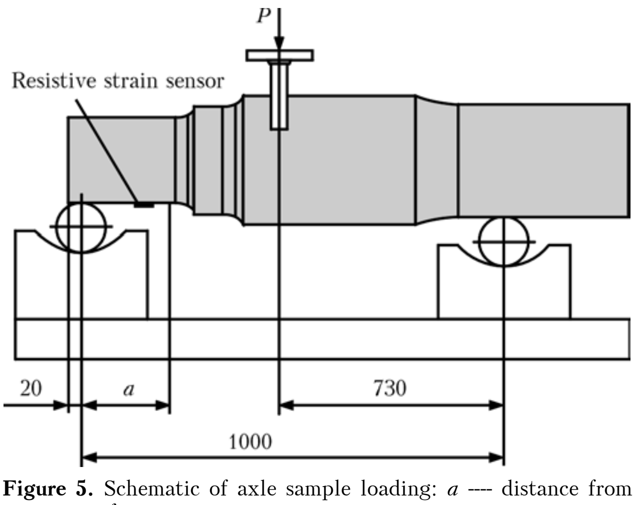

Figure 5. Schematic of axle sample loading: *a* — distance from support to fracture site

Testing of fatigue samples was conducted by the method of multiple cyclic loading at asymmetrical cycle with asymmetry of 0.1 at different load levels.

Fatigue cracks were determined by organoleptic method (visually) using kerosene test.

All samples were tested at five loading levels: five samples of axles of type RU1 — on four levels, and four samples of axles of type RU1Sh — on three levels.

Eight samples failed in fillet transition from axle journal to its under-hub part. One sample withstood the base number of $5\cdot10^6$ cycles of loading without fatigue damage or failures. Figure 6 shows the appearance of fracture of the failing sample of axle journal.

After testing maximum stresses σ_{max} in the fracture zone were found from the following formula:

$$\sigma_{max} = 0.73\,\frac{aP}{W}\ [\text{MPa}],$$

where W is the moment of axle journal resistance in the fracture site, mm^3.

Moment of axle journal resistance W was determined by the following formula:

$$W = \frac{\pi D^3}{32},$$

where D is the axle journal diameter in the fracture site, mm.

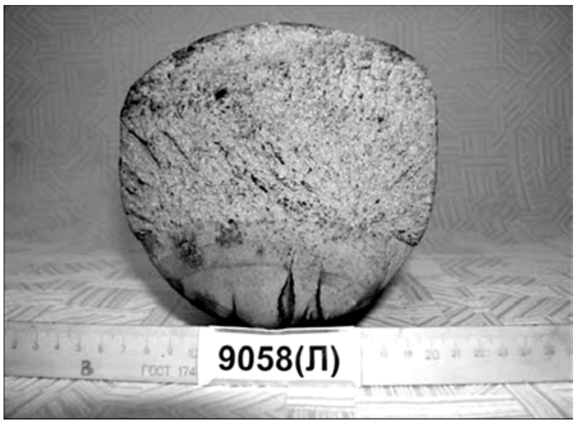

Figure 6. Appearance of fracture of failed sample of axle journal

Endurance limit in the journal fillet zone at symmetrical loading cycle was equal to 167 MPa for axles of type RU1, and 189.5 MPa for type RU1Sh.

As during testing the number of samples of each axle type was small, and years of their manufacturing were different, the probabilistic-statistical treatment was conducted by the results of testing all the samples. Endurance limit was equal to 149.5 MPa.

For new parts endurance limit in the zone of journal fillet at symmetrical loading cycle on the base of $5\cdot10^6$ cycles should be not lower than 195 MPa, thus ensuring the average service life of carriage axles of 15 years, in keeping with the requirements of GOST 30237--96 [6].

All the axles to be reconditioned should be subjected to ultrasonic testing.

Determination of the increase of surface hardness and depth of the hardened layer after rolling was performed on samples made from the journal and under-hub part of the axle, which was not tested for fatigue, in keeping with the requirements of the standards [7, 8].

Increase of surface hardness Δ after axle rolling was determined by the following formula:

$$\Delta = \frac{H_{\rm surf} - H_{\rm b}}{H_{\rm b}}\cdot 100\ [\%],$$

where $H_{\rm surf}$ is the highest value of surface hardness; $H_{\rm b}$ is the initial hardness of unhardened metal, which was determined on one of the sides normal to axle surface at the depth of 15--20 mm.

Results of calculation of increase of surface hardness and depth of hardened layer after rolling are given in Table 2.

At present the batch of reconditioned axles is going through operational testing according to testing program in the closed testing route Rokovataya--Uzhgorod--Koćice.

Thus, by the results of fatigue testing on the base of $5\cdot10^6$ loading cycles of axles of type RU1 and RU1Sh of freight carriage wheel pairs with journals and under-hub parts reconditioned by the technology of plasma-arc metallisation, the endurance limit in the journal fillet zone is equal to 149.5 MPa, which is 0.76 of the standard value (195 MPa), and corresponds to average service life of 11.4 years. Considering that axles of different services lives and types, as well as different years of manufacturing, will be reconditioned, it is recommended to specify 10 years service life for the reconditioned axles.

Table 2. Results of calculation of increase of surface hardness and hardened layer depth after rolling acc. to [6, 7]

Controlled characteristic	Parameter value	
	Standard	Actual
Hardness increase after rolling compared to initial value, not less than, %:		
journal	22	24.9
under-hub part	22	29.6
Hardened layer depth, mm:		
journal	2.6--5.2	3.2
under-hub part	3.9--7.8	4.0

Technology of plasma-arc metallisation of journals and under-hub parts of wheel pair axles allows increasing the surface hardness and depth of the hardened layer after rolling, in keeping with the standard requirements.

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REPAIR WELDING OF TURBINE CASE PARTS FROM HEAT-RESISTANT STEELS WITHOUT SUBSEQUENT HEAT TREATMENT*

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The paper deals with the issues of repair welding of damaged case parts of turbines after long-term operation at steam working parameters. A technology of welding with pearlitic electrodes without subsequent heat treatment (high tempering) is proposed. For repair of damaged components of case equipment of turbo units from cast heat-resistant steels a technology of manual arc welding with pearlitic electrodes of E-09Kh1M type is recommended. This technology involves application of preheating and concurrent heating with subsequent thermal recovery. Welded joints made by the developed technology have high crack resistance and required mechanical properties. The proposed technology has been successfully tested in repair welding of HPC of K-300-240 turbine.

Keywords: *repair welding, damage, heat-resistant cast steels, turbine case parts, electrodes, preheating, thermal recovery, residual life*

Extension of service life of power equipment of thermal power plants (TPP) is possible after examination of the condition of its individual components and technical diagnostics to reveal damage, detection of which requires conducting repair work to ensure further operation of the units. Damage of elements of equipment, which has been in operation in TPP for a long time, is due to technological, design and service factors. One of the most damaged elements of turbo units are turbine case parts, namely high (HPC) and medium-pressure cylinders, cases of steam distribution regulating valves, high-pressure steam-water fittings, etc. [1]. A number of such parts are of a complex configuration and are made of cast heat-resistant complex-alloyed steels (15Kh1M1FL, 20KhMFL and 20KhML). Turbine case parts exposed to high pressure and temperatures have damage in the form of cracks caused by metal creep, thermal fatigue and brittle fracture. In most of the cases this damage is located in part sections with an abrupt change in thickness or in casting defect zones. Increased damageability also develops in regions of welding, made with technology violations [2]. Repair of damaged parts runs into certain difficulties related to supporting work performance under production conditions. Therefore, development of advanced technologies of welding as the main process of power equipment repair is an important and urgent task to extend the life and guarantee safe operation of TPP power units [3].

Welding of cast chromium-molybdenum steels presents certain difficulties and is usually performed with application of preheating and concurrent heating of welding regions, as well as their subsequent heat treatment. Considering that under the conditions of operating TPP conducting heat treatment of repaired welded joints is problematic, application of welding processes without post-weld heat treatment is highly attractive. Work in this area is performed in specialized RF organizations (OJSC «VTI», SPA «TsKTI», SPA «TsNIITMash», etc.), which was reflected in standard RD 108.021.112–88 [4] and other sources [1–3, 5]. It is recommended to perform repair welding without heat treatment by austenitic electrodes without preheating or pearlitic electrode with preheating and concurrent heating and false heating of certain zones of the repaired section [1, 4].

Experience of application of electrodes of austenitic class is indicative of a considerable inhomogeneity of the deposited metal composition and mechanical properties of the joint, thus promoting its premature fracture in the zone of mixing of the base and electrode material and along the fusion line. Repeated repairs of these regions in case parts with austenitic electrodes are accompanied by new failures, and increase the scope of repair work.

Application of pearlitic electrodes by the recommended technologies [1, 4, 5] in combination with preheating and post-weld heating of repair welding regions ensures the required composition and necessary level of mechanical properties of the deposited metal, close to those of base metal, thus promoting a higher quality of repair and extension of residual life of repaired turbine parts.

PWI conducted a package of work to study the possibility of application of repair welding of turbine

*The article is based on the results of fulfilment of the NASU Complex Program «Problems of operating service life and safety of structures, constructions and machines» (2006--2009).

Composition of 15Kh1M1FL steel, wt.%

15Kh1M1FL steel	C	Si	Mn	Cr	Mo	V	S	P
							Not more than	
Acc. to TU 108.671--77	0.14--0.20	0.2--0.4	0.6--0.9	1.2--1.7	0.9--1.2	0.25--0.40	0.025	0.025
Studied melt	0.16	0.28	0.55	1.3	1.0	0.30	0.003	0.003

case parts from cast chromium-nickel steels without subsequent heat treatment. Variant of repair welding of widely applied cast heat-resistant steel 15Kh1M1FL with pearlitic electrodes was taken as the basic one. Composition of this steel is given in the Table.

Requirements to mechanical properties of castings from 15Kh1M1FL steel (to TU 108.671--77) are as follows: σ_m = 350 MPa; σ_t = 550--600 MPa; δ = 22 %; ψ = 69 %; KCU = 40 J/cm^2.

Repair welding technology should envisage measures preventing cold cracking in welded joints. Crack resistance of welded joints can be ensured by selection of thermal modes and conditions of welding, under which the cooling rate will promote formation of HAZ metal structure not prone to cracking. Therefore, the influence of the thermal cycle of welding on the structure and properties of cast casing steel 15Kh1M1FL was studied first of all. In keeping with the plotted thermokinetic diagram of austenite transformation in this steel (Figure 1) under different conditions of heating and cooling, characteristic for different welding conditions, in the range of cooling rates of 0.33 to 25 °C/s at 500 °C the temperature of the end of martensite transformation is above 290 °C, and hardness of structural components is on the level of HV 180--340. At increase of cooling rate above 25 °C/s, steel structure is martensitic (Figure 2). Hardness rises and at 100 °C/s is reaches HV 390--420. It is known [6--8] that after completion of martensite transformation below 290 °C and at more than 50 % martensite content, there is a risk of cold cracking. Therefore, in welding of such steel it becomes necessary to apply additional measures to adjust the process of cooling of the welding zone in the form of preheating and concurrent heating or application of welding processes providing joint self-heating.

In keeping with works [1, 3, 4] electrodes of E-06Kh1M type (GOST 9467--75) are recommended for repair welding without postweld heat treatment of steels of the type of 15Kh1M1FL, 20KhMFL and 20KhML.

Metal deposited with electrodes of grade TML-5 (E-06Kh1M type) in as-welded condition has the following composition, wt.%: 0.044 C; 0.25 Si; 0.56 Mn; 0.69 Cr; 0.51 Mo; 0.021 P; 0.017 S. Mechanical properties of deposited metal at 20 °C: σ_t = 600 MPa; δ = = 26 %; KCU = 173 J/cm^2.

In order to asses cold cracking resistance of 15Kh1M1FL steel and determine the required temperature of preheating in repair welding investigations were conducted by the Implant method [9], as well as using Tekken and Lehigh University samples [10].

Maximum (critical) stresses in the samples before the start of fracture were taken as the criterion of crack resistance of the welded joint in Implant testing. Samples withstood the load for up to 24 h. During testing beads were deposited by manual arc welding with 4 mm electrodes of TML-5 grade at I_w = 175 A. Bead length was 70 mm, deposition time was 30 ± 2 s. Deposition was performed directly in the unit under the conditions both without preheating and with preheating up to 250 °C.

Experimental data showed that cold cracking by the delayed fracture mechanism (incubation period, period of stable increase of microplastic deformations and accelerated fracture period at critical stresses) and, probably, formation of an unfavourable structure in the deposition zone occur in welding steels of 15Kh1M1FL type (Figure 3, *a*). Application of preheating up to 200 °C allowed raising the level of critical stresses to 0.70--0.75 of base metal yield point (Figure 3, *b*). Preheating promotes lowering of the cooling rate at structural transformations, is favourable for the mode of microplastic deformation development and removal of diffusible hydrogen.

Technological samples for assessment of crack resistance were made of cast steel 15Kh1M1FL 20 mm thick. Manual arc welding was performed with TML-5 and UONI-13/45A electrodes in the mode of I_w = = 170--180 A with reverse polarity current. Applica-

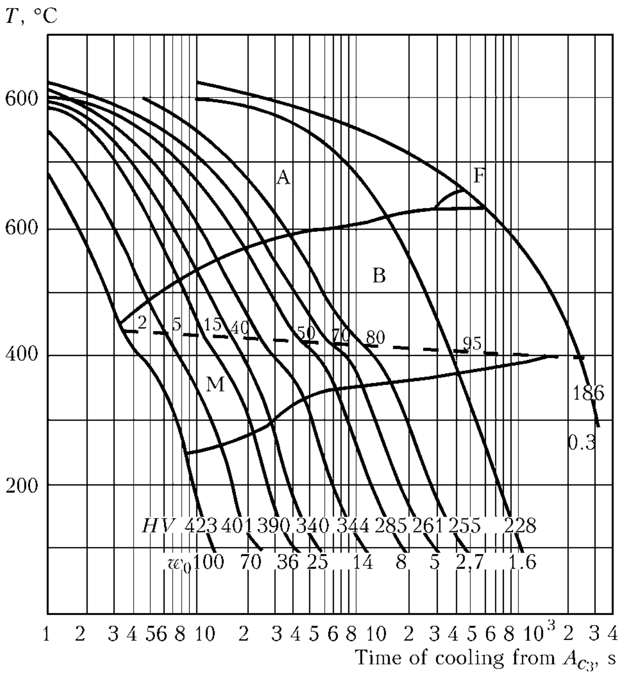

Figure 1. Thermokinetic diagram of austenite transformation in heat-resistant steel 15Kh1M1FL

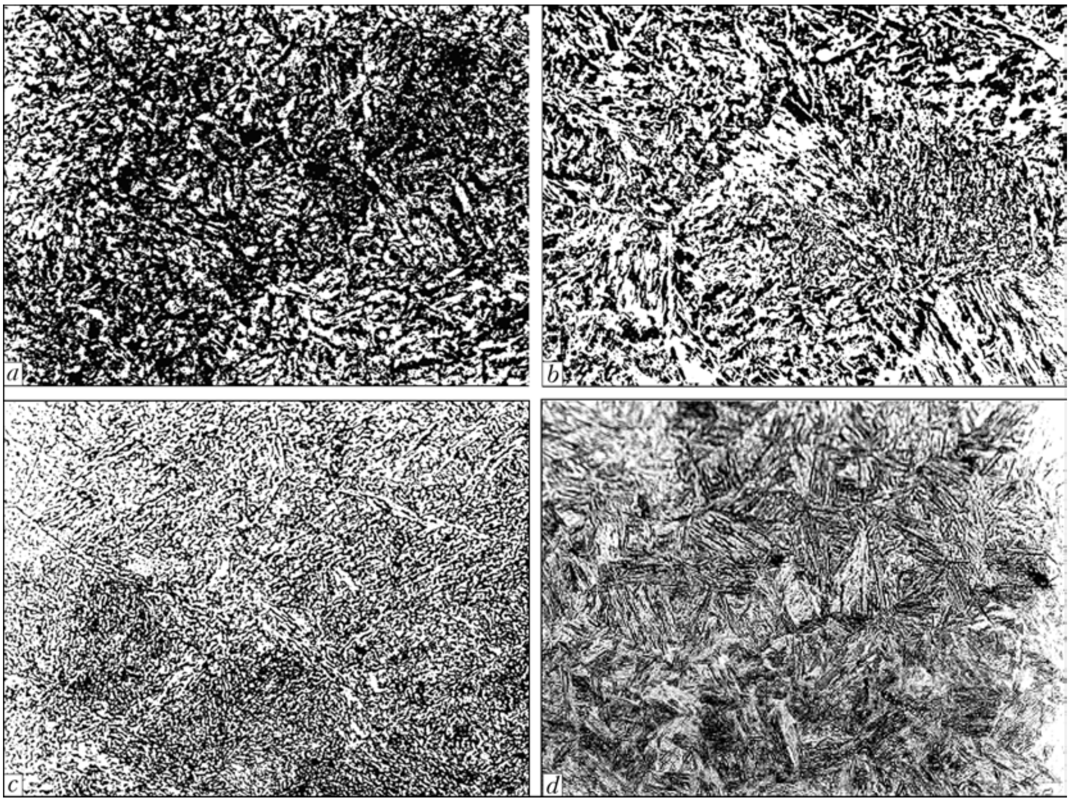

Figure 2. Microstructure (×300) of 15Kh1M1FL steel in as-welded condition (*a*) and at w_0 = 0.3 (*b*), 1.6 (*c*) and 100 (*d*) °C/s

tion of UONI-13/45 electrodes is necessary to create «soft interlayers» at multilayer welding up of defects or for coating the cut-out recess edges.

As shown by the results of the conducted technological sample testing, ensuring the crack resistance in welding cast steel 15Kh1M1FL with electrodes of E-06Kh1M type requires application of preheating up to 200–250 °C.

It is known [11] that properties of the metal of the weld and HAZ of welded joints of heat-resistant steels depend to a great extent on their ambient temperature conditions immediately after the completion of the welding process. Post-weld recovery is particularly effective for improvement of the ductile properties and crack resistance of welded joints [12, 13]. No phase transformations are observed here, but favourable conditions are in place for removal of diffusible hydrogen from the welding zone.

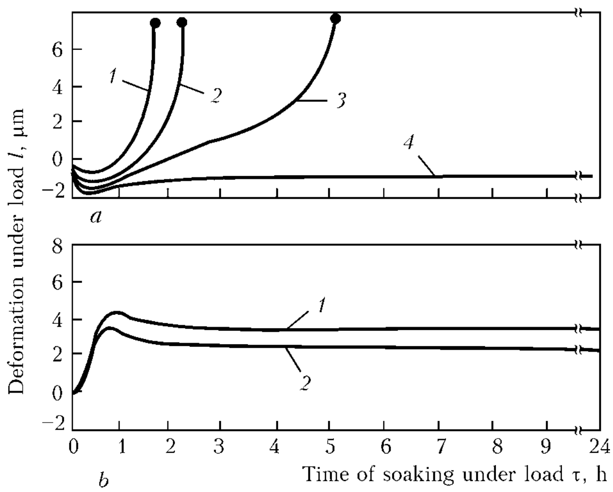

Figure 3. Deformation kinetics at Implant testing of 15Kh1M1FL steel: *a* — without preheating; *1* — critical stress 300; *2* — 280; *3* — 240; *4* — 220 MPa; *b* — preheating to 200 °C; *1* — 350; *2* — 300 MPa

It should be noted that post-weld recovery, compared to high annealing, does not lower the level of residual welding stresses. Now, relaxation of residual stresses at service temperature is small. Therefore, the repaired parts of the turbo units have a limited service life (up to the next planned maintenance). After conducting the next examination and technical diagnostics a decision is taken on their further operation in production.

Proceeding from the gained experience [13] it is shown that application of recovery at temperature exceeding the cold brittleness range of metal of a specific steel grade is the most effective to improve the welded joint crack resistance. Proceeding from this principle, the temperature of recovery of welded joints of 15Kh1M1FL type steel can be set on the level of 250–280 °C.

Conducted studies of the main technological characteristics of weldability of heat-resistant steels for turbine case parts based on 15Kh1M1FL cast steel with application of electrodes of E-06Kh1M type allow confirming the recommendations of [4] on the possibility of repairing defects in cast case parts using pearlitic electrodes. Post-weld heating in the form of thermal recovery is also necessary for stabilization of metal structure in the repair welding zone, acceleration of diffusible hydrogen evolution and prevention of cracking after welding [11, 13].

To assess self-heating in repair welding of case parts without preheating and post-weld heat treatment, «cross-hill» welding technique was tried [14], which owing to continuous deposition of welding beads over the entire section of cut-out defect recesses, ensures self-heating and allows repair welding to be performed without preheating. Recesses can be welded up in the downhand, horizontal and vertical positions.

To determine cold cracking resistance of the joints in welding up case part damage by «cross-hill» technique, welding up of cruciform cut-out recesses was performed. Two recesses normal to each other, each of 50 mm length, 30 mm width, and 40 mm depth were cut out in 60 mm plate of 15Kh1M1FL cast steel. Welding was performed without preheating or post-weld heating both with edge coating before welding with UONI-13/45 electrodes and without coating (Figure 4, *a*). Recesses were filled with 4 mm TML-5 electrodes, at I_w = 180 A in both the cases. Welding was started from recess edges.

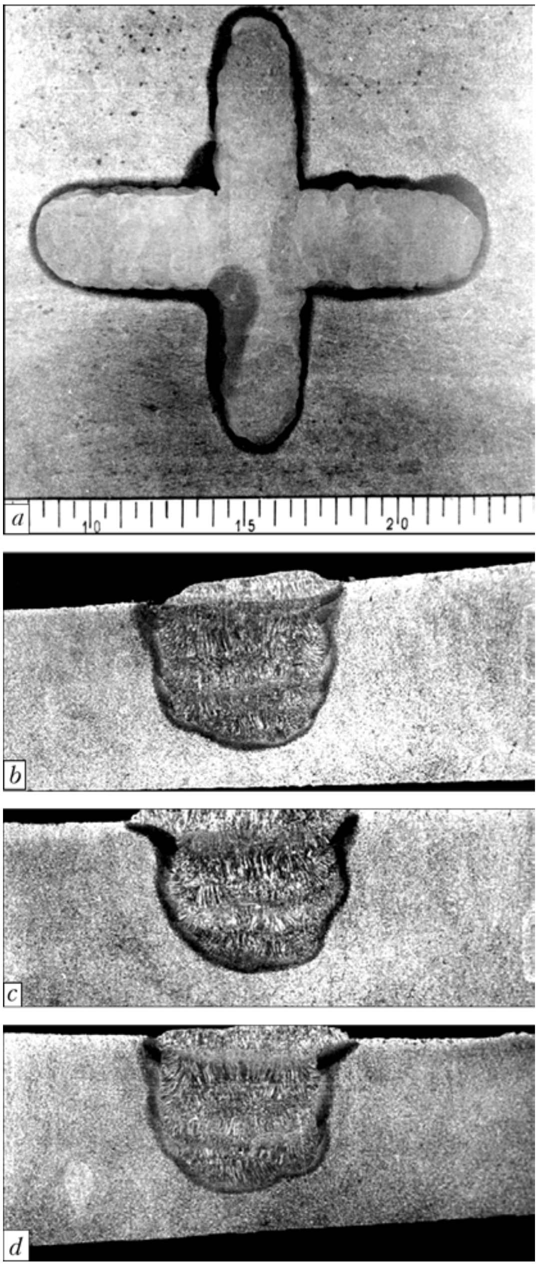

Figure 4. Macrosections of welded up cruciform recesses on 15Kh1M1F steel: *a* ---- longitudinal; *b*–*d* ---- cross-sections at the start, middle and end of recesses, respectively

After welding the samples were cut into templates to detect cracks and other defects, as well as study the microstructure. As is seen from macrosections shown in Figure 4, *b*–*d*, the appearance of the metal of the weld and HAZ is typical for joints made by the regular multilayer welding. Deposited metal is tight, without pores, cracks, slag inclusions or other defects. Obtained results allows considering the «cross-hill» welding technique as one of the possible variants at elimination of damage in cast case parts from heat-resistant steels without application of preheating or post-weld heating.

Results of the conducted investigations allowed considering the possibility of repair welding performance without subsequent heat treatment in welding up damage on turbine case parts under stationary conditions. The selected object of application of the proposed repair welding technology was the cover of HPC case of K-300-240 steam turbine from heat-resistant cast steel 20KhMFL. HPC was examined during overhauling of unit #3 at Tripolskaya TPP. Visual-optical examination (VOE) revealed non-through thickness cracks with minimum opening on the inner surface of outer cover of HPC case (Figure 5) in the region of a jaw for key connection. The turbine had been in operation for 248,667 h. Steam working parameters were as follows: temperature of 545 °C, pressure of 245 atm. In order to take a technical decision on the possibility of conducting repair welding without subsequent heat treatment the proposed technology was first certified under TPP conditions. Certification testing was conducted on a sample of 20KhMFL cast steel of 500 × 300 × 60 mm size. Recess in the sample simulated a non-through thickness crack 200 mm long and 30 mm deep. Composition of metal of 20KhMFL steel sample was as follows, wt.%: 0.20 C; 0.30 Si;

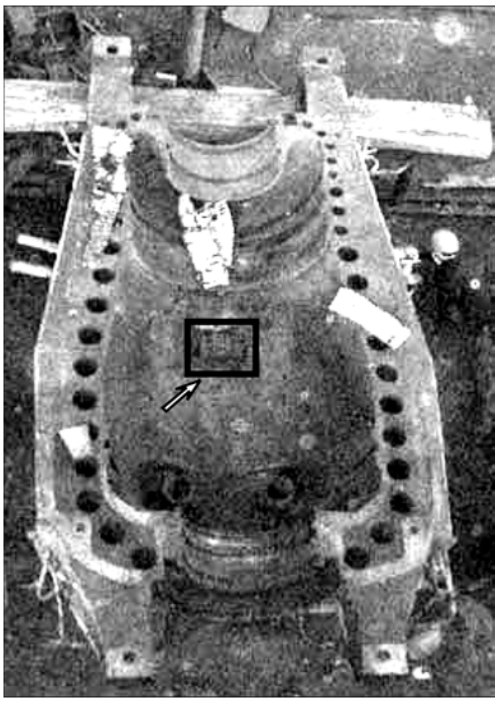

Figure 5. General view of inner surface of K-300-240 turbine HPC case cover (arrow shows key connection, near which cracked sections were found)

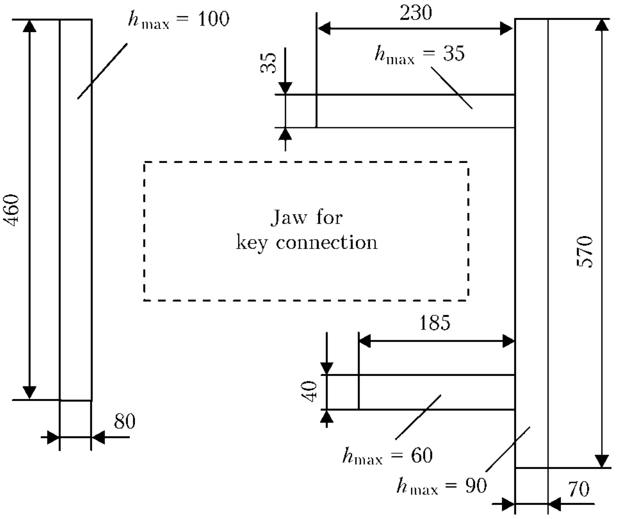

Figure 6. Layout of crack cut-put recesses on inner surface of K-300-240 turbine HPC case cover: *h* — recess depth

0.70 Mn; 1.10 Cr; 0.60 Mo; 0.25 V; 0.25 Ni; 0.28 Cu; 0.02 S; 0.02 P.

During certification testing the modes and technology of repair welding were optimized; non-destructive and destructive quality control of the welded joint was conducted by the proposed technology; physico-mechanical properties and structure of the made welded joint and their compliance with the code requirements were studied.

Certification testing was conducted by a program developed at PWI, which took into account all the requirements to repair welding of steam turbine cast case parts [4].

Recess welding up was performed with 4 mm TML-5 electrodes. Prior to welding electrodes were baked at 400 °C for 2 h.

Plate preheating was conducted up to 250 °C in the following modes: recess coating at I_w = 140–170 A; recess filling (except for its middle part) at I_w = 160–180 A; recess middle part I_w = 140–170 A.

Complete filling of the recess was followed by heating by thermal recovery mode at the temperature of 250 °C with 15 h soaking. When recovery period was over, the joint was cooled down at the rate of about 50 °C/min up to plate temperature lowering to 80 °C.

Welded joint quality was assessed by visual inspection (Section 16.3 RTM-1s–89), magnetic particle testing (GOST 21105–87), as well as ultrasonic testing (Section 16.5 RTM-1s–89). Performed quality control of the welded joint did not reveal any deviations from code requirements.

Investigations of mechanical properties showed that welded joint ultimate strength in tensile testing of samples is in the range of 530–560 MPa, and deposited metal impact toughness is equal to 148–170 J/cm^2, which corresponds to requirements to this steel (σ_t = 500 MPa and a_n = 50 J/cm^2, respectively).

Metallographic examination of macro- and microstructure was conducted. Investigations showed absence of deffects in the weld and HAZ metal. Weld metal hardness was *HB* 184, HAZ metal — *HB* 172 against *HB* 104–223 admissible for 20KhMFL steel and *HB* 150–240 admissible for weld metal.

Thus, conducted testing of repair welding up of an artificial defect on a plate from 20KhMFL steel by the developed technology in keeping with the certification testing program, showed positive results. This allowed taking a technical decision and recommending this technology for repair welding of K-300-240 turbine HPC cover from cast steel of 20KhMFL type. Welding technology was developed and technological instructions were prepared on repair welding of HPC case cover. Cracks were cut out with a pneumatic chipper and abrasive tools with periodical surface inspections. Recess layout and their final dimensions are given in Figure 6. After crack cutting-out the surface was hogged and controlled by VOE and dye penetrant testing. Control results were satisfactory.

Welding up and subsequent thermal recovery of welded-up locations were conducted by the developed technological process of repair welding. Non-destructive testing of repaired sections demonstrated the high quality of the made welded joints. Block #3 with K-300-240 turbine was accepted for further operation.

CONCLUSIONS

1. Weldability of typical cast heat-resistant 15Kh1M1FL steel was studied. This steel is widely used in fabrication of casing equipment of turbo units and high-pressure steam-water fittings.

2. It is shown that in repair welding of turbine case parts thermal recovery can be used for welded joints made with pearlitic electrodes with preheating and concurrent heating, instead of post-weld heat treatment.

3. Technology of welding envisaging application of preheating and concurrent heating with subsequent thermal recovery is proposed for repair of damaged components of case equipment of turbo units from cast heat-resistant steels. Service life of repaired turbo units can be extended for an unlimited period.

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ELECTRICAL CONDUCTIVITY OF SLAG POOL IN ELECTROSLAG WELDING WITH WIRE ELECTRODE

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Equations and dependencies of electrical conductivity of the slag pool on immersion and position of wire electrode in electroslag welding are given. Results of modeling slag pool conductivity using an electrolytic bath are presented.

Keywords: *electroslag welding, slag pool electrical conductivity, wire electrode, simulation, electrolytic bath*

Specific resistance of molten slag is several orders of magnitude higher than that of current conducting cables and metal being welded. Therefore, slag pool resistance R_{sl} largely determines the value of welding current and, therefore, the process of electrode melting and its stability.

To determine the regularities of variation of slag pool resistance in electroslag remelting (ESR), potential distribution in electrolyte placed in a measuring glass with mercury electrode on the bottom was studied in study [1]. A coated platinum electrode was immersed into the electrolyte. Obtained results were described by the non-linear equation

$$R = C\left(\frac{S}{D^2}\right)\left(\frac{S}{d}\right)^{\alpha}\left(\frac{p}{d}\right)^{\gamma}, \qquad (1)$$

where R is the impedance; S is the interelectrode gap; D is the measuring glass inner diameter; d is the electrode diameter; p is the electrode immersion; C, α, γ are the constants non-linearly dependent on the coefficient of filling, the value of which is equal to $1.07 \le$ $\le D/d \le 6/6$.

Dependence (1) is valid for ESR with an insulated mould. In simulation of electroslag welding (ESW) the measuring glass should be metallic. Therefore, formula (1) can be used for ESW only as a variant of the dependence of slag pool resistance on its parameters.

In [2] slag pool resistance is presented in the form of two resistances connected in parallel: between the immersed part of the electrode and mould wall $R1$, as well as between the electrode tip and ingot pool surface $R2$. These resistances are described by the following equations:

$$R1 = \frac{\rho L}{H}; \quad R2 = \frac{\rho l}{\left[\frac{(C_1 + C_2)}{2}\right]\left[D - \frac{AL}{B}\right]}. \qquad (2)$$

Here ρ is the slag specific resistance, Ohm·cm; L is the interelectrode gap, cm; A is the ingot cross-section, cm^2; l is the distance between the electrode and mould, cm; C_1, C_2 is the circumference of electrode and mould, respectively, cm; B is the area of circular clearance between the electrode and mould, cm^2.

Authors of [2] believe that the described model provides a sufficiently accurate approximation of the influence of various parameters of ESR process on slag pool resistance characteristics.

Formulae (2) were derived for a round mould, and equations (1) imply a non current-conducting mould. In ESW slag pool of depth h_s is in a rectangular «mould» of width b_a (corresponds to welding gap width) and length which corresponds to thickness of parts being welded. Below we will consider not the slag pool resistance, but the inverse value — electrical conductivity, as in this case the analytical dependencies are simpler. Electrical conductivity of the slag pool between the lowered into it to the immersion depth (immersion) electrode L_s into the slag and the electrically conducting slag pool walls can be presented as a sum of electrical conductivities between the electrode and each wall:

$$G = \frac{1}{R} = \sum_{i=1}^{5} G_i.$$

In the first approximation the wall length was taken to be unlimited. To calculate the slag pool conductivity between the electrode and one of the vertical walls, let us use the formula for capacitance of single-wire line and ground per a unit of length, replacing in it medium permittivity ε_a by slag pool electrical conductivity average over the pool volume γ_s [3]:

$$G_i' = \frac{2\pi\gamma_s}{\ln\left(\frac{H_i + \sqrt{H_i^2 - r^2}}{r}\right)},$$

where H_i is the distance from electrode center to i-th wall of the slag pool; r is the electrode radius; $H_3 =$ $= b_a - H_1$; $H_4 = S - H_2$. For an electrode immersed into the slag to depth l_s, we obtain electrical conductivity $G_i = l_s G_i'$.

To calculate slag pool electrical conductivity between the electrode and metal pool G_5, let us use the transformed formula for capacitance of two finite cylinders [4]:

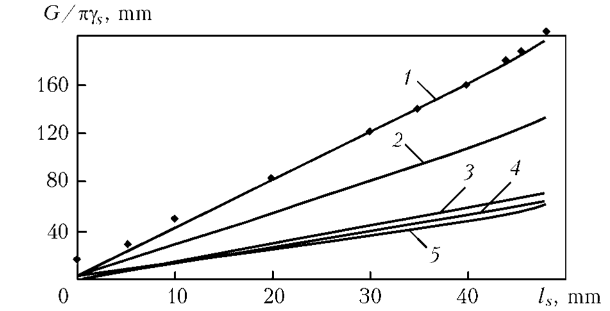

Figure 1. Dependence of slag pool electrical conductivity on electrode immersion into it: *1* — slag pool admittance G; *2* — slag pool conductivity at insulated shoes $G_1 + G_3 + G_5$; *3* — conductivity of the section electrode–molten metal pool G_5; *4* — conductivity of the section electrode–edges of parts being welded $G_1 + G_4$; *5* — conductivity of electrode–shoe section $G_2 + G_3$

$$G_5 = 2\pi\gamma_s \left(\frac{r^2}{2(h_s - l_s)} + \frac{2r}{\pi} \ln \left(\frac{4h_s}{h_s - l_s} \right) + \frac{l_s}{2} \right).$$

Figure 1 gives the dependence of slag pool electrical conductivity on electrode immersion under the following conditions: slag pool depth $h_s = 50$ mm; gap $b_a = 30$ mm; welded part thickness — 40 mm; electrode diameter $2r = 4$ mm; electrode is in the slag pool center ($H_1 = H_3 = 15$ mm; $H_2 = H_4 = 20$ mm). One can see from the Figure that the slag pool electrical conductivity in wire electrode welding rises practically linearly with increase of electrode immersion. Contribution of each of the three components of electrical conductivity (electrode–item edges, electrode–shoes, electrode–metal pool) is approximately the same.

Dependence of slag pool electrical conductivity on electrode position relative to edges of item being welded is shown in Figure 2. Electrode immersion $l_s = 25$ mm is taken in calculations.

It should be noted that the value of electrical conductivity of electrode–shoe section is somewhat higher. As the heat conductivity of copper shoes is high and they are intensively cooled by water, molten slag near the shoe surface has a lower temperature compared to pool average temperature. Influence of temperature T_{sl} on specific electrical conductivity of liquid slag γ_s is described by the following equation [1]:

$$\gamma_s = \gamma_0 \exp(-c/T_{sl}),$$

where γ_0, c are the constants for this slag. According to [5], electrical conductivity of popular flux AN-8 varies from 0 (at 950 °C) up to 4 $Ohm^{-1}\cdot cm^{-1}$ (at 2000 °C). Thus, electrical conductivity of slag decreases at temperature lowering, and a layer of slag of a lower electrical conductivity forms near the shoe surface. Solidified slag (skull) can in principle be regarded as non-conducting. In calculations electrical conductivity of this layer is included in parallel to G_4 and G_5, reducing the resultant electrical conductivity right down to zero. Unfortunately, there is a lack of theoretical or experimental estimates of boundary layer conductivity. Therefore, the total electrical conductivity of the slag pool is somewhere between G и $G_1 + G_3 + G_5$. However, dependence of electrical conductivity of the slag pool on electrode immersion and position relative to the edges of parts being welded qualitatively remains approximately the same.

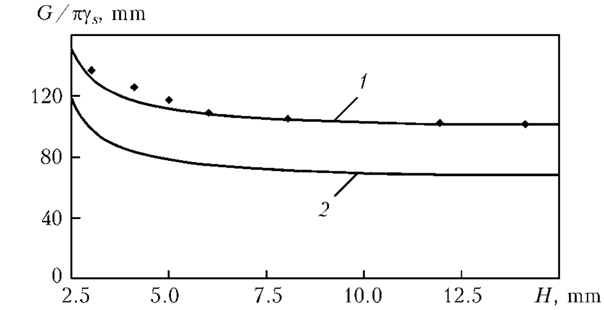

Figure 2. Dependence of slag pool electrical conductivity on distance H between electrode and closest edge of part being welded: *1, 2* — see Figure 1

To check the derived dependencies, simulation was performed on an electrolytic bath. Bath and electrode dimensions were taken to be the same as in calculations. Water was used as the electrolyte. The bath was made from copper foil, and the electrode was from steel wire. As electrical conductivity of water is several orders of magnitude lower than that of metals, selection of the kind of metal for the model of the pool and electrode is not important. To avoid electrolytic phenomena the model was powered by alternating current of 1 kHz frequency. In Figures 1 and 2 points indicate simulation results after scaling for comparison with the calculated curves, and the presented data are in quite satisfactory agreement. Some discrepancies observed at slight immersion of the electrode (see Figure 1), are attributable to the influence of the meniscus due to electrode wetting.

In view of small scope of studies and lack of valid data, the near-electrode processes on metal–slag boundary were neglected in this work [5, 6]. Allowing for the anode and cathode voltage drop does not qualitatively change the dependence of the slag pool impedance on different parameters of ESW process, determination of which is the main purpose of this study.

Thus, it was determined that in ESW with wire electrode the slag pool electrical conductivity is directly proportional to electrode immersion. It almost does not change, if the electrode is located at a distance from the welded part wall greater than its diameter.

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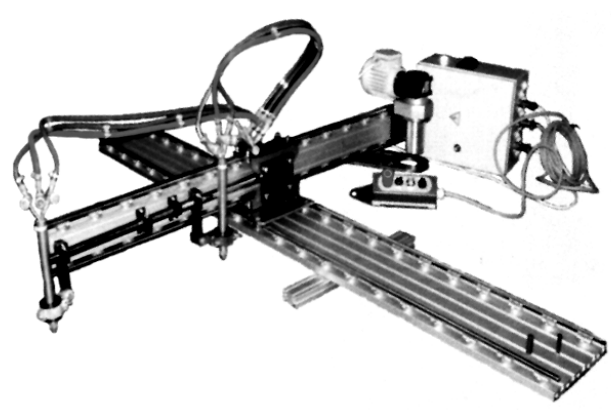
NEWS

«MAGNIT» ---- PORTABLE MACHINE FOR CURVILINEAR LAYOUT OF ROLLED METAL

«Faktor Ltd.» (Moscow) mastered the production of portable copying machines «Magnit», designed for



cutout of parts of sheet rolled metal using a magnetic copying device. The machine represents a guide along which the carriage is moved with a traverse mounted perpendicularly on it. The rotation moment is transmitted to a magnetic finger which runs around the preset contour templet. On the opposite end of the traverse the cutters are fixed. The machine can be equipped with any device for air plasma cutting of metals of the grade PURM, and also with the equipment for gas-oxygen cutting. The machine is manufactured on the modern level using the best models of driving equipment.

It has a number of considerable advantages as compared to the famous machines ASSh-2, ASSh-70, «Ogonyok» and «Strela», such as: mobility; high accuracy of reproduction of preset contour due to rigidity of the design; high speed of cutter travel (from 50 to 6000 mm/min); travel smoothness; high reliability of the units owing to use of modern element base and drives of the leading world manufacturers.

GAS-FLAME MACHINE FOR THERMAL SPRAYING OF POWDERS

«Technologic Centre «Tekhnikord Ltd.» offers a gas-flame powder thermal spraying machine MRK-10 for thermal spraying of powders of metals and alloys to deposit coatings for protection of surfaces of parts from different kinds of wear, cavitation, oxidation, fretting corrosion, corrosion in aggressive media, and also restoration of worn-out parts with simultaneous improvement of their service properties.

The machine MRK-10 includes a powder gun-sprayer PR-10 *1* and control panel PU-03 *2* for control of working gases, which is mounted on the post *3*. There is a fixture for mounting of hopper *4*, a powder proportioning device, on a gun-sprayer. The gun-sprayer is connected to a panel of working gases control through protective valves-flame extinguishers *5* by rubberized fabric hoses *6* with connectors for oxygen, combustible gas (acetylene, propane or MAF gas) and compressed air.

The oxygen and combustible gas are supplied by the hoses to the control panel from standard gas cylinders equipped with reducers. The compressed air, supplied from the compressor, is preliminary purified from the traces of oil and moisture, and then it is supplied by the hose to the input of the unit of air preparation of gas control panel.

The design of gas control panel allows its use for the work with gas-flame gun-sprayers of any companies. The machine can operate under shop or field

conditions in environments, not containing vapors of acids, alkaline and other caustic liquids.

INTERNATIONAL CONFERENCE «IMPROVEMENT OF TURBINE PLANTS USING METHODS OF MATHEMATIC AND PHYSIC MODELLING»

On 21–25 September, 2009 the Scientific-Technical Conference «Improvement of Turbine Plants Using Methods of mathematic and Physic Modelling» took place at the territory of Zmievskaya thermoelectric power station. The organizers of the Conference were the National Academy of Sciences of Ukraine, A.N. Podgorny Institute of Mechanical Engineering Problems of NASU, Ministry of Fuel and Energy of Ukraine, OJSC «Turboatom», Company «Energoprogress», Ukranian Engineering-Pedagogical Academy, Zmievskaya thermoelectric power station.

In the work of the Conference over 150 specialists of 27 organizations and enterprises of fuel-power engineering complexes, research institutes, design bureaus, universities and academies of Ukraine, Russia, Denmark, Poland and other countries took part. As compared with the previous conference the growth of representation of leading research institutes, thermoelectric power stations and higher educational establishments, in particular the E.O. Paton Electric Welding Institute, SPA TsKTI (Russia), IMS PAN (Poland), etc. was noted.

Prof. A.I. Shubenko, the deputy chairman of the Organizing Committee, opened the Conference and made a welcome speech. He greeted the participants of the Conference with the beginning of its work and also wished everybody successful and fruitful activity and new beneficial cooperation. Further, he emphasized the importance of the problem of wear of turbine plants and other equipment of thermoelectric power stations and also peculiarities of its modernizing. The reporter grounded the need in making the diagnostics more precise, and also in subsequent replacement of welded joints, as the most worn-out elements of power equipment.

Then V.E. Levchenko, the director of Zmievskaya thermoelectric power station, delivered a welcome speech, describing briefly the condition of power equipment of this thermoelectric power station and tasks connected with its modernizing.

The Conference included the works of seven sessions: improvement of thermodynamic and ecological characteristics of thermal turbine plants; improvement of gas-dynamic processes and running parts of turbomachines; diagnostics, prediction, safety of operation and residual life of turbine plants; problems of modernization and technical re-equipment of thermoelectric power plants; processes and structures of hydraulic turbines; problems of updating of designs and problems of energy-saving in gas-pumping equipment of gas transport systems. In total, 5 plenary and 117 session reports were presented. The results of applied investigations and practical developments devoted to power equipment were reported. About a quarter of reports included materials devoted to study of structure, properties, and also damage of welded joints subjected to long-term service under the conditions of fatigue and creep.

A number of reports caused active discussions, for example, on the evaluation of crack resistance of rotors of turbine K-1000-60/1500 of nuclear power station and evaluation of residual life of elements of power equipment, on the criterion of crack resistance.

The distinctive feature of the Conference, as compared with the previous one, was the participation of significant amount of scientists from the higher educational establishments, and also young scientists and post-graduate students in its work. The exchange of results of developments on the problem of modernization of uniform equipment of thermoelectric power stations between specialists of Ukraine, CIS and other countries was also quite beneficial.

The resolution, including recommendations and proposals to the governing bodies of Ministry of Fuel and Energy of Ukraine, State Nuclear Power Complex and thermoelectric power stations was adopted at the Conference.

In general, the Conference promoted the beneficial exchange of information of scientists working in the field of diagnostics of condition, determination of residual life and modernization of equipment of thermoelectric power station.

Prof. V.V. Dmitrik,
Ukranian Engineering-Pedagogical Academy

SEMINAR ON WELDING TECHNOLOGIES «FULL READINESS TO EXCELENT WELDING OF STEEL»

On October 29, 2009 in Knyazhichi village (Kiev region) a one-day seminar on welding technologies on the subject «Full Readiness to Excellent Welding of Steel» took place at the Technological Center of «Fronius Ukraina Ltd.». The representatives from a number of enterprises of different branches of industry of Ukraine, in total over 30 experts, participated there.

The program of seminar, held in the form of dialogue between managers of «Fronius Ukraina Ltd.» and its participants, included theoretical and demonstration parts on the following subjects:

• New generation of equipment Trans Steel 3500/5000 for welding of steel;

• PCS — powerful welding of steel using a pulsed arc;

• New welding trolleys FDV 15/22 MF.

V.L. Bondarenko, the marketing director of «Fronius Ukraina Ltd.», described briefly the basic areas of activity of main company «Fronius» (Austria) including development and manufacture of welding machinery (main division of the Company), starting-charging devices and also equipment on convertion of solar energy (capacity of up to 4 kW).

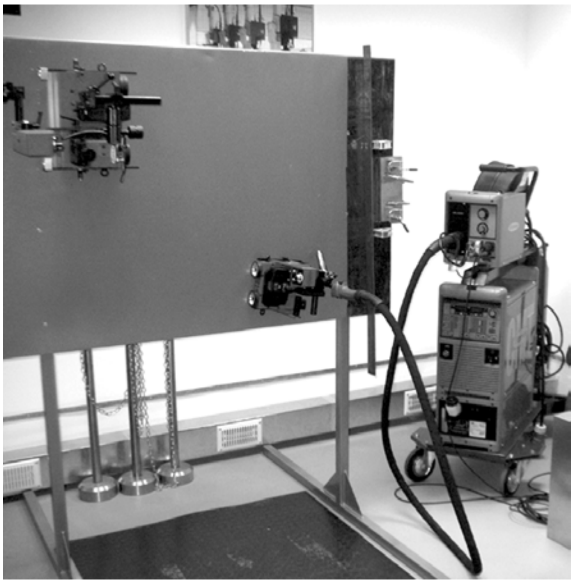
The production of welding equipment (concentrated in Austria, Chech Republic and Ukraine) includes equipment for manual arc welding, MIG/MAG processes, TIG and plasma welding. The Company offers also the system solutions on automation of welding processes. In this case the welding equipment is completed with tables, roller supports, trolleys. There is a department, specialized on development and production of equipment for orbit welding. In the last years the activity of Company in the field of development and manufacture of equipment, accumulating and transforming the solar energy into domestic electric power, has been recognized highly by many European societies.

In Donetsk and stry (Lvov region) the affiliates of «Fronius Ukraina Ltd.» were created. In Kiev the activity of Technologic Centre has lived up. Its task is to help the potential customer to choose optimal technological joining process, to select the appropriate equipment, to set-up it at the manufacturing facility, to train workers-welders, to test reference specimens of welded joints.

V.L. Bondarenko told about exposition of «Fronius» at the recent exhibition this year in Essen. At the area of 2000 m^2 17 exhibits were placed among which «Trans Steel», the system for high-quality welding; CMT, the prospects of cold metal transfer; «Virtual Welding», the training system which saves time and materials; «Autonomous Welding» (welding without human interference, the latter observes welding process on the monitor); «New Contact Tip» increases life of current-carrying tip by seven times in MIG/MAG welding; «Service of Welding Equipment», the guarantee period is prolonged up to seven years; «Mechanisation and Automatisation of Welding Processes» — autonomous magnetic trolleys of two types, systems of control of orbit welding, systems of programming and data recording.

The reporter demonstrated the examples of automation of welding processes on the screen during performance of long longitudinal welds, welding of T-joints, deposition of surfaces in the pipe of the depth of up to 3 m and other.

The advantages of cold metal transfer (CMT) were stipulated by different improvements with the aim of widening the technological fields of application. It can help for example in butt welding of two plates of thickness of not more than 0.2 mm without backing and with the highest quality. CMT is applied for the so-called studding of parts of stainless steel, aluminium or structural low-carbon steel with further deposition of a polymer layer. The deposited «studs» of metal play role of a peculiar frame. This method can be furtherly applied in producing of bimaterials, for example, of thin sheet of metal with deposited



studs of the length of up to 5 mm and with a polymer coating.

The theoretical part of the seminar was continued by the speech of R. Kulish, the manager of «Fronius Ukraina», who described the welding system «Trans Steel 3500/5000» for MIG/MAG and manual arc welding. The machines of this series (of 350 and 500 A) are equipped with a unique inverter developed by the «Fronius» and providing some characteristics of welding: standard, special –– dynamic (to increase penetration depth and welding speed) and also with a thin soft arc for welding of a root weld or welding in a wide gap. The machines are easy to control. They have all markings, such as directions to a welder for the start of the work and only two handles to control current and voltage. In manual welding mode these two parameters can be preset separately, and in the mode «Synergic» they are correlated, thus providing the maximum good results of welding.

The products of the series «Trans Steel» are easy to control and provide high reliability plus perfect welding characteristics. The central control unit is responsible for stability of process and repeatability of welding results even in the situation of changing process conditions. The Steel Transfer Technology was additionally improved in the first turn owing to innovation wire feed. Light strong unit, including a circuit-package, torch and control display, guarantees reliable welding filler wire feed. The function «Comfort wire» performs automatic wire loading. The user can easily remove the wire feed portable unit and carry it to hard-to-reach places of site area to perform welding. Irrespective of position of circuit-package the welding parameters remain stable.

The innovation connector FSC (Fronius System Connector) is designed for manual and robotic application, for systems with gas and water cooling, it improves quality, reliability, versatility and comfort of the work. Owing to central connector for all external devices, the user can refuse the external control plugs. The ergonomic torch enables quick and reliable replacement due to a lever lock.

The machines of series «Trans Steel» are suitable for operation at a long period even at intensive use.

V. Slyuta, the head of department of equipment and technologies of the Technological Center, described the development by «Fronius» of the process of high-powerful pulsed-arc welding with a drop transfer using characteristic of pulse controlled-spray arc (PCS). The characteristic PCS corresponds to welding with a constricted arc. This process is transient between a pulsed-control and spray one. The arc in a mixed mode is burning «buried» relative to a weld

pool. The minimal light radiation is provided, the increase in penetration depth even at increased welding speeds is achieved.

To realise welding process with PCS characteristic, it is necessary to apply special high-capacity inverter providing a pulsed process of arc burning.

In conclusion of theoretical part of Seminar the presentation of versatile welding trolleys with a magnetic clamp FDF 15/22MF, ensuring accurate travel of welding head at performance of welds in different spatial positions using MIG/MAG methods, was made. Unlike the trolleys applied formerly they do not require guides, they do not have cable networks and arranged directly on the workpiece, they are light, the control is simpliest, the supply is from batteries. The trolley has a unit for mounting of a manual torch. The battery unit is also arranged on the trolley. The completing of the trolley with a simple welding tractor is possible. If necessary, the system of tracking the butt and torch oscillation unit can be arranged on the trolley. Additional equipment: charging device for the battery and overcharged battery with capacity of 14.4 V/2 A·h.

In the second part of the Seminar the managers of «Fronius Ukraina» demonstrated the operation of machine «Trans Steel 3500», the process CMT in the robotic-technical complex, showed peculiarities of application of welding trolleys with a magnetic clamp. Besides, the stand for demonstration of possibilities of plasma welding, whose technology provides quality welding of stainless steels of thicknesses from 0.2 up to 12 mm of penetration for one pass was presented. The sizes of workpieces are not limited here.

The participants of the seminar were invited for the International Industrial Forum (Kiev, International Exhibition Center, 24–27.11.09) to the stand

«Fronius Ukraina». A new complex «Virtual Welding» designed for training of welders will be presented for the first time in CIS.

All participants expressed thanks to the organizers of the seminar for informative program, possibility of the detailed familiarization with advanced models of equipment and technologies.

Prof. V.N. Lipodaev,
Dr. A.T. Zelnichenko, PWI

INTERNATIONAL EXHIBITION «WELDEX/ROSSVARKA-2009»

The 9th International Exhibition «Weldex/Rossvarka-2009» took place in Moscow at International Exhibition Center «Crocus Expo» in October 12--15, 2009. It was organized by Closed Joint Stock Company «International Exhibition Company» with the assistance of Company «Elsvar» and support by the Chamber of Commerce and Industry of the Russian Federation, Russian Scientific and Technical Welding Society (RSTWS) and Moscow Inter-branch Association of the Chief Welders.

More than 75 specialized firms, companies, institutes, small and medium businesses, trade organizations from nine countries (Great Britain, Germany, China, Portugal, Russia, USA, Ukraine, Finland and Switzerland) took part in the Exhibition. The Russian exposition was the most representative (more than 60 booths). Among them were such famous manufacturers of welding equipment of Russia as ITS (St.-Petersburg), FSUE GRPZ (Ryazan), SPA «Plazma» (Rostov-on-Don), CJSC PKTBA (Penza), Faktor Ltd. (Moscow), Avtogenmash Ltd. (Tver), as well manufacturers of welding consumables ---- OJSC «Mezhgosmetiz-Mtsensk» (Orel), CJSC «Zapsibgazprom» (Tyumen).

Ukraine at the Exhibition was represented by the E.O. Paton Electric Welding Institute, «Donmet» enterprise (Kramatorsk), Ilnitsky Factory for Mechanized Welding Equipment, «Artyom-Kontakt» enterprise (Kiev), as well as journals «Avtomaticheskaya Svarka» (Automatic welding) and «Svarshchik» (Welder).

Noteworthy among the world brands that took part in the Exhibition are the American Company «Mathey Dearman» (equipment for construction and repair of main pipelines), «Lincoln Electric» (equipment for manual, arc, argon-arc and MIG welding, plasma cutting, automated and robotic systems, welding consumables for a wide range of applications, presented by the Moscow branch), KEMPPI (high-tech welding equipment for all arc processes, welding torches, masks, accessories), «Linde Gas» (manufacture of a whole range of welding gases and mixtures), ESAB (materials and equipment for welding, Moscow branch).

A number of the leading research, technical and engineering centers of Russia, such as the Alliance of the Saint-Petersburg and North-West Region Welders (St.-Petersburg), «Progress» (Izhevsk), State Engineering Center (SEC, Moscow), Moscow Inter-Branch Association of the Chief Welders, also presented their expositions at the Exhibition.

Subjects of the Exhibition traditionally included demonstration of the achievements in the field of modern technologies, equipment and materials applied in welding, cutting, cladding, brazing and soldering, heat treatment and coating; developments and productions of systems for ventilation, air conditioning, means for welder and environment protection; and production of specialized types of equipment and technologies. The tendency to a wider demonstration of achievements in the field of automation and robotization of welding processes looked natural under the conditions of the observed improvements of the economy in East-European countries. Together with a demonstration of robotics by the Moscow branch of «KUKA Robotics», the booth of the «Kontur» Ltd. (Moscow), dealing with design of blanking and welding shops for plants manufacturing metal structures, and exhibiting the possibilities of a wide application of robotic welding complexes and automated devices, looked traditionally spectacular.

Among the novelties of the Exhibition was a line of domestic technological universal robots of the TUR series with a nominal carrying capacity of 15 up to 350 kg, developed by SEC, which was appointed in 2008 by the Government of the Russian Federation

to be a head organization to ensure, together with OJSC «Avtovaz», scientific and technical development of domestic machine-tool construction and technological re-equipment of strategic branches of machine building with preferential utilization of competitive technologies and equipment. All of these robots are universal industrial robots of the articulated type, having six degrees of freedom and designed for resistant, laser, arc and hybrid welding, laser and plasma cutting, cutting with high pressure water, gluing and sealing, storage and transportation of freight.

At present, «Avtovaz» is active in preparation for building of the facilities capable of manufacturing up to 1000 such robots per year.

One-day international conferences «Automation and Mechanization in Advanced Welding Technologies for Application under Current Conditions in Leading Branches of Industry, Power Engineering and Building» (organizer — CJSC MVK, RSTWS and journal «Svarochnoe Proizvodstvo» (Welding production)), as well as scientific and practical conference on welding, cutting, brazing, soldering and related technologies in the form of a business club on professional interests (organizers — CJSC MVK, Moscow Inter-Branch Association of the Chief Welders) took place during a period of the Exhibition. Two papers covered the issues of certification in welding engineering.

G. Fernandes, member of the Board of Directors in the IIW, manager of the IIW Certification System, in his paper «International System for Qualification and Certification of Welding Staff and Institutions» considered the main IIW documents regulating procedures of certification of the staff and institutions. He noted that a special organization International Authorized Board (IAB), dealing with qualification and certification, was formed under the IIW. Also, he marked that the National Agency of Control and Welding is an authorized body for issuing certificates in the field of welding in Russia.

O.A. Tsukurov (Center for Certification of Welding Facilities) presented paper «Problems of Keeping to Technical Specifications for Welding Processes and Ways of Their Solution». He noted that currently there are no requirements in specifications to the welding processes. Thus, the Committee on Technical Regulation was formed (July 2009) under the auspices of RSTWS to solve these problems. The Committee will hold a range of seminars devoted to the issues of technical regulation in the field of welding engineering in 2009–2010.

Presentations of the developments of such companies as KUKA Robotics, Scansonic (Germany), KEMPPI (Finland), Dukon, Svacha, SovPlim, Elsvar, Tekhnikord (Russia) etc. were made at the other Conference.

It should be noted in conclusion that there were much less exhibitors at this Exhibition than at the previous ones. The same relates to the quantity of the visitors. This corresponds to «InformExpo» agency data, according to which the number of exhibitors in whole for exhibitions in the first half of 2009 in Moscow reduced at an average by 20 %.

Next «Weldex/Rossvarka» Exhibition will be held on its favorite site — in Sokolniki in 2010, which suggests certain optimism in relation to further development of activities of the main Russian Exhibition on welding and related technologies.

Dr. V.N. Lipodaev,
Dr. A.T. Zelnichenko, PWI

INTERNATIONAL SCIENTIFIC AND TECHNICAL CONFERENCE «PROBLEMS OF WELDING, RELATED PROCESSES AND TECHNOLOGIES»

The International Conference under the auspices of Prof. B.E. Paton, President of the National Academy of Sciences of Ukraine and Director of the E. O. Paton Electric Welding Institute, took place at the Admiral Makarov National Shipbuilding University (NSU) in Nikolaev, October 14–17, 2009. It was dedicated to the 50th anniversary of the Welding Engineering Chair of NSU and 75th anniversary of the E.O. Paton Electric Welding Institute of the NAS of Ukraine. Scientists from Ukraine, Russia, Belarus, China, Poland and Vietnam, and representatives of more than 60 organizations and enterprises took part in the Conference. 130 papers on the relevant trends in welding engineering, including 39 plenary papers, prepared by the researchers of the E.O. Paton Electric Welding Institute, I.N. Frantsevich Institute of Problems of Materials Science (IPMS), Physical-and-Technological Institute of Metals and Alloys (PTIMA) of the NAS of Ukraine; Institute of High-Current Electronics, Institute of Physics of Strength and Materials Science, Institute of Theoretical and Applied Mechanics of the Siberian Division of the RAS; Belarusian State University, B.I. Stepanov Institute of Physics of the NASB, Belarusian State University of Informatics and Radioelectronics; Beijing Institute of Aeronautical Materials; K.E. Tsiolkovsky Russian State Technological University (RGTU), Moscow Energy University, Voronezh State Technical University, NTUU «Kiev Polytechnic Institute», Admiral Makarov NSU, I. Pulyuj Ternopol State Technical University (TSTU), V. Dal East-Ukrainian National University (EUNU), Priasovsky State Technical University (PSTU), P. Mogila Chernomorsky State University (ChSU), as well as OJSC «Vadan shipyards»–«Okean» and State Enterprise «Zoray-Mashproekt», were presented at the Conference.

Most of the papers (13) with diverse topics were presented by the scientists of the E.O. Paton Electric Welding Institute. Three papers by the PWI researchers were dedicated to new developments in the field of welding consumables for shipbuilding and ship repair (Prof. I.K. Pokhodnya et al.), three papers were dedicated to materials weldability (Prof. V.I. Makhnenko, Prof. M.M. Savitsky et al.), and two papers — to brazing of materials (Prof. V.F. Khorunov et al.). The paper by Prof. I.V. Krivtsun was dedicated to new developments in the field of hybrid laser-plasma welding technologies and materials treatment. Other papers were dedicated to thermal spraying of coatings (Prof. Yu.S. Borisov), diffusion bonding of titanium structures (Prof. L.S. Kireev), mechanized gas shielded welding of steel (Prof. I.P. Pentegov), and surface cleaning prior to welding and related processes (Prof. A.A. Kajdalov).

Four papers, dedicated to utilization in welding and related technologies of concentrated energy flows (CEF), in particular, low-energy (20–30 kV) high-current (hundreds of amperes) electron beams (HCEB) (Profs. N.N. Koval, V.E. Ovcharenko, O.P. Solonenko, Yu.F. Ivanov et al. from the Siberian Division of the RAS) and compression plasma flows (Profs. V.V. Uglov, V.M. Astashinsky, N.T. Kvasov, N.N. Cherenda from Belarus), were presented. Application of HCEB for diffusion bonding and pressure brazing was considered in papers presented by NTUU «Kiev Polytechnic Institute», NSU, ChSU (Prof. V.D. Kuznetsov, Dr. V.V. Kvasnitsky, Profs. V.F. Kvasnitsky and L.M. Dykhta). The CEF are used for modification and alloying of surfaces by controlling structure, composition and properties of materials. They are intensively developed now, and earlier they belonged to double-application national critical technologies.

The paper by Prof. A.N. Gedrovich and Dr. A.B. Zhidkov (V. Dal EUNU) demonstrated new capabilities in improving the quality of welded structures by vibration treatment. Peculiarities and prospects of wear-resistant cladding by using flux-cored strip were presented in the paper by Prof. V.V. Chigarev and Dr. A.G. Belik (PSTU).

A range of papers was dedicated to the problems occurring in operation of welded structures. The paper by Prof. N.I. Pidgursky (TSTU) considered the mechanisms of propagation of fatigue cracks. Prof. V.I. Makhnenko and Dr. A.S. Milenin in their paper proposed a method for ranking of defects in main gas pipelines, based on the probabilistic evaluation of the risk of emergency situations and allowing planning of repair without interruption of operation of a main gas pipeline. Methods for calculation of fatigue strength of welded ship hull structures, allowing for design and technological factors, were discussed in the paper by Prof. L.I. Korostylyov (NSU).

The papers presented at the Conference also considered manufacturing technologies for ship hull construction and ship machine building. The efficiency of different methods for welding of erection joints on the ship hulls was analyzed by Drs. N.P. Romanchuk, S.V. Dragan, Yu.V. Solonichenko et al. («Vadan shipyards»–«Okean», NSU). The paper by Drs. V.V. Romanov and Yu.V. Butenko («Zorya-Mashproekt») showed the role of modern welding and related technologies in enabling development and manufacture of different-application high-efficiency gas-turbine units, competitive in the word market.

Weldability of heat-resistant cobalt alloys was studied by researchers of PTIMA (Prof. V.M. Simanovsky et al.), and new power sources based on a quasi-resonance transformer for plasma technologies were discussed in the paper by the NSU researchers (Dr. E.N. Vereshchago et al.).

The paper by Prof. R. Yastrzhebsky and associates was dedicated to technologies for welding of aluminium alloys, high-strength and stainless steels to fabricate different-purpose structures. Prof. A. Klimpel and associates (Poland) considered repair laser welding of aircraft engine valves made from nickel alloy. Eng. V.P. Slyuta (Fronius Ukraine, Ltd.) presented a new technology for electric arc welding of 0.3–3.0 mm thick sheets with controlled metal transfer.

Ten papers presented at the plenary session were devoted to solid state joining and brazing of materials. In addition to the above paper by Profs. V.F. Khorunov (PWI), Yu.V. Najdich et al. (IPMS) proposed a method for brazing of refractory metals and oxide materials by using Ni–Nb, Cu–Ni–Nb and Au–Nb filler alloys. Dr. S.V. Maksymova (PWI) suggested the developed filler alloys and technology for brazing of intermetallic titanium alloys. Filler alloys for joining of materials based on Ti_3Al intermetallic were discussed in the paper by Prof. X.P. Xing.

Solid state joining of dissimilar metals by passing a high density current pulse was considered in the paper by Prof. A.I. Vovchenko et al. (Institute for Pulse Processes and Technologies). Prof. V. Mao et al. (China) identified conditions for producing the TLP-joints (diffusion bonding through a fused insert) on single-crystal nickel superalloy DD6. The papers by Profs. V.V. Peshkov and L.S. Kireev (Volgograd State Technical University and E.O. Paton Electric Welding Institute), V.D. Kuznetsov and Dr. V.V. Kvasnitsky (NTUU «Kiev Polytechnic Institute»), Drs. G.V. Ermolaev and A.V. Labartkava (NSU) were devoted to improvement of the technologies for diffusion bonding of dissimilar metals, based on investigation of thermal deformation processes and modelling of the stress-strain state in bonding and cooling of the dissimilar joints with formation of residual stresses. Unique items were produced by Prof. O.A. Barabanova et al. (K.E. Tsiolkovsky RSTU) by using diffusion bonding to manufacture a complex metal-glass composite material with coagulation of copper for reducing structural and thermal stresses.

The papers dedicated to the history of development of the Welding Engineering Chair at NSU (Profs. S.S. Ryzhkov, V.F. Kvasnitsky (NSU), V.M. Emelianov (ChSU), as well as to the role of the E.O. Paton Electric Welding Institute in progress in the field of shipbuilding (Prof. A.N. Kornienko, Dr. A.P. Litvinov, and Prof. A.G. Potapievsky), were also presented at the Conference.

The poster session was held on October 14, as well as during the plenary session breaks on October 15 and 16, 2009. Subjects of the poster papers included almost all the industrial sectors, fusion and pressure welding methods, as well as related processes and technologies.

The poster papers were presented by virtually all chairs related to welding, which exist in Ukraine.

The plenary papers were published in the Transactions of NSU (2009, Nos. 3, 4), and the poster papers — in book «Problems of Welding, Related Processes and Technologies»: Proceedings of the International Scientific and Technical Conference Dedicated to the 50th Anniversary of the Welding Engineering Chair of NSU and 75th Anniversary of the E.O. Paton Electric Welding Institute of the NAS of Ukraine.

A decision was made as a result of the Conference, emphasising a high scientific level and practical importance of the presented papers and active participation of welding scientists and specialists in the corresponding research. It was decided to hold the Conference «Problems of Welding, Related Processes and Technologies» on a regular, every two years basis.

Participants of the Conference visited OJSC «Vadan shipyards»–«Okean» and State Enterprise «Zoray-Mashproect» in Nikolaev.

Prof. V.F. Kvasnitsky, NTUU

INTERNATIONAL CONFERENCE «HIGH MAT TECH»

On October 19–23, 2009 the International Scientific-Technical Conference «High Mat Tech», devoted to materials science problems, took place in Kiev at the NTUU «Kiev Polytechnic Institute». The Conference was organized by Ministry of Science and Education of Ukraine, the National Academy of Sciences of Ukraine (NASU), Ukrainian Materials Science Society (UMSS), NTUU «Kiev Polytechnic Institute», I.N. Frantsevich Institute of Problems of Materials Science of NASU, «Intem Ltd.» (Ukraine). The informational partners of the Conference were journals «Tekhnika Mashinostroeniya» (Machinery Engineering) (Russia), «Poroshkovaya Metallurgiya» (Powder Metallurgy) (Ukraine), «Nanostrukturnoe Materialovedenie» (Nanostructured Materials Science) (Ukraine), «Deformatsiya i Razrushenie» (Deformation and Fracture) (Russia). The Conference took place under the auspices of the Federation of European Materials Science Societies, European Materials Science Society, Secretariat of European Association of Powder Metallurgy (EUREKA), National Informational Centre on RP7.

In the work of the Conference about 170 scientists, teachers, post-graduate students and engineers of the leading research institutes, research centers, universities, academies and other organizations of 19 countries took part.

A.G. Kostornov, Prof. of NASU, opened the Conference and also delivered a welcome speech. He wished all the participants successful work, business cooperation, briefly reported on the tasks of the Conference and organizational matters.

The Conference included work of nine sessions: metallic materials and technologies of their producing and treatment; ceramics of functional and structural purpose; surface engineering; modern technologies of materials joining; powder metallurgy: state-of-the-art of science and production; innovation materials based on disperse particles (powders, fibers and other), properties, technologies; fundamentals of modern materials science; diagrams of state, modeling of technologic processes of material production and properties of modern materials; materials of medical purpose; composite materials: special properties and prospects of practical use; nanomaterials science: technologies and materials.

The number of reports provoked active discussions caused by great interest of the Conference participants to the new scientific results in some scientific areas. One of such areas was development of nanotechnologies and nanomaterials with improved service characteristics. In the development of this area, as followed from the reports, the famous research centers of the world took an active part: I.N. Frantsevich Institute of Problems of Materials Science of NASU, E.O. Paton Electric Welding Institute, Institute fuer Metallkunde und Metallphysik PWTN (Germany), A.A. Bajkov Institute of Metallurgy and Materials Science of the RAS (Moscow, RF) and many other.

The interesting were the reports devoted to the technologies of joining of materials, including also welding technologies. For example, the interest was shown to the report «Diffusion welding of refractory metals and heat-resistant alloys» (OJSC «Ramenskoe Instrument Engineering Design Bureau», RF), and also to the report «Prospects of producing layer metal-ceramic materials using explosion welding» (Institute of Structural Macrokinetics and Problems of Materials Science of the RAS, RF).

In accordance with the program of the Conference along with the session reports the poster reports were also presented. In total, 220 reports and oral presentations were prepared.

The majority of information presented at the Conference proved the high scientific-technical level of experimental works. The level of the Conference organization was also high. In the course of the Conference its participants exchanged information, discussed the ways of further development of problems of materials science area, strengthened old and established new business contacts, and also defined the ways of performance of joint scientific programs. The prospects for the further scientific cooperation were also outlined.

At the summing up of results the participants of the Conference noted its actuality and usefulness for the further development of materials science, including area connected with producing of new structural materials using different welding processes.

Prof. V.V. Dmitrik,
Ukranian Engineering-Pedagogical Academy

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INFORMATION