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HYBRID PLASMA-ARC WELDING OF THIN-WALLED PANELS FROM ALUMINIUM ALLOY

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The urgency of this work is associated with the need to develop accessible highly efficient technology of welding thin-walled ship panels from Al–Mg system alloys, which will allow minimizing the effect of deterioration of strength characteristics of the produced joints, characteristic for traditional arc welding methods, as well as reducing weld width and welding heat input without any essential increase of welding equipment cost. Research performed by the author was the base to propose the technology of hybrid plasma-MIG welding with axial feed of wire through hollow circular electrode, allowing production of joints of thin-walled (5–8 mm) ship panels from aluminium alloys of Al–Mg system, with strength higher than 80 % of that of base metal and by 3–6 % higher than strength provided by consumable electrode pulsed-arc welding. Developed technology allows improvement of the efficiency of manufacturing ship panels 5–8 mm thick, compared to currently applied consumable electrode pulsed-arc welding due to improvement of welding speed by 25–40 % and elimination of the need for edge preparation. It is shown that application of hybrid plasma-arc welding, compared to traditional consumable electrode arc welding allows reducing weld width by approximately 20 % and decreasing by 10–15 % the quantity of wire used for weld formation of the same process speed. Here, welding heat input is reduced by 20–30 % that promotes an improvement of strength characteristics and reduction of the width of base metal softening zone under the impact of welding arc heat. 10 Ref., 3 Tables, 5 Figures.

Keywords: *aluminium alloys, direct action plasma, consumable electrode arc, hybrid welding, welding mode, weld hardness, joint strength*

Aluminium and its alloys are widely applied in modern shipbuilding. They are used to manufacture ship hulls, deck superstructures, communication systems and all kinds of ship equipment [1]. The main advantage achieved here is up to 50–60 % reduction of ship weight, compared to application of steel. This enables increasing ship tonnage or improving its tactical and technical characteristics (maneuverability, speed, etc.).

Alloys of Al–Mg system (for instance, 1530 (AMg3), 1550 (AMg5), 1560 (AMg6) and 1561 (AMg61) are becoming the most widely accepted of aluminium alloys for fabrication of structures of river and sea fleet. These alloys are characterized by good weldability. With increase of magnesium content, the coefficient of cracking in welding decreases. However, welded joints of these alloys, produced by traditional arc welding processes, are weaker compared to base material [2]. This, primarily, concerns strength and ductility characteristics that may lead to negative consequences in sea ship manufacture. It is rational to develop accessible highly efficient welding technology, which allows minimizing the effect of deterioration of strength properties of the produced joints of Al–Mg system alloys, as well as reducing weld width and welding heat input without any essential increase of welding equipment cost.

One of the welding processes allowing the defined task to be solved is hybrid plasma-MIG welding [3]. This process was presented for the first time in 1972 by Willhelm Essers and others at Philips Research Center (The Netherlands) [4]. With such a welding process a hybrid heat source is formed, consisting of a direct action constricted arc, enclosing the consumable electrode arc. Further constriction of the latter provides a high rate of wire melting and considerable reduction of spattering. Application of such a process for manufacturing aluminium alloy structures can provide formation of fine-grained weld structures, as well as high quality and efficiency of welding [5].

In early designs of heads for hybrid plasma-MIG welding regular pin nonconsumable electrode was applied. In modern designs it was replaced by hollow, namely tubular or annular one to increase welding process stability [6]. Modern modified process of hybrid plasma-arc welding still has not become sufficiently widely accepted, being, however, actively pursued by researchers [7]. Technologies of welding diverse materials by this process are also at the development stage.

The objective of this work was development of such a technology of manufacturing thin-walled (5–8 mm) ship panels from aluminium alloys of Al–Mg system based on hybrid plasma-MIG welding with axial wire feed, which will allow eliminating the

Table 1. Chemical composition of welded samples (δ = 5 and 8 mm)

Alloy	Normative document	Mg	Mn	Cu	Fe	Si	Cr	Zn	Ti	Zr	Be
5083	EN 573-3	4.0–4.9	0.4–1.0	0.1	0.4	0.4	0.05–0.25	0.25	0.10–0.15	–	0.005
1561 (AMg61)	OST 1 92014–90	5.5–6.5	0.7–1.1	0.1	0.4	0.4	–	0.2	–	0.02–0.12	0.0001–0.003

Table 2. Chemical composition of electrode wire (1.2 and 1.6 mm diameter)

Grade	Mg	Mn	Cu	Fe	Si	Cr	Zn	Ti	Zr	Be
ER5356	4.5–5.5	0.08–0.2	0.1	0.4	0.4	0.05–0.25	0.1	0.06–0.20	–	0.0005
Sv-AMg61	5.8–6.8	0.5–0.8	0.1	0.4	0.25	–	0.2	0.02–0.10	–	0.0002–0.005
Ok. Autrod 18.22	5.5–6.2	0.8–0.9	0.05	0.2	0.4	–	0.2	0.02–0.20	0.02–0.10	0.005

softening of welded joint metal, characteristic for arc processes.

A number of technological studies of the processes of hybrid plasma-arc welding (Plasma-MIG) and consumable electrode reverse polarity pulsed-arc welding (MIG) were performed to achieve the defined objective, using aluminium-magnesium alloys of 5083 and 1561 grades 5 and 8 mm thick with up to 370 MPa strength. Used as electrode wires were those from alloys of 5356 grade (for 5083 alloy), as well as Sv-AMg61, or its European analog Ok. Autrod 18.22 (manufactured by ESAB Company) (for welding 1561 alloy). Chemical composition of the above alloys is given in Tables 1, 2.

Modes were selected on samples of 400x200xδ mm size made from alloys specified in Table 1. Modes of welding butt joints of sheets of thickness δ = 5 and 8 mm were optimized. Weld deposits were made for preliminary selection of the modes, and after selection of mode parameters butt welding was performed. No edge preparation was made for 5 mm thickness. For 8 mm thickness Y-shaped edge preparation with angle of opening of 60° and 2 mm toe was performed only in the case of pulsed-MIG welding, as the hybrid process provided sound square edge welding in this case also. Removable substrates from nonmagnetic austenitic steel were used to produce the reverse reinforcement bead in this case — for welding samples with δ = 5 mm the groove size in the substrate was equal to 6.0×2.0 mm, and for welding samples with δ = 8 mm it was 8.0×3.0 mm.

Experiments were performed with application of specialized complex of equipment developed at PWI, which included [8]: inverter welding power source for nonconsumable electrode argon-arc welding TIG AC-DC EVO 450/T Robot, plasma module FPM, EVO Speed Star 520 TS Robot, autonomous cooling unit, plasmatron for machine hybrid plasma-MIG welding with axial wire feed, multiposition laboratory manipulator based on welding column and rotator, and common control system of hybrid welding complex. Welding was performed according to technological schematic given in Figure 1, *a*. Here, the effect of additional compression of consumable electrode arc by constricted arc from hollow nonconsumable electrode was achieved, Figure 1, *b* [9].

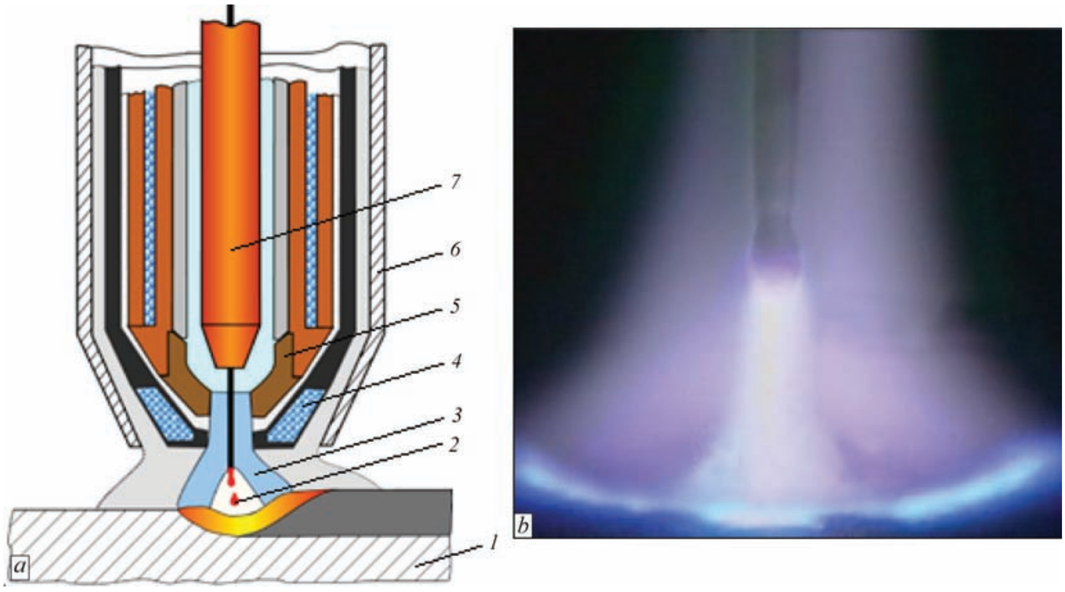

Figure 1. Flow diagram of the process of (*a*) hybrid plasma-arc welding: *1* — welded sample, *2* — consumable electrode arc; *3* — direct action constricted arc; *4* — plasmaforming nozzle; *5* — plasmatron tubular electrode (anode); *6* — protective nozzle; *7* — consumable electrode feeding nozzle; photo of joint action of constricted arc and consumable electrode arc (*b*)

Table 3. Parameters of modes of consumable electrode (MIG) welding and hybrid plasma-arc (plasma-MIG) welding of 5083 and 1561 alloys

Welding speed, m/min	Constricted arc current, A	Constricted arc voltage, V	Plasma gas flow rate, l/min	Consumable electrode arc current, A	Consumable electrode arc voltage, V	Electrode wire feed rate, m/min	Central gas flow rate, l/min	Sample thickness δ, mm	Heat input (Plasma-MIG) + MIG, kJ/m	Electrode wire diameter, mm
5083 alloy										
0.6	–	–	–	280	26.5	8.4	–	5.0	0+740	1.6
0.6	115	26	5.0	165	18	7.6	7.0	5.0	300+297	
0.3	–	–	–	251	27.0	9.5	–	8.0	0+1350	
0.4	168	22.8	5.0	213	23.0	7.0	7.0	8.0	570+730	
1561 alloy										
0.6	–	–	–	253	25.8	8.0	–	5.0	0+650	1.6
0.6	100	25.4	5.0	155	17.4	12.5	7.0	5.0	255+270	1.2
0.6	100	24.6	5.0	165	17.4	7.4	7.0	5.0	246+287	1.6
1.0	178	29.2	3.5	154	18.2	7.5	6.5	4.5	311+170	
0.3	--	--	--	251	27.0	9.5	--	8.0	0+1350	
0.4	155	21.8	5.0	213	23.0	7.0	7.0	8.0	505+730	

Plasma forming nozzle diameter was varied in the range of 6–10 mm. Anode design was composite, consisting of a copper case with an insert from tungsten of 6.0 mm diameter. A hole of 4.0 mm diameter was made in the tungsten for electrode wire feeding. In all the experiments the distance between the plasmaforming nozzle and sample was 6.0 mm. This distance was selected from the condition of ensuring electrode extension (distance from current-conducting tip to electrode wire) in the range of 16–18 mm. Here minimum spatter deposition on plasmaforming and protective nozzles of the plasmatron is achieved.

The criterion of weld suitability for subsequent mechanical testing was correspondence to requirements to admissible surface defects, according to the results of external inspection and measurements, in keeping with the requirements of [10] and GOST 14806–80.

After making weld deposits, modes of hybrid plasma-arc welding were selected, which were then used to conduct butt welding of samples for mechanical testing. Similar samples were made by traditional pulsed-MIG welding with consumable electrode arc (Table 3). Welding was performed in the downhand position in shielding atmosphere of argon with flow rate of 25–30 l/min at velocities of 0.3–0.6 m/min. Results of application of both the methods were compared (Figures 2, 3).

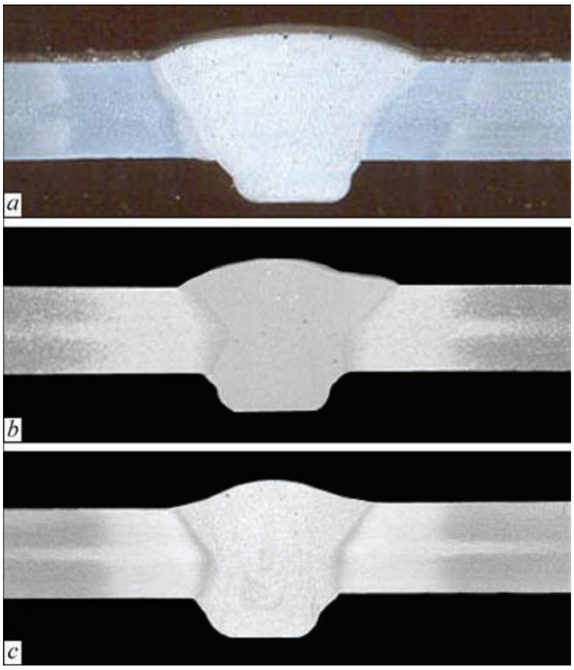

Figure 2. Transverse sections of welded joints of sheets from 1561 alloy (δ = 5.0 mm) made by pulsed-MIG welding (*a*) and hybrid plasma-arc welding with electrode wire of 1.2 (*b*) and 1.6 mm (*c*) diameter

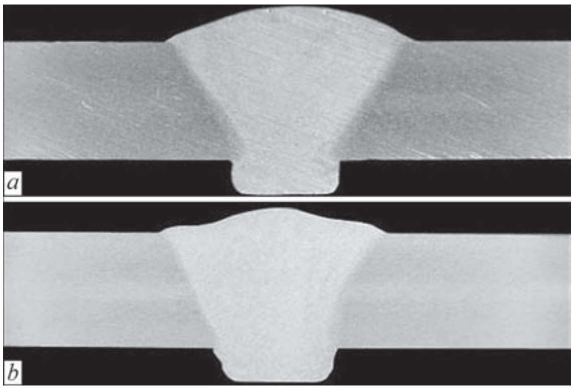

Figure 3. Transverse sections of welded joints of sheets of 1561 alloy (δ = 8.0 mm) made by pulsed-arc MIG (*a*) and hybrid plasma-MIG welding (*b*)

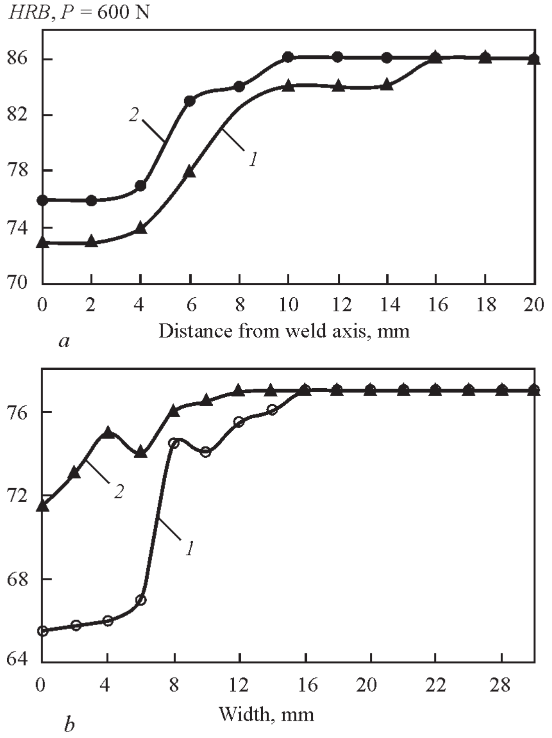

Figure 4. Hardness distribution in the cross-section of welded joint produced by MIG (*1*) and plasma-MIG (*2*) welding on samples of: *a* — 1561 alloy (δ = 5.0 mm) at welding speed of 0.6 m/min; *b* — 5083 alloy (δ = 8.0 mm) at welding speeds of 0.3 and 0/4 m/min, respectively

Comparison of heat inputs of consumable electrode and hybrid plasma-arc welding of 5 mm thick aluminium alloys performed at the same speed, shows lowering of this parameter in the second case by approximately 20–30 % (Table 3). Welding of 1561 alloy (δ = 5.0 mm) by hybrid process without edge preparation allowed process speed to be increased up to 1.0 m/min, that is by 40 % higher than that of traditional pulsed-MIG welding (Table 3). In the case of welding 8 mm thick samples, the approximate matching of heat inputs in both the cases makes comparison of these process results valid, despite the different welding speeds (Table 3).

Welds, produced by consumable electrode welding of samples from 5083 alloy (δ = 8.0 mm), had pores in weld upper part, weld width being 18.0 mm at reinforcement height of 3.0 mm. Reduction of geometrical dimensions of welds at selected preparation of edges to be welded was impossible, as in order to achieve the respective penetrability of the arc, welding current of about 250 A was required, which was directly related to electrode wire feed rate and certain quantity of metal added to the weld pool, respectively.

In hybrid plasma-MIG welding it is possible to dose wire feed rate by selecting the ratio of heat inputs of each of the components so, as to ensure formation of upper and lower beads. Heat input required for complete penetration of the sheets being joined is ensured by the action of nonconsumable electrode constricted arc. This allowed in hybrid plasma-MIG welding of sheets of 5083 alloy (δ = 8.0 mm) reaching weld width of 15.0 mm at weld reinforcement height of 1.7 mm, i.e. reducing these parameters by approximately 20 and 45 %, respectively.

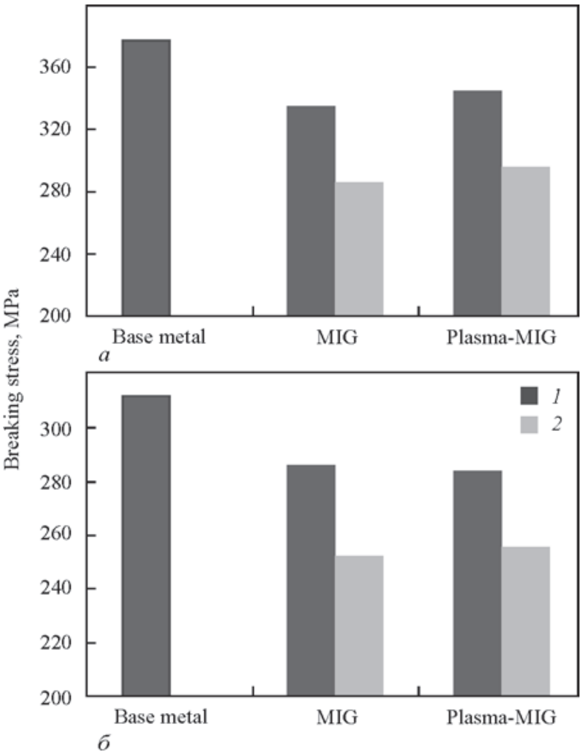

Figure 5. Strength values at static tension of welded joints produced by MIG (*1*) and Plasma-MIG (*2*) welding on samples of: *a* — 1561 alloy (δ = 5.0 mm) at welding speed of 0.6 m/min; *b* — 5083 alloy (δ = 8.0 mm) at speeds of 0.3 and 0.4 m/min, respectively (*1* — welded joint; *2* — weld metal

Templates for conducting microdurametric analysis were cut out of butt welded joints produced by the compared processes, as well as samples of type XIIIa for static strength testing according to GOST 6996–66. Comparison of hardness distributions in the cross-sections of welded joints produced by the traditional pulsed-MIG welding in argon atmosphere and hybrid-MIG welding is given in Figure 4. It follows from the Figure that hybrid welding leads to certain (up to 4 % for 1561 alloy and up to 8 % for 5083 alloy) increase of the joint hardness.

Comparison of strength of welded samples at static loading with removed lower reinforcement of the weld (reverse bead), as well as those with removed lower and upper weld reinforcements for pulsed-MIG welding and hybrid plasma-MIG welding, is given in Figure 5. This comparison shows that the studied welding process, compared to the traditional one, allows increasing strength of 1561 alloy joints up to 3 %, and of those of 5083 alloy — up to 6 %.

Conclusions

1. Performed research was the base for development of the technology of hybrid plasma-MIG welding with axial wire feed through hollow annular electrode, which allows producing joints of thin-walled (5–8 mm) ship panels from aluminium alloys of Al–Mg system with the strength of more than 80 % of that of base metal and by 3–6 % higher than the strength provided by pulsed-MIG welding.

2. Developed technology allows increasing the efficiency of manufacturing ship panels of 5–8 mm thickness, compared to currently applied pulsed-MIG welding through increasing welding speed by 25–40 % and elimination of the need for edge preparation.

3. Application of hybrid plasma-MIG welding, compared to traditional consumable electrode arc welding at the same process speed allows reducing weld width by approximately 20 % and lowering by 10–15 % the quantity of wire used for weld formation. The value of welding heat input decreases by 20–30 % that promotes improvement of strength characteristics and reduction of the width of the zone of base metal softening under the impact of welding arc heat.

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