FEATURES OF CONSUMABLE ELECTRODE PULSED-ARC WELDING OF ALUMINIUM ALLOYS WITHOUT APPLICATION OF FORMING BACKING ELEMENTS

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Technological features of automatic one-sided consumable electrode pulsed-arc welding in argon of butt joints of sheet aluminium alloys AMg6 and 1915T up to 3 mm thick without application of forming backing elements («gravity» welding) were studied. Influence of welding mode parameter modulation on the geometrical shape of welds and their macrostructure was shown. Recommendations on «gravity» welding technology are given.

Keywords: *consumable electrode welding, sheet aluminium alloys, pulsed arc, welding parameter modulation, butt joints, weld geometry, joint macrostructure*

It is known that consumable electrode pulsed-arc welding in inert gases of aluminium alloys compared to consumable electrode steady-arc welding allows improvement of weld formation, increasing the penetration depth of metal being welded, stabilizing the process of electrode metal drop transfer, burning out (evaporation) of low-boiling alloying elements from electrode wire and improvement of mechanical properties of welded joints [1–4].

Over the last decade welding machines, which include pulsed power sources with synergic control of the process of electrode metal drop transfer with maintenance of synchronous process of «one pulse — one drop» and push–pull type mechanisms have become widely accepted abroad for consumable electrode pulsed-arc welding [3–5]. Such power sources of the type of TransPulseSynergic (TPS) are designed for automated and robotic lines for consumable electrode pulsed-arc welding of various-purpose products and allow performance of single-pass welding of thin metal [5].

To prevent metal burn-through and for sound formation of weld back bead in consumable electrode steady-arc welding and consumable electrode pulsed-arc welding of aluminium alloy structures, removable forming backing elements (FBE) from stainless steel with grooves of various diameters of segment, rectangular or triangular shape are used [5, 7]. In case it is impossible to apply removable FBE from steel, permanent backing elements made from sheet material of composition close to that of the metal being welded are used. Such FBE are tack-welded to one of the sides of the abutted sheet and remain on the structure after lock welding.

Aluminium panels are used very often for fabrication of welded structures. In these extruded panels a «protrusion» having the function of remaining FBE, is already envisaged on one side [8]. However, not all the aluminium alloys can be extruded, and the extruded panels proper are much more expensive than the rolled sheet in terms of manufacturing cost. In addition, all the permanent FBE can essentially increase the weldment weight.

Consumable electrode pulsed-arc welding without FBE application («gravity» welding) can be regarded as an energy-saving technology, as it allows elimination of FBE material costs, time for its fabrication, as well as lowering the total power consumption. The main factor restraining the wide application of welding without FBE is the possibility of metal burns-through formation [9], because of absence of special electric welding equipment.

In this connection in most of the cases aluminium alloy joints produced in «gravity» position (particularly, at relatively large and extended gaps in the butts) are made by manual nonconsumable electrode argon-arc welding or semi-automatic consumable electrode steady-arc welding. The welder monitors shrinkage of weld pool liquid metal and makes the arc longer to lower welding current and/or increases the welding speed. Such manual manipulations keep the welding operator in continuous physical tension and do not always provide a satisfactory formation of welds in «gravity» welding.

In terms of thermal physics, joint burn-through in welding is determined by mobility of liquid metal, which depends on weld pool temperature and action of internal and external forces, namely pool metal gravity and welding arc pressure [10]. The only counteraction to liquid pool running out is the metal surface tension force and strength of oxide elastic film, formed from the weld root side. Its strength is inversely proportional to deformation and under certain conditions it is equal to zero, thus leading to burn-through formation [10, 11]. It is experimentally established that it is possible to select the necessary mode of automatic consumable electrode steady-arc welding, at which an equality of counteracting forces is observed. However, such an equilibrium condition is highly unstable because of the presence of gaps of different size in the abutted elements, and action of random external disturbances. In practice, in order to improve the stability of welding process performed in the «gravity» position, forced oscillations (modulation) of its parameters, namely arc voltage (welding current) and welding speed, are most often applied. Periodical modulation of one of them leads to changes of weld pool temperature and dimensions, as well as arc pressure [10–13], thus allowing variation of heat input into the metal being welded, controlling the speed of pool metal solidification and, thus, performing welding without FBE application.

The simplest method to control heat input into the metal being welded is modulation of one of the parameters, namely power source output voltage U_a, welding speed v_w or electrode wire feed rate $v_{w.f}$ at other welding process parameters being constant [14].

Equipment with synergic control of the process of consumable electrode pulsed-arc welding is becoming widely accepted now. In this equipment the output parameters of the welding power unit and electrode wire feed rate are electrically interconnected by a synergic equation [4]. Interrelation of power source output voltage U_a with $v_{w.f}$ can allow a periodical transition from higher to lower welding mode, using an additional modulator, connected into the circuit of wire movement electric drive. A similar welding process can be achieved also, when using a current source and electric drive of welding wire feed, not connected electrically to each other, but synchronized by modulation.

Monitoring heat input into the metal being welded in welding without FBE application can be achieved also at a simultaneous variation of two or three parameters of the welding process, both when using synergic equipment, and regular equipment with separately operating functional components of the system for consumable electrode pulsed-arc welding. It should be noted that because of the presence of inertia links in the electric control circuits the modulated parameters of the welding process change not jump-like, but by an exponential law, taking into account the time constant of their electric circuits. The different rate of increase (decrease) of modulated parameters, which affects weld bead formation, requires preliminary lengthy adjustment of welding modes. Therefore, controlling three parameters of the welding process is irrational, if positive effect can be achieved at their smaller number. It should be noted that the process of consumable electrode steady-arc welding of sheet aluminium alloys proper is much more difficult to perform that the nonconsumable electrode welding process, and even more so in «gravity» welding of metal with relatively large gaps in the sheets being joined. Therefore, in keeping with GOST 14806–80, developed at the start of 1970s and still valid now, the process of consumable electrode steady-arc welding of aluminium alloys can be applied only for elements of not less than 3 mm thickness for butt and tee joints, and not less than 4 mm thickness for fillet and overlap joints.

The purpose of these investigations was improvement of the equipment and determination of the features of the technology of automatic one-sided consumable electrode pulsed-arc welding in argon without FBE application, allowing a satisfactory weld formation to be achieved in joints of aluminium alloys less than 3 mm thick.

Experimental procedure. Aluminum alloys AMg6 1.8 mm thick, 1915T 2.8 mm thick (GOST 4784–74) and welding wires SvAMg6 (GOST 7871–75) of 1.0, 1.2 and 1.6 mm diameters were used to conduct investigations. Highest grade argon was used as shielding gas. Consumable electrode pulsed-arc welding of butt joints was performed using Fronius TPS-450 power source on ASTV-2M welding head. Before welding plates of 400 × 150 × δ mm size were subjected to chemical etching and scraping of the edges and

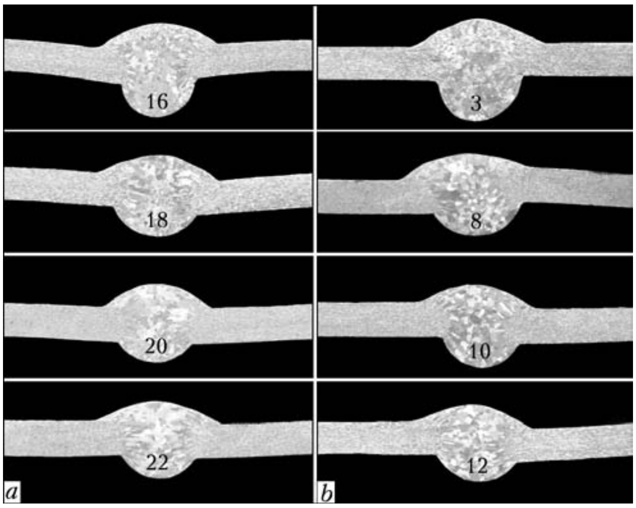

Figure 1. Macrostructure (×3) of welds, depending on modes of welding AMg6 alloy with 1.2 mm wire with $v_{w.f}$ (*a*) and v_w (*b*) modulation. Here and further the numbers on sections correspond to sample numbers

Table 1. Modes of welding AMg6 alloy with 1.2 mm wire with $v_{w.f}$ and v_w modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
$v_{w.f}$ modulation					
16	57–60	17.1–17.2	18	3.7–4.0	1.440
18	66–70	17.2–17.5	27	4.3–4.6	1.129
20	75–79	17.5–17.7	36	4.8–5.1	0.976
22	85–89	18.0–18.2	45	5.4–5.7	0.907
24	95–99	18.4–18.7	53	5.8–6.1	0.878
v_w modulation					
3	59	17.8	16–18	4.0	1.600
8	70	18.0	25–28	4.6	1.232
10	80	18.3	34–37	5.1	1.069
12	89	18.5	41–44	5.7	1.004
14	96	18.8	47–51	6.0	0.955

Table 2. Modes of welding AMg6 alloy with 1.0 mm wire with $v_{w.f}$ and v_w modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
$v_{w.f}$ modulation					
28	56–61	15.4–15.7	20	5.0–5.3	1.175
30	72–78	16.7–17.0	40	6.5–7.0	0.816
31	84–89	17.1–17.5	50	7.5–7.9	0.776
32	94–99	17.6–17.9	60	8.3–8.7	0.742
v_w modulation					
34	61	15.6	19–22	5.3	1.203
35	71	16.6	29–32	6.2	1.002
36	77	17.0	40–43	7.0	0.818
37	89	17.4	48–52	7.9	0.803

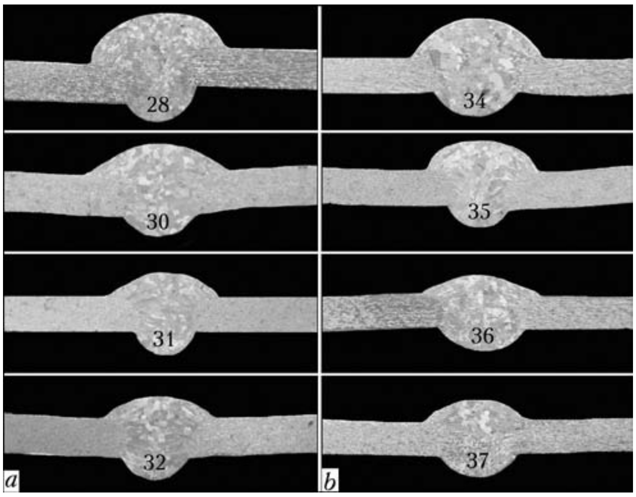

Figure 2. Macrostructure (×3) of welds, depending on modes of welding AMg6 alloy with 1.0 mm wire with $v_{w.f}$ (*a*) and v_w (*b*) modulation

HAZ from both sides. Abutted plates were tack-welded on the edges by manual nonconsumable electrode welding and a fixture with a groove of 50 × 15 mm size was mounted, thus simulating «gravity» welding.

To study the influence of gaps on weld root formation in the plates, recesses of 0.25 × 90 and 0.5 × 90 mm size were cut out in the metal from the side of abutted edges, this corresponding to the total gap in the assembled butt joint of 0.5 and 1.0 mm. Distance between the recesses was 50 mm. This eliminated considerable shrinking of the edges during welding and allowed maintaining a constant gap in the joints.

Angle of welding head inclination to the metal was 10–12°, distance between the torch nozzle and metal being welded was 10 mm, with argon flow rate of 15–20 l/min. Geometrical parameters of welds (width B and height H of weld reinforcement, as well as width b and height h of weld root) were determined on transverse macrosections with up to ±0.1 mm accuracy. Values of welding process heat input $w_{h.in}$ were calculated allowing for the fact that arc effective efficiency in argon is 0.72. Welding wire consumption P_{wire} in welding one running meter of weld was also determined.

To perform modulation of one or several parameters of the welding process, a device was proposed, allowing the necessary switching to be performed in electric control circuits of U_a, $v_{w.f}$ and v_w. This device was a programmable electronic time relay with an infinite cycle number and three-channel output. Each output was a key with a variable resistor connected to it in parallel, which was connected into the break of electric circuit in series with the main resistor — device controlling parameters U_a, $v_{w.f}$ and v_w, respectively. During performance of consumable electrode pulsed-arc welding of aluminium alloys without FBE, two programmable time relays RV-3 and RV-8 with three- or eight-channel output assembled by pulse–pair circuit were used. Continuous modulation period was 2.2 ± 0.2 s at 1.1 ± 0.1 s duration of increase or

Table 3. Modes of welding 1915T alloy with 1.0 mm wire with $v_{w.f}$ and v_w modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
$v_{w.f}$ modulation					
120	72–76	17.1–17.3	20	2.5–2.8	1.650
130	87–92	17.0–17.8	30	2.8–3.1	1.346
140	101–106	17.9–18.1	40	3.4–3.5	1.207
150	115–119	18.5–18.7	49	3.7–3.8	1.151
160	126–130	19.5–19.6	57	4.1–4.2	1.135
v_w modulation					
220	77	17.3	20–22	2.8	1.644
230	92	17.5	30–32	3.2	1.346
240	106	18.4	40–43	3.5	1.218
250	119	18.7	49–52	4.0	1.142
260	131	19.2	54–57	4.2	1.174

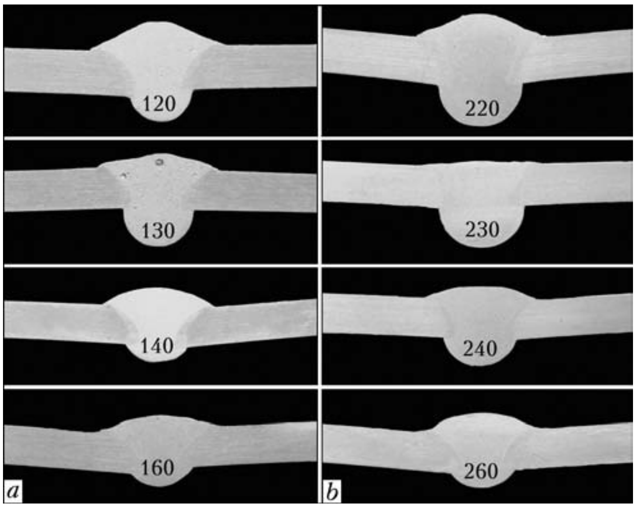

Figure 3. Macrostructure (×3) of welds, depending on modes of welding 1915T alloy with 1.6 mm wire with $v_{w.f}$ (*a*) and v_w (*b*) modulation

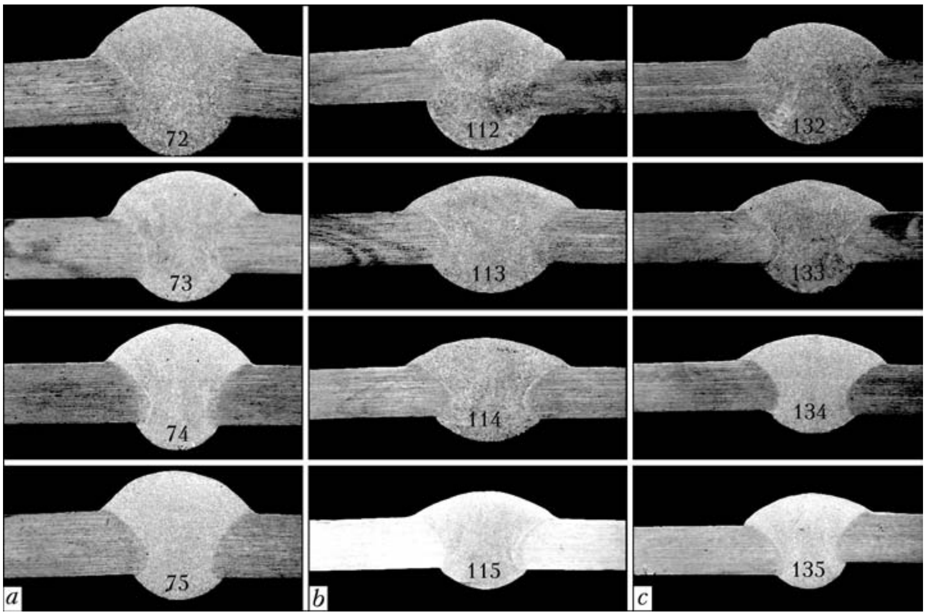

Figure 4. Macrostructure (×4) of welds, depending on modes of welding 1915T alloy with 1.2 mm wire with U_a modulation (*a*), with simultaneous $v_{w.f}$ and v_w modulation (*b*) and with simultaneous U_a, $v_{w.f}$ and v_w modulation (*c*)

decrease of modulated values. Frequency F_p of welding current pulses generated by TPS-450 machine corresponded to value $F_p = KI_w$, Hz, where K is the coefficient of proportionality, dependent on electrode wire grade and diameter and equal to 0.9–1.3 Hz/A for SvAMg6 wire of 1.2 mm diameter.

Experimental results. Table 1 gives the modes of consumable electrode pulsed-arc welding of AMg6 alloy with wire of 1.2 mm diameter with $v_{w.f}$ and v_w modulation, and Figure 1 gives the macrostructures of welds made in these welding modes. In the range of the above values of consumable electrode pulsed-arc welding modes change of $v_{w.f}$ by 0.3 m/min and of v_w by 3 ± 1 m/h (during modulation period of 2.2 ± ± 0.2 s) allows adjustment of the rate of metal solidification in the weld root part and producing joints without burns-through. Here, the most satisfactory weld formation on AMg6 alloy of 1.8 mm thickness can be achieved at $I_w > 85$ A and $v_w >> 45$ m/h.

Approximately the same dependencies are observed also at consumable electrode pulsed-arc welding of AMg6 alloy with 1.0 mm diameter wire (Table 2 and Figure 2) with modulation of $v_{w.f}$ (Figure 2, *a*) and v_w (Figure 2, *b*). Analysis of the data given in Tables 1, 2 and in Figures 1, 2 leads to the conclusion that in one modulation period increase of $v_{w.f}$ by 0.3–0.4 m/min leads to increase of I_w by 4–5 A and of U_a by 0.2–0.4 V. Irrespective of welding parameter, which is modulated, optimum formation of weld root is achieved at $w_{h.in} \leq 0.8$ kJ/cm using 1.0 mm diameter wire.

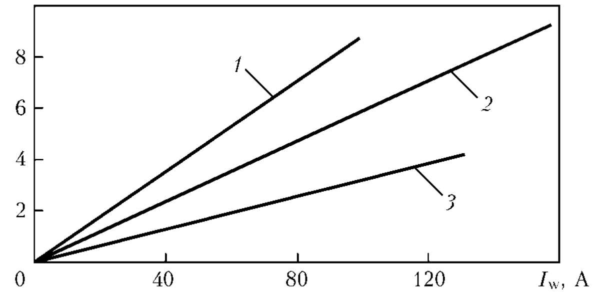

Figure 5. Interaction of values of welding current and feed rate of SvAMg6 electrode wire of 1.0 (*1*), 1.2 (*2*) and 1.6 (*3*) mm diameter

Table 3 gives the modes of consumable electrode pulsed-arc welding of 1915T alloy with 1.6 mm wire without application of FBE and with modulation of $v_{w.f}$ and v_w, and Figure 3 gives the macrostructures of welds produced in these welding modes. In the entire range of the above modes of consumable elec-

Table 4. Modes of welding 1915T alloy with 1.2 mm wire with U_a modulation, with simultaneous $v_{w.f}$ and v_w modulation and with simultaneous U_a, $v_{w.f}$ and v_w modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
U_a modulation					
72	76–78	16.6–17.0	18	4.9	1.862
73	91–93	17.4–17.8	27	5.7	1.554
74	105–107	18.6–18.9	36	6.5	1.427
75	116–118	20.1–20.3	45	7.3	1.561
$v_{w.f}$ and v_w modulation					
112	75–79	17.6–17.8	15–18	4.6–4.9	2.141
113	88–92	18.5–18.7	23–27	5.3–5.6	1.736
114	101–105	19.3–19.4	36–41	6.1–6.4	1.338
115	115–118	20.1–20.3	47–49	6.9–7.2	1.265
U_a, $v_{w.f}$ and v_w modulation					
132	71–75	16.7–17.2	15–18	4.6–4.8	1.938
133	87–89	17.3–17.6	23–27	5.2–5.5	1.588
134	97–101	18.1–18.4	36–41	5.9–6.2	1.213
135	109–111	19.1–19.4	47–49	6.6–6.8	1.140

Table 5. Modes of welding 1915T alloy with 1.2 mm wire with $v_{w.f}$ modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
320	76–79	17.9–18.1	18	4.8–5.1	1.996
330	87–91	18.6–18.8	27	5.4–5.7	1.580
340	101–105	20.0–20.3	36	6.2–6.5	1.490
350	111–115	20.3–20.6	45	6.8–7.1	1.328
360	122–126	21.2–21.4	53	7.3–7.6	1.292

Table 6. Modes of welding 1915T alloy with 1.2 mm wire with v_w modulation

Sample #	I_w, A	U_a, V	v_w, m/h	$v_{w.f}$, m/min	$w_{h.in}$, kJ/cm
420	77	18.3	16–18	5.1	2.148
430	88	19.0	24–27	5.7	1.700
440	102	19.5	33–36	6.3	1.497
450	115	20.6	42–45	7.1	1.411
460	132	21.5	51–53	8.0	1.415

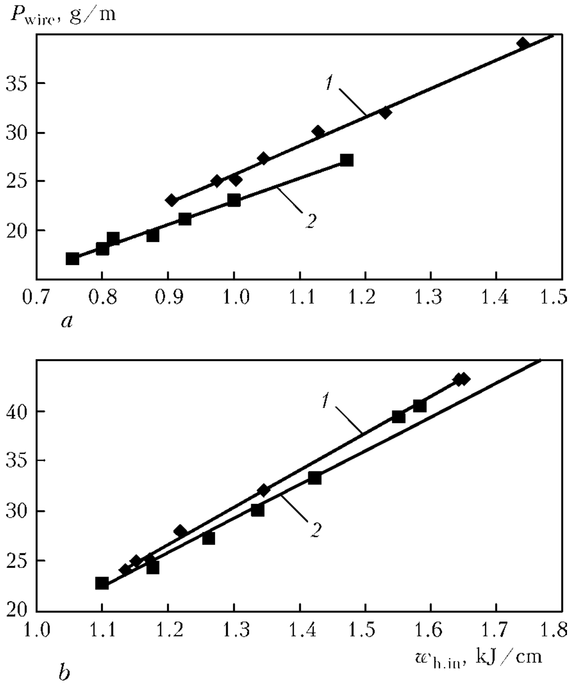

Figure 6. Influence of heat input of the welding process and electrode wire diameter on deposited metal consumption per one running meter of weld: *a* — AMg6 alloy, 1.2 (*1*) and 1.0 (*2*) mm wire; *b* — 1915T alloy, 1.6 (*1*) and 1.2 (*2*) mm wire

trode pulsed-arc welding change of $v_{w.f}$ by 0.1–0.3 m/min and of v_w by 2–3 m/h allows achieving a satisfactory weld root formation without burns-through of the joints. Optimum geometrical dimensions of welds can be achieved at $I_w \geq 120$ A, $v_w \geq$ ≥ 45 m/h and $w_{h.in} < 1.15$ kJ/cm.

Table 4 gives the modes of consumable electrode pulsed-arc welding of 1915T alloy by 1.2 mm diameter wire with U_a modulation, with simultaneous modulation of two parameters ($v_{w.f}$ and v_w) and with simultaneous modulation of three parameters (U_a, $v_{w.f}$ and v_w), and Figure 4 gives macrostructures of welds made in these modes. At continuous modulation of U_a within 0.2–0.4 V (as a result of changing the power source idle travel) value of I_w decreases only slightly, and arc length is increased, thus allowing a certain smoothing of the rippled surface of welds. At simultaneous modulation of two or three parameters, the process of weld formation is more stable. Irrespective of the number of parameters, which are simultaneously modulated, optimum formation of weld roots in 1915T alloy is observed at $w_{h.in} < 1.1$ kJ/cm.

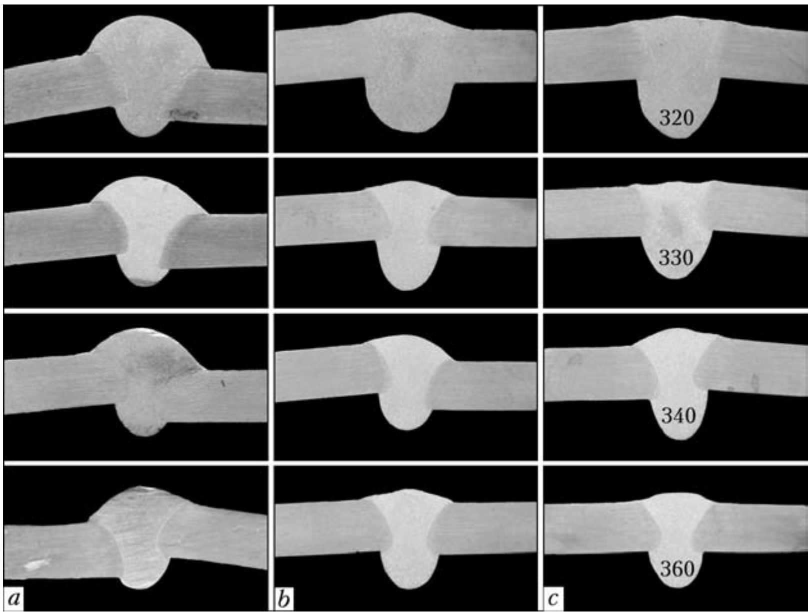

Figure 7. Weld formation, depending on modes of welding 1915T alloy with 1.2 mm wire with $v_{w.f}$ modulation in joints without a gap (*a*) and with 0.5 (*b*) and 1 (*c*) mm gap

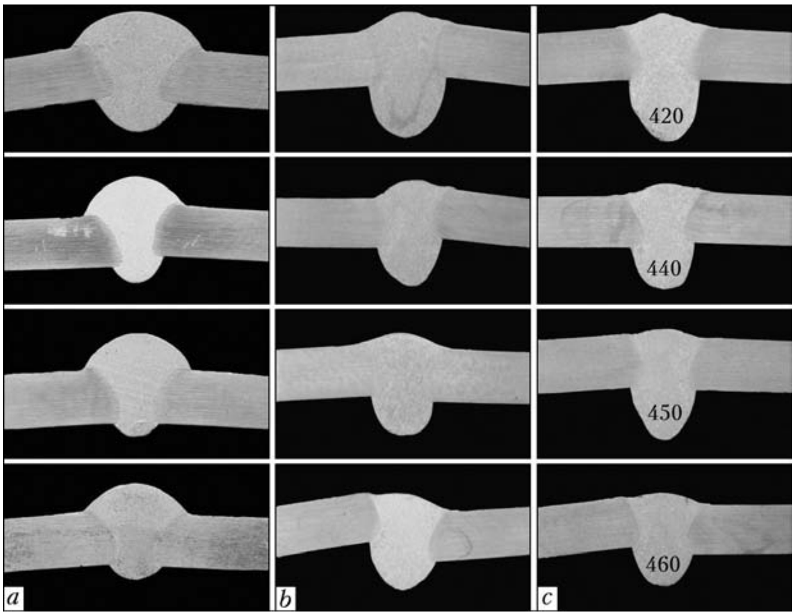

Figure 8. Weld formation, depending on the modes of welding 1915T alloy with 1.2 mm wire with v_w modulation in joints without a gap (*a*) and with 0.5 (*b*) and 1 (*c*) mm gap

Analysis of the modes of consumable electrode pulsed-arc welding of AMg6 and 1915T alloys given in Tables 1–4 showed that at any random disturbances of electrode wire feed rate, for instance, at abrupt increase of $v_{w.f}$ by 1 m/min, I_w value will change differently: for 1.0 mm diameter wire I_w will increase by 10 A, at 1.2 mm diameter — by 16 A, and at 1.6 mm diameter — by 30 A (Figure 5). The larger the diameter of wire of SvAMg6 grade, the greater I_w «jump» and the greater the probability of burn-through formation, which is one of the causes accounting for the rationality of application of small wire diameters in «gravity» welding.

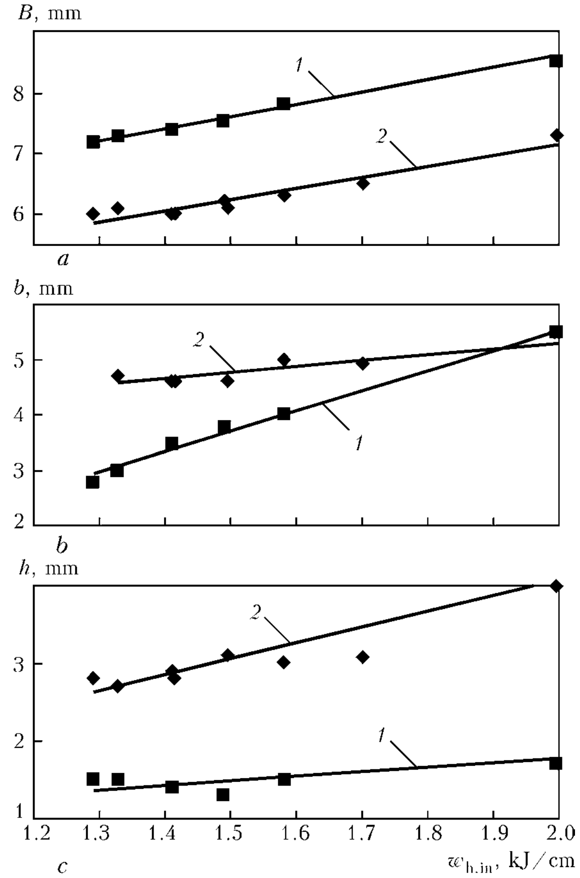

Figure 9. Influence of heat input of the process of welding 1915T alloy and gap (*1* — 0; *2* — 1 mm) in butt joints on the width of weld reinforcement (*a*), width (*b*) and height *h* of penetration root (*c*)

The cause for effectiveness of application of small diameter wires also is lowering of the weight of pool liquid metal and reduction of the time of metal solidification and of weld root «sagging» under the joint. Figure 6 shows welding wire consumption in consumable electrode welding of one running meter of the weld depending on $w_{h.in}$ and wire diameter. At the same heat input into the metal being welded, the minimum pool mass forms, when 1.0 mm wire is used, and the higher $w_{h.in}$ of the process of welding AMg6 alloy obtained at minimum values of I_w and v_w, the more noticeable is this difference.

Assessment of the influence of gap values in the abutted joints on stability of weld root formation and development of through-thickness burns-through of the metal is of special interest in consumable electrode pulsed-arc welding, particularly, of thinner sheet aluminium alloys. «Gravity» welding of 1915T alloy with wire of 1.2 mm diameter with modulation of $v_{w.f}$ (Table 5) and v_w (Table 6) was performed at the same modes at different width of artificially made gaps in the joints. Macrostructures of welds made with modulation of $v_{w.f}$ and v_w at different gaps are given in Figures 7 and 8. It is established that modulated control of the heat input allows at even relatively large gaps in the joints (more than 10 % of welded metal thickness) containing the liquid metal in the pool and prevents its flowing out of the weld root. Irrespective of $w_{h.in}$ value gaps in the joints lead to reduction of the width and height of weld face reinforcement and greatly increase the width and height of its root part (Figure 9).

CONCLUSIONS

1. Modulation of the main parameters of the mode of consumable electrode pulsed-arc welding of sheet aluminium alloys allows periodically changing the heat input into the metal being welded, controlling the pool metal solidification and obtaining a reliable weld root formation without application of FBE at «gravity» welding.

2. Electronic devices additionally connected to systems of TransPulseSynergic type allow performing a separate or simultaneous modulation of consumable electrode pulsed-arc welding parameters, namely U_a, I_w, $v_{w.f}$ and v_w. Continuous modulation with the period of 2.2 ± 0.2 s allows performing automatic welding of butt joints in «gravity» position in case of extended (up to 90 mm) local gaps up to 1 mm wide.

3. In consumable electrode pulsed-arc welding without application of FBE it is rational to apply relatively thin electrode wires: 1.2 mm wire for 2.5–3.0 mm metal, and 1.0 mm diameter wire for less than 2.0 mm metal.

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NEWS

MACHINE MT-501 FOR SPOT RESISTANCE WELDING

The OJSC «Electric machine-building plant «SELMA company» has mastered the manufacture of machine MT-501, designed for AC resistance spot welding of products of low-carbon and low-alloy steels. Machine consists of a vertically-arranged casing with a power unit and system of pneumatic drive of welding electrode clamping, and also of an external control unit for control of resistance welding controller RKS-801M, designed for control of sequence of operation of the resistance spot welding machine. The system of pneumatic drive is equipped with a controller of electrode clamping force.

The principle of machine operation is based on passing the welding current through parts, clamped at a requited force during a preset time.

Main advantages of machine MT-501 (with a pneumatic drive):

- compactness and small size;
- control unit is made in the form of a small-size remote control panel of the resistance welding controller with a safe supply voltage;
- smooth adjustment of welding current passing duration;
- presence of thermal protection from overheating;
- adjustment of force of clamping and unclamping of electrodes;

- water cooling of electrodes;
- class of insulation H.

The machine can be used in a mass production for welding thin-sheet structures (casings, shells, linings) in machine building, in construction site (reinforcement welding), as well as repair-restoration works.