https://doi.org/10.37434/tpwj2021.04.05

WELD FORMATION IN CONSUMABLE ELECTRODE WELDING OF BUTT JOINTS OF AMg5M ALUMINIUM ALLOY IN SITE WITH A FORMING BACKING ELEMENT AND WITHOUT IT

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The paper presents the results of studying the features of weld formation at consumable electrode pulsed-arc welding of 4 mm AMg5M alloy in different positions at the speed of 23 m/h with forming backing element (FBE) and without it. It is shown that sound welds form irrespective of the angle of butt joint inclination relative to the horizontal plane. FBE presence increases the geometrical dimensions of welds made with consumable electrode by 4–12 % on average, depending on the position of butt joints. Obtained data clearly demonstrates the possibility of achieving the required quality of welds and high level of mechanical properties in consumable electrode welding of aluminium-magnesium alloys at different positions of the butt joints without FBE application. 6 Ref., 3 Tables, 4 Figures.

Keywords: aluminium alloy, argon-arc welding, consumable electrode, filler wire, butt joint positions, forming backing element, welded joints, welds, solidification, structure, mechanical properties

AMg5M aluminium alloy belongs to the class of deformed magnaliums of Al–Mg–Mn alloying system (4.8–5.2 Mg, 0.3–0.8 Mn) and is not heat-hardenable. Its strength is σ_t = 295–305 MPa. It has high ductility (δ = 20 %) in a broad range of application temperatures, as well as considerable corrosion strength (after performing the annealing operation) and vibration resistance [1]. This alloy and its welded joints are applied for manufacturing parts and components of various-purpose structures, in particular, panels of shells and cases, bottoms, flanges, tube plates, etc.

Metal heating in welding leads to a change of the structure — increase of grain size, localizing and coagulation of phases along the grain boundaries, appearance of oxide inclusions that on the whole negatively affects the values of mechanical properties of welded joints [2, 3]. Therefore, relevant is the need to ensure the quality of welded structures from AMg5M aluminium alloy, sensitive to the heat treatment cycle of welding. The process, which takes place in site, requires searching for more perfect technologies of welding the butt joints, when it is not always possible to use the forming backing elements that promote sound formation of the weld root. The joints here are made in different positions, which differ from the generally accepted ones. In this connection, the objective of this work is studying the nature of weld formation on 4 mm AMg5M aluminium alloy at consumable electrode pulsed-arc welding (CEPAW) and establishing its impact on mechanical properties of welded joints produced in different positions with application of forming backing element (FBE) and without it.

It should be noted that the main feature of CEPAW method is the possibility of transfer of electrode metal drop is a short time period of the order of several milliseconds. It is known that the weld pool mobility is associated with its fluidity and temperature, respectively [4]. It mainly depends on the average value of welding current, which is lower at CEPAW than in classical welding processes. That is, electrode metal transfer and kinetics of weld pool solidification are separated in time. During extended impact of the pulse, the welding current rises and corresponds to metal transfer mode. The drop formed at the electrode tip is detached due to considerable electromagnetic forces applied to it. During the period, when the welding current pulse is low, no electrode metal melting takes place, but just the arcing mode is supported. Reduction of average welding current, compared to DC welding conditions allows obtaining a smaller volume of the weld pool [2].

Investigation procedure. Before welding, AMg5M aluminium alloy plates of 350×100×4 mm size and 1.6 mm filler wire of SvAMg6 grade were traditionally cleaned in a solution of caustic soda with subsequent rinsing in cold water. Clarifying the plates and wire was performed in a solution of nitric acid,

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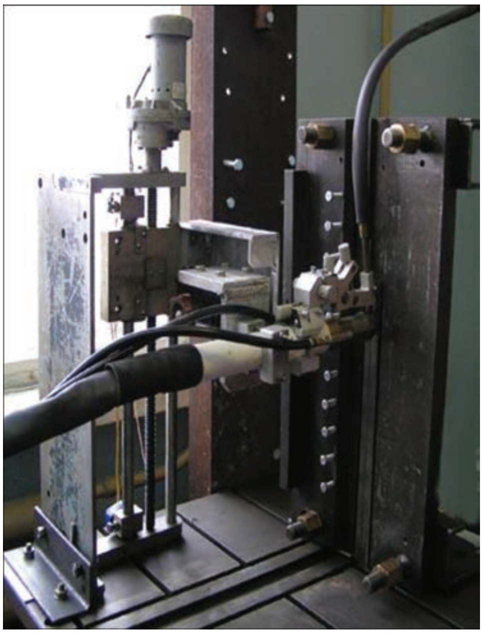


Figure 1. Appearance of PSO-600 unit for providing an adjustable angle of butt joint inclination from 0 up to 90° relative to the horizontal of the mobile platform in welding

with mandatory rinsing in water and final drying [5]. Ends of the butt joints were cleaned mechanically to the depth of not less than 0.1 mm. The scheduled operations were performed in keeping with the generally accepted procedure [6] and GOST-14806.

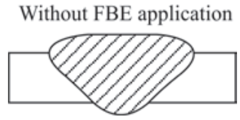
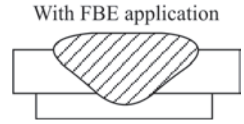
Welding of plates from AMg5M alloy was performed with consumable electrode by modulated pulse current at the speed of 23 m/h, using TPS 2700 power source of Fronius and PSO-600 unit to ensure an adjustable angle of inclination of the butt joints within 0 to 90° relative to the mobile platform horizontal (Figure 1). Welded joints were produced in one pass in process modes specified in Table 1. The arc length was equal to 3–5 mm, electrode extension was 8–10 mm, the flow rate of high-purity argon shielding gas of grade «A» (GOST 10157–76) was equal to 20 l/min, while the angle of the torch inclination relative to the vertical axis was 10–15°. The process of welding the butt joints was conducted with application of forming element (FBE) and without it, thus modeling different site conditions, applied in berth welding. Figure 2 presents the appearance of AMg5M alloy welds, made in different positions at welding speed of 23 m/h without FBE and with it.

Visual control of the produced welds was conducted by their appearance, and radiography method (GOST 7512–89) was used to evaluate their quality. Analysis of the radiographs showed that the welds are tight and do not have coarse defects of the type of cracks, lacks-of-penetration or pores. Geometrical dimensions of the welds (*B* is weld width from the joint face side (technological reinforcement), *b* is the weld width from the reverse side of the joint (weld root), *H* is the height of technological reinforcement convexity, *h* is the height of weld root convexity; δ is the blank thickness) were measured by electronic caliper APT – 34460-150 with 0.01 mm accuracy. By the data of Table 2, the width of the studied welds has close values, and the small difference observed in this case, can be due to impact of the gravitational component, that acts on the metal pool at different angles of its inclination relative to the horizontal surface.

At FBE application in welding butt joints by modulated pulse current in the horizontal plane (angle of the butt joint inclination is 0°), the weld width is equal to 10.55 mm, and without the technological backing it is 10.20 mm. Welding of butt joints at up to 30° angle to the horizontal leads to widening of the welds up to 11.65 mm, and without backing — to its narrowing to 9.96 mm. In the case, when butt welding was performed at an angle of 60°, the width was 11.40 mm, and without FBE it was 9.74 mm. At welding of butt joints in the vertical position, i.e. at an angle of 90° to the horizontal, the weld width was 10.74 and 10.12 mm, respectively.

The values of weld root width here were as follows: at welding in the horizontal plane (0° angle) it was 4.58 mm without FBE and 5.9 mm with FBE. In the butt joint position at 30° angle relative to the horizontal, the root width was 5.24 and 4.84 mm, respectively. At butt joint location at 60° angle, the width of the weld root made without FBE was 6.96 mm, and that with FBE was 4.84 mm. Under the conditions of vertical welding of butt joints (90° relative to the horizontal) it was 6.62 and 5.21 mm, respectively.

Table 1. Modes of CEPAW of 4 mm AMg5M alloy at 23 m/h speed in different positions of butt joints relative to the horizontal plane

Angle of butt joint inclination to the horizontal plane in welding, deg	Without FBE application 			With FBE application 		
	U_a, V	I_w, A	$V_{w.f}$, m/min	U_a, V	I_w, A	$V_{w.f}$, m/min
0	18.9	100	6.9	19.0	112	7.5
30	19.0	100		18.9	111	
60	19.3	101		18.9	114	
90	19.1	103		19.11	115	

Note. U_a — arc voltage, V; I_w — welding current, A; $V_{w.f}$ — welding wire feed rate, m/min

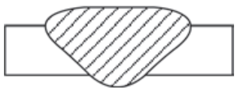
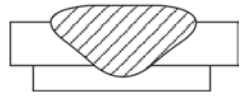
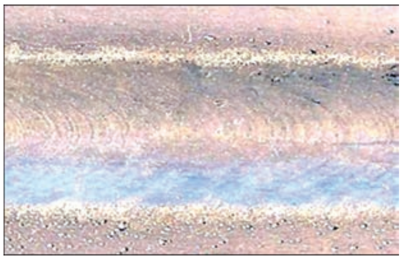
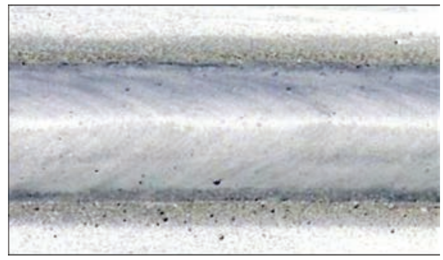
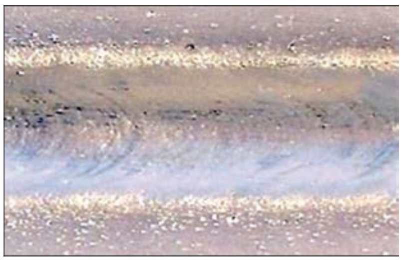
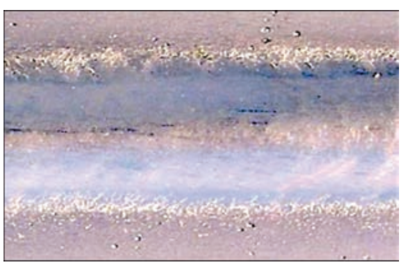
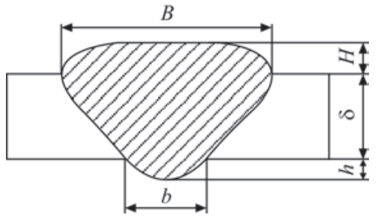
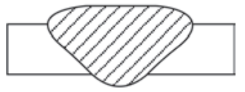
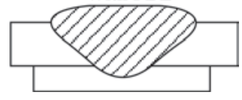
Angle of butt join inclination to the horizontal plane, deg	Appearance of welds without FBE 	Appearance of welds with FBE 
0		
30		
60		
90		

Figure 2. Appearance of AMg5M alloy welds made by consumable electrode in different positions at welding speed of 23 m/h without FBE application and at its application

The metal hardness value which reflects it sensitivity to the thermal cycle of welding in joints of 4 mm AMg5M aluminium alloy, was measured by hardness meter by the generally accepted standard procedure (GOST 9012–59, Rockwell hardness). Dependence of the values of this characteristic on the angle of butt joint inclination is presented in Figure 3. As shown by analysis of hardness measurement results, application of SvAMg6 wire with higher magnesium content (6 %) provides increase of weld metal hardness, compared to base metal of AMg5M alloy. The values of the characteristic are almost not affected by the angle of butt joint location in welding. Hardness level coincides with the base metal in as-annealed condition and is equal to (*HRB* 72–73). In the weld central zone hardness is higher by 3–4 units than that in the HAZ and base metal. This is attributable to positive influence of welding filler wire. Hardness of the metal of welds made in the horizontal position (0°) on a backing and without it is the same and is equal to 75 units. Hardness value of welds made in 30° position, is 75 units without FBE application and 77 units, when FBE is used. At butt joint location at 60° angle, hardness is equal to 77 units in both the cases. Butt welding in the vertical position (90°) without FBE ensures weld hardness on the level of 75 units, and with FBE — on the level of 76 units. Under the conditions of welding in the horizontal plane, HAZ extent is equal to 24 mm, including the weld, irrespective of FBE application. Change of the position from 0 to 90°, causes a reduction of the HAZ

Table 2. Geometrical parameters of welded joints of AMg5M alloy made by CEPAW in different positions at welding speed of 23 m/h without FBE and with FBE

Angle of butt joint inclination to the horizontal plane, deg	Geometrical parameters of the weld 									
	Without FBE 					With FBE 				
	B, mm	b_{pen}, mm	H_{reinf}, mm	h_{pen}, mm	*K*	*B*, mm	b_{pen}, mm	H_{reinf}, mm	h_{pen}, mm	*K*
0	10.11–10.2	4.58–4.60	1.45–1.50	1.85–1.90	1.85	10.53–10.57	5.82–5.99	2.14–2.18	1.64–1.70	1.71
30	9.96–10.10	5.24–5.25	1.64–1.81	1.43–1.47	1.79	11.6–1.69	4.78–4.9	1.85–2.06	1.69–1.7	1.95
60	9.74	6.94–6.98	1.66–1.70	1.49–1.70	1.71	11.40–11.7	3.95–5.56	2.17–2.27	1.64–1.84	1.82
90	10.03–10.26	6.54–6.71	1.87–1.93	1.42–1.52	1.72	10.69–10.79	5.16–5.27	2.28–2.46	1.48–2.16	1.69

Note. 1. *K* is the weld form factor equal to the ratio of weld width (*B*, mm) to its thickness ($H + \delta$, mm): $K = B(H + \delta)$ 2. Admissible *K* values are in the range from 0.5 to 4.0, values from 1.2 to 2.0 are regarded to be optimal.

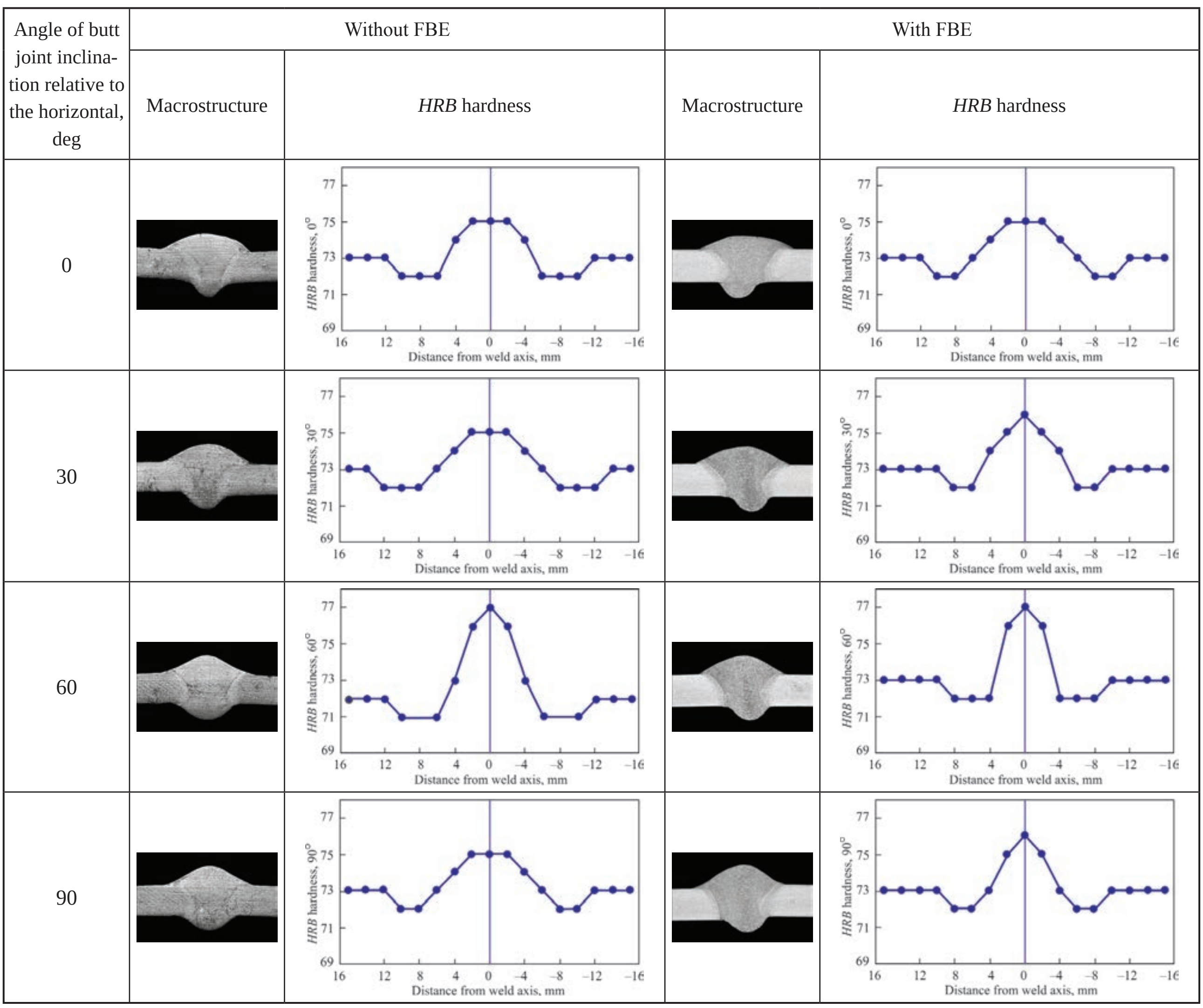


Figure 3. Macrostructure and hardness of welded joints of 4 mm AMg5M alloy made with consumable electrode in different positions at welding speed of 23 m/h without FBE application and with it

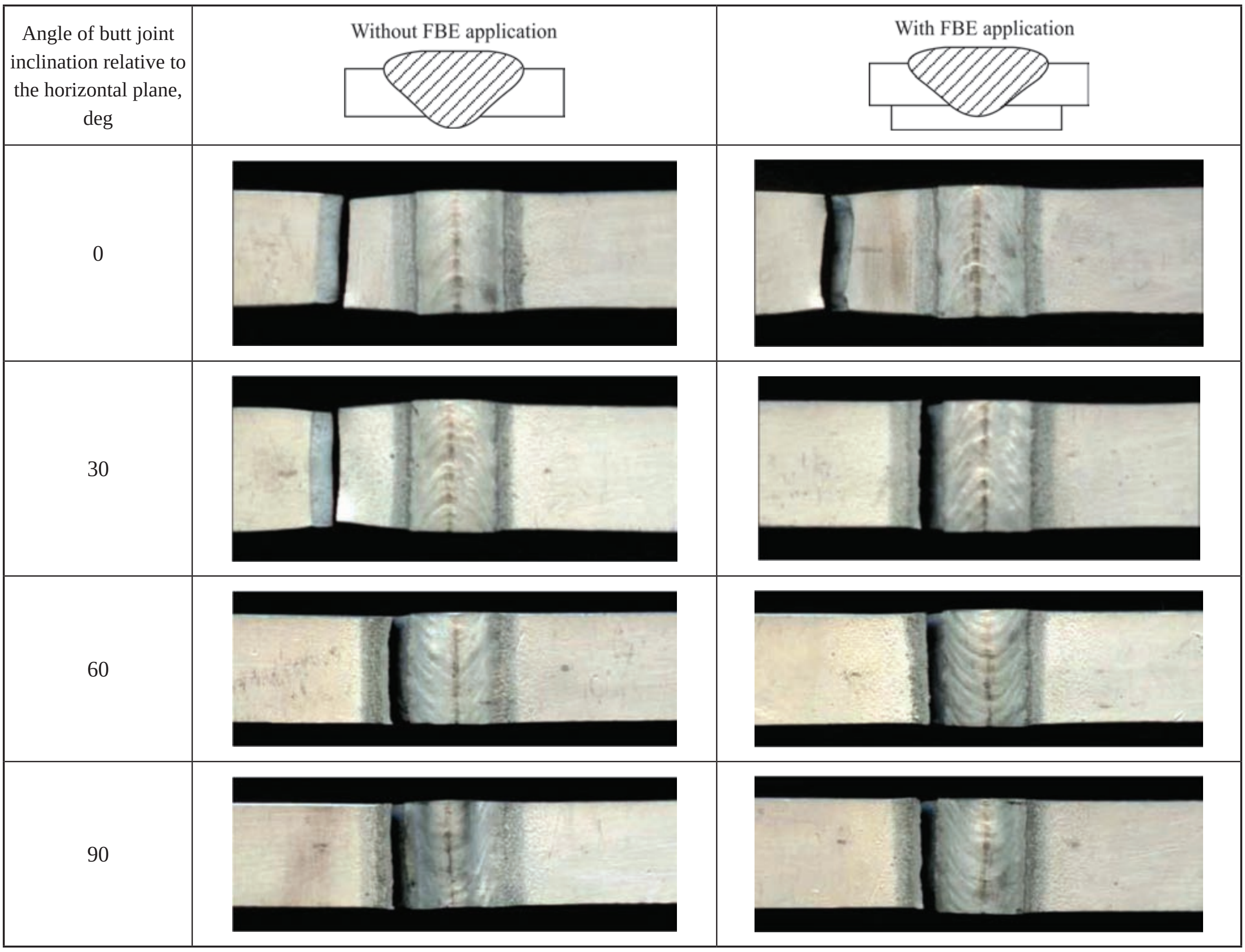


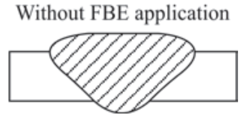
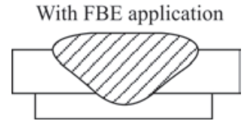
Figure 4. Fracture mode of welded joints of 4 mm AMg5M alloy produced by CEPAW in different positions with FBE and without it

extent to 20 mm in butt joints made by the technology variant with FBE application. In the case of welding at an angle of 30° to the horizontal without backing application, HAZ size is 28 mm. At the change of welding position from 60 to 90°, when welding was performed without FBE application, the HAZ extent was reduced and was equal to 24 mm, including the weld.

Strength values ($\sigma_t^{w.j}$) of welded joints were established on standard samples with technological reinforcement on the weld face and with removed weld root. Weld metal strength (σ_t^{w}) was determined on samples without reinforcement and weld root (GOST 6996–66). Welded joint samples failed in the base metal, as well as in the HAZ that was indicative of lowering of metal strength at heating (Figure 4). Proceeding from analysis results (Table 3), the strength of welds in the joints produced without FBE in the horizontal position, is equal to 280.0 MPa, and at BFE application, it is 299.3 MPa. The strength of joints made in the position at 30° angle, was 285.0 and 294.8 MPa, respectively. In the case, when welding is performed at 60° angle, the strength of the joints is equal to 291.3 and 279.8 MPa, and in the vertical position (90°) strength values are 282.0 MPa without FBE and 280.4 MPa with FBE. The strength coefficient of welded joints ($K_T^{w.j}$) produced in different positions in space, was equal to 0.89–0.95, when welding was performed without FBE, and to 0.92–0.98 with FBE (Table 3).

Ductility value (bend angle α) of welded joints was assessed under the conditions of three-point bending with application of working load from weld root side. Technological reinforcement and weld root, respectively, were removed mechanically as required by GOST 6996–66. For comparison, the deformability characteristic was determined on base metal samples. Proceeding from analysis results (Table 3), the ductility values of the joints welded in the horizontal position, are as follows: without FBE — 85°, and with FBE — 129°. After welding the butt joints in 30° position without FBE application, the ductility value is equal to 105°, and at its application it is 127°. In the case, when welding is performed without FBE in butt joint position at 60° angle, the joint ductility is equal to 103°. Welding of butt joints with FBE application almost does not influence the ductility values (106°). In butt welding in the vertical position (at 90° angle), when FBE was not applied, the joint ductility was equal to 113°, and in the case of FBE application it was 98°. Compared to base metal (α = 180°) the ductility values are lower in all the studied joints, but the following should be noted here. Welding of AMg5M alloy without FBE application leads to proportional increase of the ductility level with greater

Table 3. Influence of forming backing element and positions of butt joints of 4 mm AMg5M alloy on welded joint mechanical properties

Mechanical property values of welded joints	Without FBE application 				With FBE application 			
	Welding angle, deg							
	0	30	60	90	0	30	60	90
$\sigma_t^{w.j}$, MPa	276.2–287 280.0	283.0–286.1 285.0	288.0–297.0 291.3	269–290 282	297.0–301.0 299.3	291.9–300.3 294.8	264.3–293.3 279.8	267.0–291.6 280.4
σ_t^{w}, MPa	268.8–294.4 282.7	280.2–285.1 282.1	274.0–284.0 280.2	269–278 272.8	287.3–289.4 288.0	285.0–285.0 285.0	271.0–284.0 278.6	277.0–281.9 278.8
α, deg	78–89 85	107–110 105	93–116 103	106–126 113	128–130 129	125–130 127	104–108 106	97–98 98
$K_t^{w.j}$	0.92	0.93	0.95	0.92	0.98	0.97	0.92	0.92
K_t^{w}	0.93	0.92	0.92	0.89	0.94	0.93	0.91	0.91

Note. 1. Mechanical properties of AMg5M alloy: σ_t^w = 305 MPa, $\sigma_{0.2}^w$ = 180 MPa, δ = 20 %, α = 180°. 2. $K_t^{w.j}$ — strength coefficient of welded joint, $K_t^{w.j} = \sigma_t^w/\sigma_t^{b.m}$, strength coefficient of weld metal $K_t^w = \sigma_t^w/\sigma_t^{b.m}$, respectively.

angle of the butt joint position: 85, 105, 103, 113°. If FBE is used in welding, then a reverse dependence is found – ductility value decreases: 129, 127, 106, 98°, respectively, while staying at a high enough level.

Investigations of the macrostructure of welds showed that they are tight, and characterized by presence of a granular structure. No coarse inadmissible porosity is observed in the structure of welds or fusion zone. The morphology of the cast metal of welds is the same, irrespective of the value of the angle of butt joint inclination in welding (see Figure 3). Temperature range of metal heating during welding of AMg5M alloy leads to characteristic formation of the following structural zones: weld, zone of weld metal fusion with the base metal and HAZ. The latter has an essential influence of the properties and fracture mode of welded joints.

Conclusions

1. Additional data were obtained on the features of weld formation during consumable electrode pulsed-arc welding of 4 mm AMg5M in different positions at the speed of 23 m/h with application of forming backing elements (FBE) and without it. It is found that the process of consumable electrode welding without FBE, irrespective of the angle of butt joint inclination relative to the horizontal plane provides the required conditions for formation of sound welds of the alloy and does not have any significant influence on the level of joint strength. FBE presence leads to increase of the geometrical dimensions of welds made with consumable electrode, by 4–12 % on average, depending on butt joint position.

2. The found features of structure formation in welded joints of AMg5M alloy in different positions allow recommending the process of consumable electrode welding of various aluminium hull structures without FBE for application in site. This is due to the fact that the welds have a macrostructure identical to that of welds produced with FBE application. In both the cases, the welds have no coarse inadmissible defects in the form of large pores, cracks, discontinuities, and oxide inclusions. Experimental results clearly demonstrate that FBE application in consumable electrode welding of aluminium-magnesium alloys in different positions of butt joints is not mandatory, in order to provide the due quality of the weld and high level of service properties. This CEPAW process can be recommended for working in site without FBE application, using optimal parameters of the welding modes at the respective angles of structural element inclination, without lowering the quality values of the welded joints.

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Received 10.03.2021